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Renewables to Strengthen Energy Security in Europe and Japan

July 2022

Renewable Energy Institute (REI)

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Author

Romain Zissler, Senior Researcher at Renewable Energy Institute.

Editor

Masaya Ishida, Senior Manager – Business Alliance at Renewable Energy Institute.

Acknowledgements

The author would like to thank BloombergNEF, the global authority on economic data on energy investments, who allowed Renewable Energy Institute to make use of BloombergNEF's data in some key illustrations of this report.

Suggested Citation: Renewable Energy Institute, Renewables to Strengthen Energy Security in Europe and Japan (Tokyo: REI, 2022), 44 pp.

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Introduction

On February 24, 2022, the invasion of Ukraine by Russia raised worldwide concerns about energy security. These concerns are rightly particularly serious in major fossil fuel importing economies such as those of Europe and Japan.

This report, primarily focusing on energy supply, aims at shining a light on energy security related issues which should be relevant to European and Japanese stakeholders as they face decisive energy and climate crises. To achieve this objective, the report contains three chapters with the following key findings:

Chapter 1 describes Europe and Japan's reliance on fossil fuel imports is unsustainable from both economic and geopolitical (Africa, the Middle East, and Russia) perspectives. It makes them vulnerable to overseas fuel price fluctuations and supply disruptions. Therefore, Europe and Japan should immediately proceed with strategies strengthening their energy security.

Chapter 2 recommends strengthening energy security by accelerating renewable energy electricity because renewables are abundant and available domestically, and because of their cost competitiveness to generate electricity. The new power supply plans of France, Germany, the United Kingdom, and Japan all grant essential role to renewable energy electricity, but to different extents. It is found that: Germany's goal of 100% renewable energy electricity by 2035 and beyond is challenging. Yet, it is recognized to be certainly more pragmatic than to heavily rely on struggling nuclear power like France and the United Kingdom where outages are affecting existing reactors and significant delays and cost overruns are plaguing new reactors under construction. Also, it is more well-founded than hoping for unproven carbon capture and storage like in the case of Japan. Moreover, it may be noted that in the case of nuclear power, uranium is often imported: with natural uranium mining largely concentrated in one country, Kazakhstan, and uranium enrichment as well, Russia – a weakness in terms of energy security.

Chapter 3 recognizes that an energy security based on renewable energy electricity also comes with challenges. On the one hand, demand and supply flexibility must be improved. On the other hand, the current geographical concentration of critical minerals, as well as that of some clean energy technologies manufacturing capacity must be reduced. Portfolios of solutions to these challenges are highlighted. Regarding the former: demand response, interconnections, pumped storage hydro, batteries, decarbonized thermal, and market operations. Regarding the latter: recycling, optimizing efficiency, substituting materials, and expanding domestic manufacturing capacity.

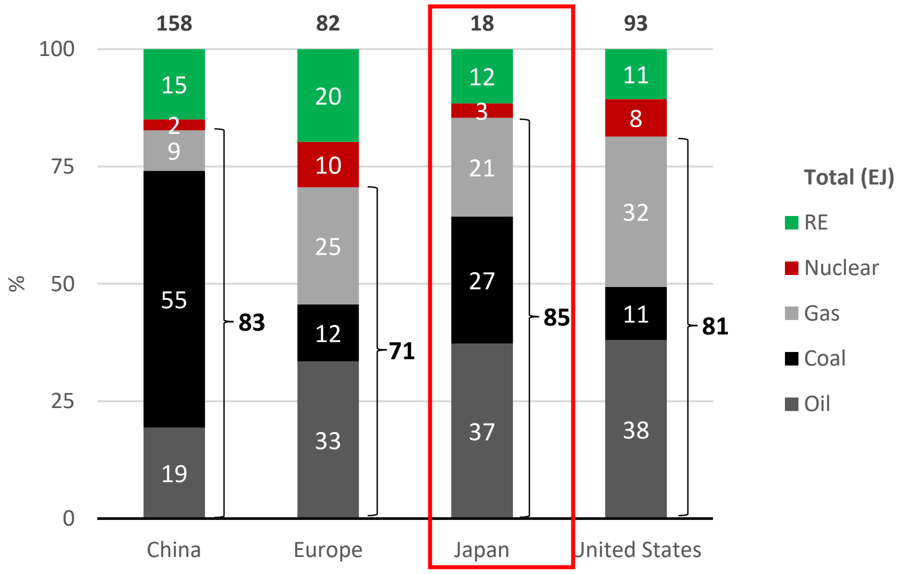
Chapter 1: Reliance on Imported Fossil Fuels Makes Europe and Japan Vulnerable

Global energy consumption is still largely dominated by fossil fuels (oil, coal, and gas): 82% of the world's total primary energy consumption in 2021. The world's four largest economies: China, Europe, Japan, and the United States are no exceptions to this reality. Among these four economies, to meet their energy needs Europe and Japan are the most reliant on imported fossil fuels. Without almost none of these fuels available domestically, the situation of fossil-fuel-poor Japan is by far the most unsustainable. Reliance on imported fossil fuels makes Europe and Japan vulnerable to overseas fuel price fluctuations and supply disruptions. This chapter analyzes how much Europe and Japan are economically energy insecure and points out problematic geopolitical dependence on fossil fuel imports from Africa, the Middle East, and Russia in particular.

