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Transformation of the Energy Sector and Consequences for the Energy Mix: A Case Study of Japan

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Abstract

Japan is regarded as an interesting source for drawing useful lessons that could help in drafting the process for transforming the Polish energy mix. The reason is very simple: the two countries have relatively similar starting points. A large proportion of the Japanese energy mix is still based on fossil fuels. We can already observe a slow but evident drift away from fossil fuels (from some 85% in 2013 to less than 75% in 2019). Another reason why Japan is relevant to the Polish conditions is the recent decision of the new government in Japan to return to nuclear energy after the Fukushima disaster. Other interesting solutions in the Japanese way forward include the wide use of hydrogen and ammonia; that could be interesting for Poland, because it is a major producer of hydrogen: the fifth in the world and the third in Europe. Grey hydrogen is currently produced, but that could easily be transformed into green hydrogen produced using distributed solar installations. It also seems that nobody in Poland is seriously working on the use of ammonia in the energy sector. Those reasons alone would be enough to choose Japan as the country for the analysis presented below, therefore the literature review is limited to the Japanese sphere. A short historical view of the energy-mix configuration is followed by an enumeration of the important aspects to consider for Polish conditions: energy security and energy efficiency, followed by an analysis of important sources of energy: nuclear, renewable energy sources (RES), hydrogen, and ammonia as well as thermal power development.

1. INTRODUCTION AND LITERATURE REVIEW

This article is meant to be the first in a series of case studies of countries' efforts to develop new energy policies. These case studies could deliver valuable lessons for the plan for the new Polish energy mix, as described in the new national energy policy document PEP 2040 (Poland Energy Policy 2040) and as confronted with the targets set up in the newest UE legislative package 'Fit-for-55'. For Japan, a country that is the fifth largest greenhouse gas (GHG) emitter in the world (after China, the US, India, and the Russian Federation), the very ambitious aim of meeting climate neutrality by the year 2050 is an extremely difficult task. Meeting this goal would require, in the first place, rapid decarbonisation of the energy sector, which is responsible for 40% of CO₂ emissions. The decarbonisation process has been slowing down for years, mainly due to the Fukushima Daiichi nuclear accident in 2011 and its consequences, which resulted in the tightening of safety standards and, therefore, the suspension of operation of all existing nuclear reactors in the country. In the beginning of 2022, there were only nine reactors available to start up operations. What is the way forward out of the current

situation and what lessons could Poland learn from the Japanese when considering our own difficult challenges presented by decarbonisation process? This is particularly important in view of the Russian aggression in Ukraine, which also redefined the importance of the aims of the Polish energy policy. The aim of this article is to understand the Japanese approach and also shape recommendations for policy development in Poland.

A comprehensive world and UE literature review on the subject of energy-mix transformation has already been presented in my first article of the series [Mitroczuk 2023]. Here, I will limit my report to look at the principal elements of the Japanese debate about decarbonisation. In the Japanese discussions over the energy-mix transformation, we will find many researchers underlining the vital role of energy transformation for economic growth. That is a subject of prime importance; indeed, energy transformation that could guarantee energy for industry that is just, secure, and economically efficient has a vital role in the competitiveness of the whole economy—compare Jingbo [2012], Fankhauser et al. [2013], and Hartwig et al. [2023]. In order to ensure justice in designing a future energy mix, the aspirations of the country's

citizens must be combined with technical understanding of system components and interlinkages in order to build such an energy system, bolstered by the right policy as well as economic and behavioural tools to provide an environment in which an energy transition can occur [McLellan et al. 2014, Hartwig et al. 2023].

In the case of the Japanese, the energy-mix transformation is often discussed from the perspective of the regional community or the major city of that community, which is connected with the strong regional role in the country [McLellan et al. 2014, Hori et al. 2020, Masuda et al. 2022, Okubo et al. 2022, Shono et al. 2023]. The security of energy is one of the very primary concerns for the Japanese. The reason for this involves a number of factors, the first being Japan's own limited energy sources, the second being an increasing population, the third is the instability of energy prices, and the fourth the limitations in energy supply. We can find those considerations discussed in several articles, for example, in Zhu et al. [2020], Schreurs [2021], and Okubo et al. [2022]. Security is often used as a rationale for the call for higher levels of energy efficiency—interesting considerations are presented in the text below and can also be found in Ren et al. [2012] and Shimoda et al. [2021]. A separate and vast literature is focused on the role of nuclear energy in the Japanese energy mix, which is associated with the fact of social tensions resulting from the Fukushima accident and discussions about whether nuclear energy is a viable option for the transformation of the Japanese energy mix [EPRI 2017, Cherp et al. 2017, Murakami 2021, Hartwig et al. 2023].

Quite a lot of the literature discusses the importance of renewable energy sources (RES) development [da Silva et al. 2014; Schreurs 2021, Gao, Ashina 2022]. Another important consideration is the development of hydrogen and ammonia, which are perceived as necessary elements of the future energy mix [Burandt 2021, Oshiro, Fujimori 2022]. It is important to note that hydrogen and ammonia could serve not only as a storage enablers, but also as fuel for industry and transport [Tippichai et al. 2009, Trencher 2021, Kii et al. 2023]. Last, but not least, it is also important to note the literature on carbon dioxide removal technologies and CCUS (carbon capture utilisation and storage) that can be found in Cachola et al. [2023], among others.

2. THE ENERGY MIX OF JAPAN

In Japan, energy shortages, resulting from the complete exclusion of nuclear power from the energy mix in the initial phase, resulted in an increase in imported fossil fuels. That in turn, in the first years after 2011, resulted in an increase of CO₂ emissions. With time, thanks to the increased use of renewable energy and solutions directed at increasing energy efficiency, the increase in emissions has been partly halted, but the share of fossil fuels in the Japanese energy mix is still higher than before 2011, as illustrated by Figure 1. The share of fossil fuels stayed at 64% in 2010, but increased to as much as 77% in 2018.

Many analyses point out that the pace at which Japan succeeds in reversing the proportions in favour of zero-emission sources will be decisive for achieving climate neutrality by the date declared by Prime Minister Suga.¹

The Fukushima accident had a profound impact on the electricity power mix. The share of nuclear energy in electricity generation in particular has fallen from some 25% in 2010 to nil in the year 2014. After that, it increased slowly from 2% to 4% from 2015 to 2017 to a more or less stable level of 6% in recent years. Nuclear power reopened operations as of 2015 to produce 64 TWh in 2019, still far from the level of 258 TWh in 2008. The huge gap of 300 TWh has been filled by fossil fuels: oil and natural gas. The other addition starting in 2013 was the slow growth of renewable sources output. Figure 2 illustrates the growth of particular RES in Japan. RES electricity generation has almost doubled in the last 10 years from a mere 101 TWh in 2009 reaching 184 TWh in 2019. This was due to an increase in installed solar power sources that grew as a result of the introduction of a generous feed-in tariff (FIT) system. The mix of RES was as follows: solar energy, 9%; hydro power, 8%; bioenergy and waste, 4%; and small shares of wind-generated and geothermal sources. Japan has a premium second-highest share of solar power among the IEA countries in 2019 and also the second-highest solar power generation in absolute terms.

The reliance of Japan's energy mix on fossil fuels has been declining since 2014, but those sources still represented 71% of the total electricity generation in 2019. Natural gas accounted for 34% of the total. Coal-fired sources stood stable at 32%. The use of natural gas in power generation reached its peak in 2014 and has slowly declined since then by some 23%, reaching 339 TWh in 2019. Power generation from oil has also decreased dramatically by almost 75%, after peaking in 2012. Coal has provided the remaining need for energy. The peak use of coal was seen during the middle of the period 2010–2019 with more or less stable levels of 350 TWh, which finally decline in 2018 and 2019 to 316 TWh.

This reduction was accompanied by lower electricity demand due to the COVID-19 pandemic. In 2019, Japan's total electricity generation was 993 TWh, 15% below the level in 2010. The total installed generation capacity increased by 22% from 2008 to 2018 and reached 344.9 GW. That was largely due to the development of solar capacity alone, which increased from 2.1 GW in 2008 to 56 GW in 2018. Over the same period, wind power capacity has doubled, but still remains very small at below 2 GW

¹ The October 2021 declaration by the Prime Minister Yasuhide Suga should be assessed primarily as a consequence of the global trend, according to which over 122 countries and regions, including the EU, pledged to reduce GHG emissions to zero in 2050. In the case of Japan—often criticised for 'sluggishness' and 'indifference' in implementing decarbonisation targets—the declaration allows Japan to win the favour of international public opinion and accelerate the process of reducing the emissions of the Japanese economy, which has been going on for several years.

Energy Sources in Percentage of Total Generation

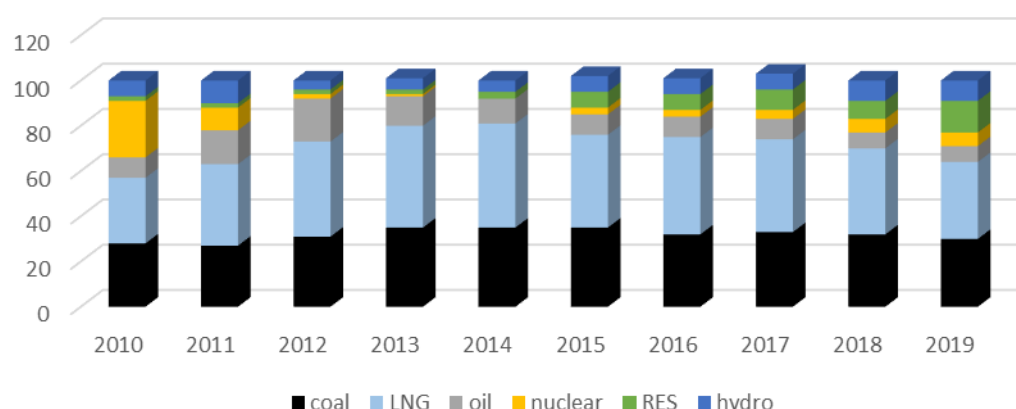


Figure 1. Energy mix 2010–2020.

Source: Author's own calculations on the basis of METI 2019] (may not add to 100 because of rounding).

Percentage of Total Generation

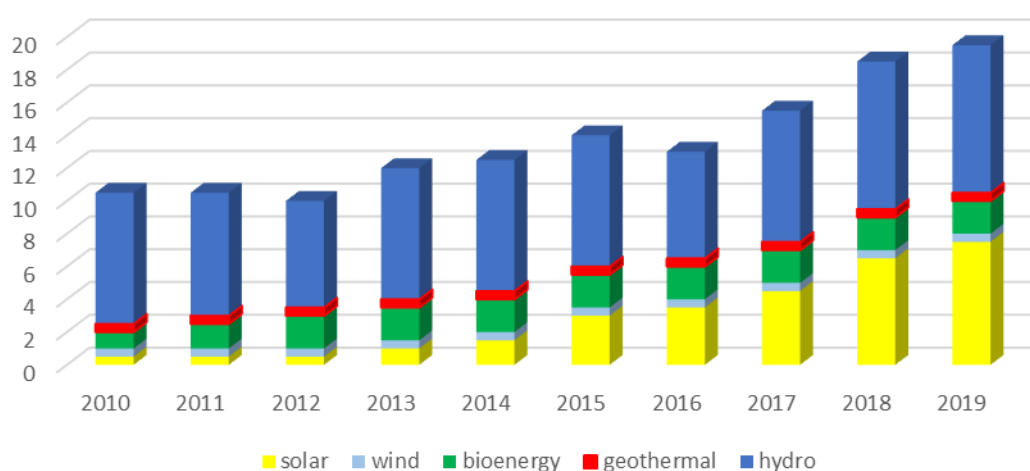


Figure 2. RES generation by type.

Source: Author's own calculations on the basis of IEA data [IEA 2022].

in 2018. The installed energy generation capacity using fossil fuels has increased by 8% from 182 GW in 2008 to 197 GW in 2018. As for the capacity of other RES, hydro and geothermal energy remained almost stable at 50 GW and 0.5 GW, respectively.

Between the years 2012 and 2019, RES electricity generation has grown by 70% as a result of a solar power share increase, but only a small contribution came from wind power development. The share of RES sources in total power generation increased from 10% in 2012 to almost 19% in 2019.

Hydropower and bioenergy were the most important sources of renewable energy in Japan in 2010. They accounted for 67% of the total RES in 2018. Hydropower accounted for almost 50% of Japan's renewable electricity

generation, but the output has been rather stable during 2010–2019, as the country had already developed the majority of available and feasible sites.

Starting with minimal levels in 2010, solar PV (photovoltaics) output has been increasing rapidly since 2012 and reached almost 1/3 of all RES electricity produced in 2018 and even more in 2019. The rest came from the smaller shares of wind power, geothermal power, and geothermal heat.

Japan introduced a FIT policy for a number of RES options: solar PV, wind, bioenergy, hydropower and geothermal in 2012. Solar PV has been the one that benefited the most. Its share in power generation grew from less than 1% in 2012 to almost 7.5% in 2019. Back in 2012, the FIT for solar PV was at a generous level of around USD 0.4/kWh [OECD 2020], but after some adjustments it has decreased

to USD 0.11–0.12/kWh in 2020. The FIT scale for other RES, onshore wind and small hydropower, was also declined. The offshore wind power as well as small hydropower tariffs have remained unchanged since their introduction. FIT schemes are also in operation for bioenergy and geothermal energy, but the deployment of geothermal is relatively limited. Remuneration for bioenergy within the FIT scheme ranges from USD 0.12/kWh to USD 0.47/kWh depending on the fuel type. Given the very generous support levels for bioenergy, the government has received a high level of FIT applications since 2012, which has obviously led to an increased capacity of almost 2 GW between 2014 and 2019. Since the year 2019, co-firing of biomass with coal, so very popular in Polish conditions, is no longer eligible for FIT support. The costs of the generous FIT scheme are being paid by the end users by way of renewable energy surcharges. Since the very beginning of FIT, the surcharge has been steadily increased, from an initial USD 0.00165/kWh in 2011 to USD 0.022/kWh in 2020 [METI 2020]. Especially in the case of industrial consumers, the surcharge represents a higher share of their electricity bill. There are exemptions, however, for very large consumers who are granted surcharge discounts between 20% and 80%.

METI (Ministry of Economy, Trade and Industry of Japan) initially was not commissioning all the deadlines for the FIT applications filled strictly, and as a consequence in March 2015, around 80% of all projects with FIT-awarded schemes were not in operation. Therefore, in May 2016, the government passed new regulation that required FIT projects to submit necessary grid-connection contracts by mid-2017. As a result, some projects were cancelled, but the number of non-operational FIT-eligible projects remained high. Accordingly, METI introduced another FIT revision in 2019, giving another commissioning deadline (March 2020) for solar PV that received FIT approval before March 2015. If these projects do not meet the deadline, their FIT rate will be cut by almost half² [IEA 2021a, p. 100]. As we can see from graph 2, the number of solar PV projects started to grow immediately.

Another policy that was planned to strengthen the development of RES in Japan consists of competitive auctions with 20-year power purchase contracts for all utility-scale solar PV and bioenergy projects. The November 2017 auction for solar PV for 0.5 GW with prices between USD 0.12 and 0.18/kWh. In the third and fourth solar PV auctions held in 2019, auction prices decreased, and average bid prices were between USD 0.118 and 0.122 / kWh. In addition, in all but one auction, the sum of winning bids did not cover the capacity on offer [IEA 2021b].

² June 2020, the Japanese Parliament passed the law 'Proposal to Amend the Renewable Energy Act' which stipulates that new renewable energy projects with a competitive outlook, such as large-scale solar PV and wind, would be eligible for receiving a feed-in premium on top of the market price from April 2022 onward. The details on the implementation of the feed-in premium mechanism are currently under discussion at the time of this report.

3. THE FUTURE OF ENERGY MIX IN JAPAN

Following the adoption of the Green Growth Strategy in December 2020, during the online climate summit organised on the initiative of the United States in April 2021, Japan declared the goal a 46% reduction in GHG emissions by the year 2030 as compared to the base year of 2013. That is 20% more than previously committed. In reference to the then-former Prime Minister Suga's decision to reach climate neutrality by 2050, Prime Minister Kushida, who took office in October, stated that Japan was 'ready to demonstrate to the world its leadership in global decarbonisation', upholding the declarations of his predecessor. This support is visible, inter alia, in the 6th Basic Energy Plan (PPE) adopted in November 2021, in which the share of renewable energy sources in the forecasts until 2030 was increased from 20% to 22% to an even more ambitious 36% to 38%. One novelty of this plan is the appearance of ammonia and hydrogen in the energy mix for the first time, the share of which, according to the 6th PPE, is to amount 1% in the year 2030.

The plan also kept the share of nuclear energy at an almost unchanged level, as did the previous 5th Plan which set its share at the level of 20%–22% by the year 2030. We should add that the level of maintaining nuclear power was set in spite of many controversies and limitations resulting from the advanced age of most nuclear power stations in operation. Still, even though there is a lack of information on new investments in the nuclear energy sector in the 6th EPP, it seems that nuclear power is to remain an important element of the decarbonisation plan until 2030.

An important element of the 6th Plan is to allocate USD 100 million to the development of technologies that generate electricity from ammonia and hydrogen, as well as ZEV (zero emissions vehicles) technology. The year 2022 began with the signing of a significant agreement with Indonesia on cooperation in the decarbonisation of economies, under which both countries declared their will to jointly work on the development of zero-emission energy sources, including hydrogen and ammonia as well as the clean coal technologies: carbon capture, utilisation, and storage (CCUS) and CO₂ recycling.

The data of the ambitious version of the future 2030 electricity mix of the Japanese Government presented by METI in the 6th Strategic Energy Plan is presented in relation to the base year 2019 in Figure 3.

In the government's new 6th Strategic Energy Plan, the principal aim is to show the parameters of the energy policy in order to realise carbon neutrality goals by the year 2050. This was announced by the Prime Minister of Japan in October 2020. Another important goal is to reduce greenhouse gas emissions by 46% in fiscal year (FY) 2030 from its FY 2013 levels, while continuing strenuous efforts in its challenge to meet the very ambitious goal, announced in April 2021, of cutting its emission by 50%. The same goal was set in the 5th Strategic Energy Plan at the level of a 26% reduction of GHG emissions in FY 2030 compared with its FY 2013 levels. In a political sense,

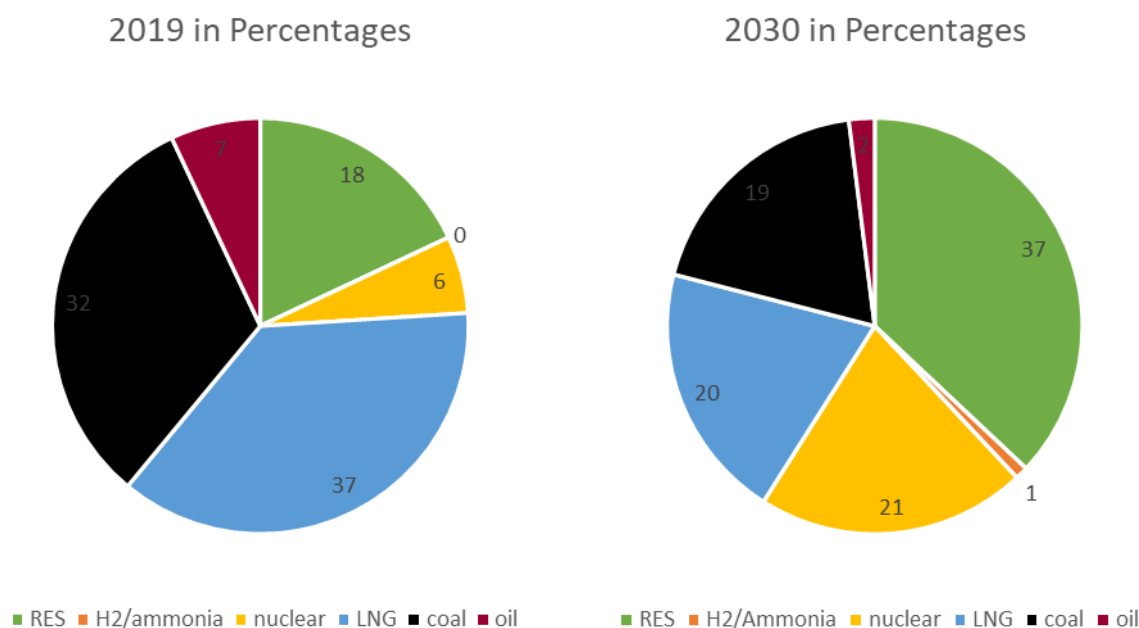


Figure 3. The 2019 and 2030 energy mixes

Source: Author's own calculations on the basis of METI data [METI 2021, p. 12]

this goal was explained by the need to guarantee that in the face of a truly global move for decarbonisation, Japan would lead international efforts. That would mean strengthening international competitiveness by the way of decarbonisation technology that has already been implemented as well as implementing a new innovation wave necessary to further the development of decarbonisation processes. One of the key priorities of the 6th Plan is developing an approach for how to overcome the challenges of the energy supply-demand structure that Japan faces today. Within that larger challenge is the major premise of energy supply safety. The plan stipulates that efforts need to be made to guarantee energy security and, importantly, the economic efficiency of the energy supply in the process of promoting today's climate change countermeasures.

The plan stresses that all necessary efforts be taken in the energy sector, which accounts for more than 80% of all GHG emissions, are of the highest importance. Also, the planning must take into account the fact that the current industrial structure of the country, in which manufacturing accounts for more than 20% of gross domestic product (GDP), is petrified and also take into account the specific natural conditions existing in Japan, the aim of realising carbon neutrality of Japan is not an easy goal. That reality is also underlined in the document, which states that in order to overcome the above-mentioned challenges, the full support and far-reaching efforts of all sectors of society such as the government, industry, and consumers is necessary. That aim will require a maximal introduction of RES as the major power sources as well as implementation by the entire society of hydrogen/ammonia and CCUS. This also means that the required amount of nuclear power

must be continuously utilised while also operating under the assumption that a full safety guarantee and a high level of public trust are maintained. We also see these kinds of efforts being undertaken in Poland with good results.

Taking all of the above into consideration, this report will now concentrate on the ways in which the entire power sector will be steadily decarbonised. Innovations in thermal power generation, by means of new technologies in hydrogen- and ammonia-fired power generation will be examined, among others, including CCUS and carbon recycling. Furthermore, the non-power sector will be electrified by decarbonised sources. The sectors in which electrification is not feasible—one example being industries with high-temperature heat demands—will need to utilise hydrogen, synthetic methane, and other synthetic fuels. The industry sector will require new innovations such as hydrogen-reduced iron production and artificial photosynthesis. In other areas, where CO₂ emissions are unavoidable, the decarbonisation processes will be allowed by means of direct air capture with carbon storage (DACCS), bioenergy with carbon capture and storage (BECCS), and also by forest and ground sinks, which are highly advocated for in Poland.

4. ENERGY SECURITY

According to the data collected by IEA, Japan's energy self-sufficiency in 2020 was at the level of 11% as compared with 106% for the USA and around 55% for Poland and the UK [IEA 2022]. After the war in Ukraine begun, energy security became one of the primary concerns of Japan and other countries, mainly because of limited energy sources, but also increasing population in some regions, energy

price fluctuations, and the limits of the overall energy supply. 'Japan is considered as one of the largest energy consumers and energy importers throughout the world which almost 96% of its primary energy supply in national level relies on the imports from other countries. After experiencing several harsh energy supply conditions over the last 40 years, Japan realised the sensitivity of its energy supply and decided to fundamentally restructure its energy supply and rely more on energy mix diversification, renewable energies, energy efficiency improvement, and carbon emissions reduction' [Zhu et al. 2020].

Having a secure and reliable energy is certainly essential for the sake of economic stability and development in every country of the world. Japan, as the fourth largest exporter, imports 96% of its national primary energy and is highly dependent on external energy imports. And after two energy crises—the 1970 oil crisis and the 2011 Fukushima disaster—Japan fully realised the sensitivity of energy supply. The country decided to reconsider its energy policy and focus on energy-mix diversification, developing RES, reducing its GHG emissions, and also considerably improving energy efficiency.

METI does realise that the process of decarbonisation involves some risks, most importantly, energy security in view of the decreasing supply of current energy sources. Therefore, there are measures planned to remedy the risk. They include wide application of new and efficient storage systems as well as water-electrolysis installations that should be funded by expected cost reductions. Another measure is directed at the improvement of electrical system flexibility with a role for batteries in the power grid. Electricity consumers would be in a position to purchase green electricity directly from that market. In case of rapid disruptions and disasters, the plan is to upgrade the cross-region interconnection network lines and to reinforce measures for cyber security [METI 2021].

In order to guarantee the security of energy supplies, oil and gas will continue to be a reserve fuel with decarbonised processes implemented in refinery plants with the use of CO₂-free hydrogen. It is expected that a demand-side shift to the natural gas will occur. Also, METI plans to utilise methanation technology in the gas decarbonisation process, in order to decarbonise heat demand. Energy security recently has become an even higher priority as a result of the war in Ukraine, leading to some changes in energy paradigms. Appropriate investments will be needed to secure adequate a supply of energy sources, as well as surpluses for establishing a reserve supply. It is also important to recognise the desirability of the value of a stable baseload of power sources for energy security [Koyama 2022].

5. IMPROVEMENT OF ENERGY EFFICIENCY

Research shows that there are two main issues with energy conservation policies in Japan. The first is rising energy demand after the World War II, especially during the period

of the two oil crises. Therefore, energy conservation, which is the foundation of Japan's energy policy, is based on a sense of resource scarcity. The second driver is a growing view of the importance of the environmental impact of fossil fuels. Energy conservation has changed a lot since the oil shocks in the 1970s, as a result of concerns about the state of the global environment, especially the need to cut carbon emissions. Being an advanced economy, Japan adjusted energy conservation policy by introducing the adjustment of the Energy Conservation Law back in 1979 [Ren, Du 2012]. The METI-planned activities will concentrate on the industrial sector. The Benchmark Program is to be regularly reviewed with the aim of improving the energy efficiency of industries. The next are the development of new energy technologies that are to be promoted within the new 'Energy Efficient Technological Strategy'. Looking at the efforts, the introduction of the newly available technology, including highly insulated apartments and detached houses, high-efficiency electrical equipment including high-efficiency home and garden appliances, mass-electrification, as well as the buildings integrated photovoltaics in detached houses, all played an important role in energy efficiency. The results show that decarbonisation can be mostly achieved through the dissemination of highly insulated buildings and water heaters of high efficiency as well as the installation of PV for all detached houses. They would then be in a position to reduce the total primary energy demand by 61% relative to demand levels in 2013 [Shimoda et al. 2021].

The second area of efficiency improvements is the commercial and residential sectors. The Act on the Improvement of Energy Consumption Performance of Buildings will enhance these sectors to meet energy efficiency standards. The best technologies and equipment, including new standards for building materials, will be developed. All new houses and buildings to be built from 2030 and forward will be obliged to meet government's zero energy homes/zero energy buildings (ZEH/ZEB) efficiency standards.

The third sphere is transport, where the broad introduction of electronic vehicles (EVs) and the related infrastructure would be promoted. Also, the EVs' related technologies—batteries and the entire supply chain—will be supported using artificial intelligence (AI) technology to encourage the optimisation of freight transport.

METI also plans to amend the Act on the Rationalization of Energy Use. The aim here is to promote the efficient use of fossil fuels and the rationalisation of overall energy consumption. The process will be strengthened by the promotion of zero-emission fuels. METI also plans to assess business entities that enhance the use of non-fossil fuels in their energy-mix or engage in optimising energy demand [METI 2021].

METI plans to enhance secondary energy structure by the means of effective use of distributed energy resources. The efficiency of energy utilisation, enhanced resilience, and activation of local communities to guarantee that what is locally produced is also locally consumed.

Especially in non-power generation sectors, decarbonisation is expected to follow the circular carbon economy (CCE) rules. This means four things: First, reducing the amount of carbon before it enters the system, by promoting efficiency in energy and material use, using renewable and nuclear energy including hybrid use with fossil fuel, using advanced USC (ultra-supercritical) technologies for coal-fired power plants, use of hydrogen and ammonia (blue or green) and also direct reduction in steel making with the use of hydrogen. Second, reusing carbon without chemical conversion (i.e. the utilisation of CO₂ in advanced greenhouses for vegetable growing as well as the production of biofuels from algae synthesis). Third, recycling carbon with chemical conversion (i.e. the use of CCU as well as artificial photosynthesis), recycling bioenergy in the paper and pulp industry, coal ash concrete curing with accompanying CO₂ absorption, producing synthetic liquid fuel as well as synthetic chemical feedstock from hydrogen and carbon dioxide. Fourth, removing carbon from the system through the use of CCS, DAC (direct air capture), and the use of sinks [IEEJ 2022].

6. THE FUTURE ROLE OF NUCLEAR ENERGY

It has been decided that the Japanese government will follow the Nuclear Regulation Authority opinion and will continue to restart their nuclear power plants. The process will require the highest level of understanding the risk prevention equation and cooperation of the nuclear plants' host municipalities. To that end, local authorities will be consulted about the industry's future development plans with the view of diversification and employment growth. Japan's Nuclear Regulation Authority (NRA) confirms the conformity of all existing nuclear power units with the regulatory requirements, which are among the most stringent in the world [METI 2021]. It is worth mentioning that the costs of nuclear energy for Japan are estimated to be cheaper (USD 0.11/kWh including system costs) than PV (USD 0.15/kWh) or on-shore wind (USD 0.14/kWh) and off-shore wind (USD 0.20/kWh) with the cheapest energy coming from liquified natural gas (LNG) (USD 0.075/kWh). That is due to the fact that space scarcity in Japan highly influences price-competitive locations of RES [CNIC 2021]. Several means exist by which the stable use of nuclear power would be restarted and promoted. This will require a high level of public trust and a maximum level of safety. One approach is to create a special restart-acceleration task force that would bring together human resources and knowledge to maintain technological capability in the area of civil nuclear energy. In relation to spent nuclear fuel, is the plan is to construct new interim fuel storage facilities and also to develop appropriate technologies aimed at the reduction of the volume and harm potential of radioactive waste. Another plan is to complete the operation of the Rokkasho reprocessing plant built within a public private partnership (PPP) financial model. Yet another is to promote the plutonium-thermal mixed oxide (MOX)-fuelled, power-generation technology and the development of

fast reactors, also by means of international cooperation projects. Efficient small modular reactor (SMR) technology will be demonstrated and proven through the same sort of cooperation. That approach has also been supported by the Energy and Environment Ministers in May 2022, when they met in Berlin—system flexibility and SMRs will further recognise the role of nuclear energy in decarbonisation and energy transition [G7 2022].

Another Japanese project planned, also relevant to Poland's experience, is the development of new components used for hydrogen production within high-temperature gas-cooled reactor (HTGR) technology. On May 18, 2017, an agreement was signed between the NCBJ (National Centre for Nuclear Research in Poland) and the JAEA (Japanese Atomic Energy Agency) regarding the exchange of experience in research on nuclear cogeneration technology, including participation of experts in joint materials research and creating a concept for the implementation of developed solutions already on the market.

In 2019, the Polish Ministry of Energy signed an agreement with the National Centre for Research and Development for the implementation of a research project regarding the possibility of implementing high-temperature gas-cooled reactor technology (HTGR) in Poland. The Minister of Education and Science of Poland made the decision to finance the design and licensing of this project with PLN 60.5 million. On December 28, 2020, the Council of Ministers in Poland acknowledged the fact that the project was carried out and entrusted it to the Minister of Climate and Environment [Rada Ministrów RP 2020]. Another promising technology is nuclear fusion to be developed through international cooperation projects such as ITER (iter.org).

Even though Japanese society is divided in terms of support towards nuclear energy, after the war in Ukraine started, several Prime Minister's statements of 2022 made it clear, that 'Japan will go back to safe and effective utilisation of nuclear reactors in addition to renewables, not only to address urgent climate change issues but also to contribute to the de-Russian efforts of the world' [Reuters 2022] and "Restart as many nuclear reactors as possible...so that 10 percent of power consumption should be secured with ample room for stable electricity supply for peak hour will be obtained" [PM Office 2022].

7. RENEWABLE ENERGY SOURCE DEVELOPMENT

RES are by nature the domestic source of energy; therefore, they are secured and can be considered a strategic opportunity in the energy mix of Japan. They not only reduce dependency on energy imports but also diversify energy mix, thus increasing energy security and reducing CO₂ emissions, as low-carbon sources of energy. Therefore, increased attention has focused on the subject of renewable energies in Japan over recent years Results

of Japanese research show that PV-generated electrical power would be enough to satisfy between 15% and 48% of the annual electricity demand of the entire building stock of the country by the year 2050 [Cheng et al. 2022]. Another RES, the offshore wind potential in Japan remained untapped despite generous FIT levels. This was mainly due to relatively high technology and administrative risks concerning the process of permitting. In 2013, the first offshore floating windfarm demonstration project (14 MW) started operation in Fukushima. In November 2018, the Japanese Parliament approved the Act for the Promotion of Use of Marine Areas for Development of Marine Renewable Energy Generation Facilities, in order to introduce a new national framework for offshore wind projects [METI 2019]. The act designates sea areas for the construction and development of offshore wind farms and introduces a competitive auction scheme that will provide a seabed lease for 30 years. By entering into effect in April 2019, the procurement price and period are decided by the auction guidelines. In June 2020, METI and the Ministry of Land, Infrastructure, Transport and Tourism issued a call for developers to participate in the auctioning of a 16.8 MW (or larger) floating wind farm off Goto City [METI 2020]. The project will receive remuneration at the current offshore FIT (floating) level of USD 0.27/kWh. The call for tender closed in December 2020, and all the bids were won by the Mitsubishi Group. The tender process was revised after the first phase, because only one operator won all the tenders. Currently, the second phase of the application process is open to the public [METI 2022].³ From 2021 onwards, Japan aims to develop 1 GW from three to four wind power projects annually [reNEWS 2020].

How is Japan going to reach these ambitious goals? The most important imperative for the future of the energy policy is to guarantee a stable supply of energy, but also to supply low-cost energy and to ensure the safety of the system. Environmental suitability—the 3E+S⁴ rule is also mentioned by the policy makers [METI 2021]. The results of studies show that a typical model Japanese smart-community is one that contains a fuel cell as well as PV and storage battery, has the capacity to become a positive energy district, and is capable of generating 1916 GJ [Okubo et al. 2022].

³ Oga City, Katagami City, and Akita City in Akita Prefecture; Murakami City and Tainai City in Niigata Prefecture; and Eshima and Saikai City in Nagasaki Prefecture were newly designated as promotion areas for the new tender. METI invited those who will operate offshore wind power generation projects in these four areas.

⁴ “3E+S” focus of the nation’s energy policy is emphasising energy security (E), economic efficiency (E), and environmental protection (E) without compromising safety (S). It also emphasises the need to look at both supply- and demand-side options by creating a supply-demand structure that is multi-layered, diversified, and flexible.

8. THERMAL POWER GENERATION

The thermal power share of the total power generation will be lowered, but this is under the assumption that it is needed to keep the necessary supply levels in view of possible instantaneous or continuous RES power generation reductions. The government wants to watch data on procurement risk carefully, watching the GHG emissions generated from a given source, as well as recognising and verifying the contribution of thermal power to an improvement in resilience. Having these in mind the appropriate thermal generation capacity will be maintained, based on liquid natural gas (LNG), hard coal, and oil [METI 2021]. A very important new trend that should also be considered in Poland is the introduction of fossil fuels cofiring together with such decarbonised new fuels as ammonia and hydrogen. Through the use of CCUS and carbon recycling, METI hopes to slowly exchange inefficient thermal units and to replace them with new efficient and decarbonised thermal power units.

Japan promises in the 6th Strategic Energy Plan to put an end to new government support for unabated coal thermal power generation until the end of 2021 in the international arena. This plan would be enforced through the ODA (Official Development Assistance) channel as well as through export finance, foreign direct investment, financial, and trade promotion support activities.

9. THE ROLE OF HYDROGEN AND AMMONIA

The meetings of the G7 environment, climate, and energy ministers in Germany confirmed that there is a special role for hydrogen and ammonia in building energy security and energy transition [G7 2022]. Hydrogen presents a valuable resource in various sectors of the energy system, and importing hydrogen can positively impact energy-mix decarbonisation. The plans mean that as much as 19 Mt of H₂ will be imported to avoid doubling power demand by 2050 compared to that of 2019, a process due to extensive electrification in non-energy Japanese economy sectors. In all cases, however, large-scale investments into renewable energy sources need to be made. Scenarios for hydrogen imports at a price of about USD 2/kg are possible, meaning that RES development poses a cost-efficient way to decarbonise the energy mix and reduce power generation prices. Electricity produced from hydrogen is nearly as cost-efficient as RES. Cheap imported hydrogen is a valuable and possible alternative for energy production in heavily urbanised regions as a substitute for local renewable energy [Burandt 2021].

Japanese Government plans to position hydrogen as a new energy super-resource. One of the issues elaborated upon in the 6th Strategic Energy Plan is the importance of societal acceptance for the hydrogen revolution. It is assumed that Northeast Asia and Asia will import as much as 500 Mtoe by the year 2050, with Middle East and North

America being the biggest exporters, exporting in excess of 300 Mtoe [IEA 2021]

The plans to build a cost-effective supply of hydrogen and ammonia in Japan are based on low-cost imports of hydrogen from overseas as well as the constant development of the domestic production facilities based on domestic resources. The plan is to utilise water-electrolysers to tap the RES excess energy, but also to develop innovative and cost-efficient hydrogen production by the means of heat sources in the high-temperature spectrum: photocatalyst and the HTGR (mentioned in section 6 on nuclear energy). The expectation is that the amount of hydrogen supplied to the market will be increasing from the current level of 2 million tons per year to 3 million tons in 2030, and as much as 20 million tons in the year 2050. The costs are to be reduced to fossil fuel levels of cost. It is expected that reduction will be one-third of the current level of USD 0.75/Nm³ in 2030 and one-fifth of that level in 2040 [METI 2021].

The market for hydrogen also requires the construction and development of the demand side which will encompass power-generation, the transport sector, industrial-use, and household consumers. In the power generation demand alone, an expansion of 30% is expected in hydrogen co-firing in gas-fuelled power generation and hydrogen-fuelled power generation and as much as 20% of ammonia co-firing in coal generation is expected. The initial steps required are innovative demonstration projects on co-firing and single-fuelled firing. Overall, it is expected that hydrogen and ammonia will be responsible for 1% of the total energy mix in the year 2030. In transportation, the plan is to build hydrogen stations to further stimulate the expansion of current (fuel cell vehicles) FCVs as well as of future FC trucks.

It is expected that in the industrial sector, large-scale changes in manufacturing processes will happen, including hydrogen-reduced iron manufacture. Another expected process is the development of burners and large hydrogen-fuelled boiler technologies. In the housing sector, it is also planned that cost reductions will be possible via quick expansion of the stationary fuel cells and also the pure hydrogen fuel cell. The hydrogen-based energy carriers, including hydrogen, ammonia, and synthetic hydrocarbons, are all expected to help reduce residual carbon dioxide emissions, although their full potential has not yet been fully understood and measured in terms of their competitiveness and complementarity with other mitigation options such as electricity-use promotion, the development of biofuels, and the CCUS [Oshiro, Fujimori 2022].

As for ammonia use for power generation, the Basic Energy Strategy target for the year 2030 is 1% of the power mix (3 million tonnes of ammonia) [METI 2021]. And the JERA demonstration project uses a 20% input of ammonia into co-firing with a coal power plant, whereas up to 60% is possible. It is also possible to use it with coal to obtain thermal power, where co-firing with gas power is possible up to 70% and 100% in gas turbines [JERA 2022].

10. CONCLUSIONS AND LESSONS FOR POLAND

While the carbon-neutrality declaration of the Japanese government was perceived as an early signal of the political will, it is unlikely that it could in any way affect the change of the government's approach to energy security, which is based on the need to diversify energy sources, still assuming further use of fossil fuels. In the case of Japan, climate neutrality, according to the assumptions, is to be achieved not as a complete departure from fossil sources, but rather through the use of clean coal technologies, accompanied by the increased use of renewable energy sources. The forecasted decrease in energy demand in the coming years, resulting mainly from the development of energy storage technologies and the improvement of energy efficiency, will also have a positive effect. The declaration proved to have mobilised both the governmental administration as well as businesses, encouraging both, starting in Autumn 2020, to try to compete in identification and creation of ideas and initiatives for reducing the GHG level to zero by the year 2050. The issue of nuclear energy is one of the main socially sensitive issues the government will have to tackle.⁵

From the moment that Prime Minister Suga announced plans to achieve climate neutrality by 2050, there has been a discussion among experts regarding whether this target is actually achievable in the case of Japan. Many consider the declaration ambitious, but possible, while some voices claim that it is not realistic. The declarations of the Japanese government regarding the reduction of emissions by 46% compared to 2013 emission by 2030 are controversial, as seen from the perspective of large business. Because it will not be possible to achieve climate neutrality by 2050 without a reduction of this order, Japan's ability to reduce CO₂ emissions sufficiently in the short term is questionable. According to analysts from the Central Research Institute of Electric Power Industry (CRIEPI), achieving such a high level of reduction may be difficult. According to the calculations of the centre, the demand for energy in Japan in 2030 will amount to 981.1 TWh. With this assumption, even if the share of nuclear energy by that time is 20% and the share of renewable energy sources, mainly thanks to the large-scale installation of solar panels and wind farms, will increase to 30%, the maximum possible reduction of CO₂ will not exceed 40%. To fill the 6% gap, Japan would have to increase solar power to 219 GW, according to CREPI estimates, which means that every year the increase in solar power would have to exceed the growth rate in 2014, which was the time of the most dynamic increase in the power of this energy source. Due to the completion of the FIT system and the lack of space for large-scale solar panel installations, CREPI considers such a scenario unrealistic.

⁵ 'We need to change our thinking to the view that taking assertive measures against climate change will lead to changes in industrial structure and the economy that will bring about great growth'. [Reuters World News 2020].

Experts from the Renewable Energy Institute (REI) are of a different opinion, which is that reaching a ceiling of a 46% reduction by 2030 is possible provided that coal energy is completely abandoned. Interestingly, REI analysts believe that the achievement of the above-mentioned the ceiling is possible even with a zero share of nuclear energy in the national energy mix.⁶

A major obstacle to the achievement of the zero-emission target is the still very high prices of renewable energy in Japan. The alternative—coal-fired energy, thanks to the low import costs of this raw material—are still considered efficient. Experts indicate that the introduction of a carbon tax in Japan, the income from which could be allocated to the development of renewable energy and the promotion of decarbonisation, would be one of the ways to reverse the current price proportions. Despite pressure from the Japanese Ministry of the Environment, the introduction of a carbon tax was not included in the tax reform planned for fiscal 2022. Other obstacles hindering the introduction of RES on a large scale in Japan are also the high costs of connecting RES to the power grid, excessive monopolisation of the market by the largest energy companies and too-slow production pace necessary to reduce the cost of the economies of scale.

The war in Ukraine will have a profound influence on all planned strategies and will completely distort price relationships. The pragmatic Japanese will find a way to navigate out of this crisis; this will be a subject for further analysis when more data are available. The position of the Japanese government on imposing an embargo on the imports of energy resources from Russia is shared by Japanese businesses, due to their considerable capital investment in energy projects in the Russian Far East. It is estimated that the value of Japanese investments in the energy sector in Russia, where Japanese companies also own shares in Novatek on the Yamal Peninsula, amounts to USD 8.4 billion.⁷

Japanese businesses are also eager to pick up on the argument put forward by the government of their country that the possible withdrawal of Japan from liquid natural gas and crude oil trade with Russia could benefit China by

increasing the amount of these raw materials China could import from Sakhalin. As a result of such actions, Russia would, in fact, not suffer any losses.

Lessons drawn from Japan for the future of the Polish energy mix can be numerous. The first observation is that RES capacity development is rather an evolutionary process, that can and should be supported by the state. Otherwise, RES development would be sluggish and nonlinearly dependent on changing fossil fuel energy sources alone. That is seen in the logarithmic growth of PV in Poland, which is powered by the generous public support schemes.

The second observation is that as a result of geopolitical changes, the need for and the role of energy security cannot be overstated: the use of nuclear energy seems to be the best, though not necessarily the cheapest, solution in the medium term for managing electricity shortages resulting from high prices for fossil fuels. That might include the future use of SMRs in the industries the most need of electricity. New, not fully developed commercially, nuclear technologies, like HTGR, will have to demonstrate their business efficiency before they can play an important role in the energy mix.⁸

The third observation is that new technologies, in which I put CCUS as well as hydrogen and ammonia together, can and should play an important role in green transformation, but will have to be strongly supported by the government funds, because of the high investment costs, both for the CAPEX and network development costs for hydrogen and ammonia.

The fourth observation is the fact that in the non-power generation sector, where decarbonisation is difficult, hydrogen storage and CCUS technologies could be used to decarbonise fossil fuels wherever their use is still necessary. Finally, the fifth observation is that the use of carbon dioxide removal (CDR) will have to be considered to reach carbon neutrality using negative emissions.⁹

ABBREVIATIONS

AI	artificial intelligence
BECCS	bioenergy with carbon capture and storage
CCE	circular carbon economy
CCS	Carbon Capture and Storage

⁶ According to the institute's estimates, effecting a decrease of 10 per cent by 2030 compared to 2018 will allow Japan to achieve zero CO₂ emissions by 2050 by using exclusively renewable energy sources (solar, wind, hydro, geothermal, and biomass [Renewable Energy Institute 2020]).

⁷ According to recent data, Japan Sakhalin Oil and Gas Development Co. (SODECO) has a one-third stake in the Sakhalin 1 project. METI has a one-half stake in SODECO, while Japan Petroleum Exploration holds over 15% interest, Itochu 14%, Marubeni 12%, INPEX 6%, and Itochu Oil Exploration almost 2%. Japan Mitsui has a one-eighth stake, and Mitsubishi has a one-tenth stake in the Sakhalin 2 project. State-owned Japan Oil, Gas and Metals National Corp. provides equity financing and a loan guarantee to Japan Arctic LNG, a subsidiary of Mitsui, which has a 10% stake in the Arctic LNG 2 project [S&P Global Commodity Insights 2022].

⁸ Worth mentioning is the fact that in April 2022 JAEA and MHI (Mitsubishi Heavy Industries) started to produce hydrogen using that technology [WNN 2022]. Nevertheless, there are 14 countries that plan to use nuclear energy in the future that do not have it now, including Turkey, Egypt, Indonesia, Poland, and Kazakhstan, and 25 countries plan to use existing plants into the future, including the USA, France, and China [IAEA 2022].

⁹ This has also been confirmed by the Japanese experts [JICC, 2022]. In Polish conditions these could include afforestation and reforestation, soil carbon sequestration (SCS), bioenergy utilisation with carbon capture and storage (BECCS), as well as direct air capture (DACCS) [Minx 2018].

CCU	carbon capture and utilization	JERA	JERA Co., Inc.
CCUS	carbon capture, utilization, and storage	JICC	International Cooperation Center
DAC	direct air capture	LNG	liquid natural gas
DACCS	direct air capture with carbon storage	METI	Ministry of Economy, Trade, and Industry (of Japan)
FC	fuel cell	MOX	mixed oxide
FCV	fuel cell vehicles	NCBJ	National Centre for Nuclear Research (in Poland)
FIT	feed-in tariff	NRA	Nuclear Regulation Authority (Japan)
FY	fiscal year	PPE	6th Basic Energy Plan (of Japan)
GDP	gross domestic product	PV	photovoltaics
GHG	greenhouse gas	REI	Renewable Energy Institute
HTGR	high-temperature gas-cooled reactor	RES	renewable energy sources
IAEA	International Atomic Energy Agency	SMRs	small modular reactors
IEA	International Energy Agency	USC	ultrasuper critical
ITER	International Thermonuclear Experimental Reactor	ZEV	zero emission vehicles
JAERA	Japanese Atomic Energy Agency	ZEH/ZEB	zero energy homes/zero energy buildings

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