1) Dependance on Fossil Fuel Imports Severely Weakens Europe and Japan's Economies

Global energy consumption is largely dominated by fossil fuels, so is the energy consumption of the world's four largest economies. Indeed, in China, Europe, Japan, and the United States the combined shares of oil, coal, and gas in total primary energy consumption ranged from 71% (Europe) to 85% (Japan) in 2021 (Chart 1).

Chart 1: China, Europe, Japan, and United States Primary Energy Consumption by Fuel 2021



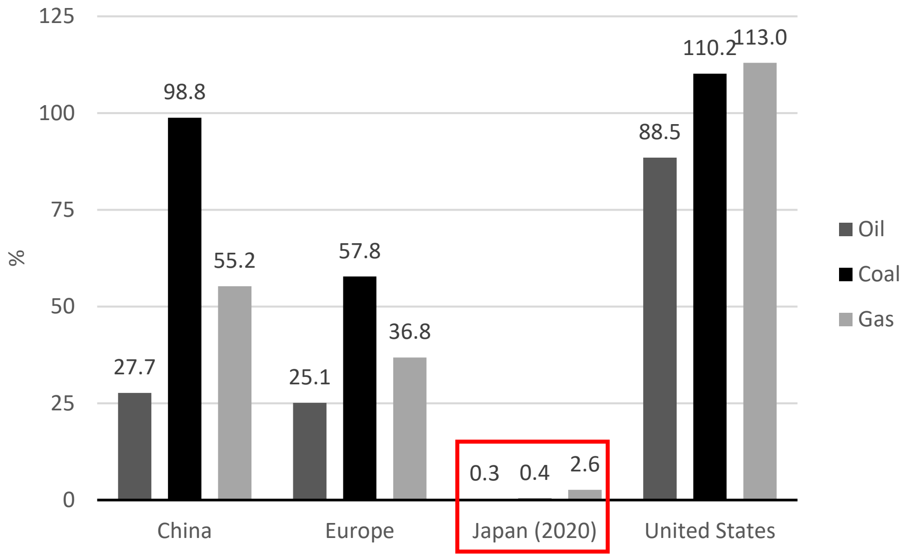
Source: BP, Statistical Review of World Energy 2022 (June 2022).

For clarification purposes, Europe is defined by BP (the main statistical source referred to in this report) as: OECD Europe, Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Georgia, Gibraltar, Malta, Montenegro, North Macedonia, Romania, and Serbia. This definition of Europe is very similar to that of the International Energy Agency with a few exceptions.

Apart from being heavily polluting, the other main problem with fossil fuels is that their geographical distribution is uneven across the world. While some countries have more resources than they need, others do not.

Still considering the world's four largest economies, because of their lack of domestic fossil fuel resources Europe and Japan face greater challenges than China and the United States to meet their current energy needs (Chart 2).

Chart 2: Fossil Fuels Production/Consumption Ratios China, Europe, Japan, and United States 2021



Sources: For China, Europe, and the United States; BP, Statistical Review of World Energy 2022 (June 2022). For Japan; International Energy Agency, Data and Statistics – Balances, Japan 2020 (accessed May 12, 2022).

Indeed, the ratio between fossil fuel production and consumption of the United States ranges from around 88% for oil to 110-113% for coal and gas. This means that the United States is close to be completely self-sufficient for all fossil fuels.

The situation of China is less favorable, but still rather manageable with a notably high 99% production/consumption ratio for coal which is indisputably the country's most important energy source (55% of total primary energy consumption).

In Europe, where oil and gas prevail (combined: 58% of total primary energy consumption), the production/consumption ratios for each of these fuels are only 25% and 37%, respectively.

Finally, in the case of Japan the production/consumption ratios for oil, gas, and coal range between 0% and 3%. This means Japan is almost completely self-insufficient for all fossil fuels and that it has no choice, but to massively rely on imports for these fuels.

It may be emphasized here that Japan's situation is extreme because of the world's four largest economies it combines both the highest reliance on fossil fuels to meet its energy needs (85%) and – by far – the worst self-sufficiency rates for these fuels (0-3%).

Considering all the world's economies now, it may be highlighted that Europe and Japan are unsurprisingly consistently among the top importers for all fossil fuels. Because of its enormous energy consumption China is another heavyweight fossil fuel importer (Table 1).

Table 1: Fossil Fuel Importers Ranking 2021

Rank	Oil (global share)	Coal (global share)	Gas (global share)
#1	**EUROPE (22%)**	China (26%)	**EUROPE (38%)**
#2	China (21%)	India (20%)	China (18%)
#3	Other Asia-Pacific (17%)	**JAPAN (19%)**	**JAPAN (11%)**
#4	United States (14%)	**EUROPE (17%)**	Other Asia-Pacific (9%)
#5	India (9%)	Other Asia-Pacific (10%)	United States (8%)
#6	**JAPAN (5%)**	South & Central America (3%)	Mexico (7%)
#7	Middle East & Africa (4%)	Middle East & Africa (3%)	India (4%)
#8	South & Central America (4%)	Canada (1%)	Canada (3%)
#9	Mexico (2%)	United States (1%)	South & Central America (2%)
#10	Canada (2%)	N/A	N/A

Notes: Country grouping is used because breakdowns are not always available. Intra-regional trade is excluded. Group of countries/countries which rounded global share is 0% are not included. "Other Asia-Pacific" includes all countries of this geographical area except China, India, and Japan.

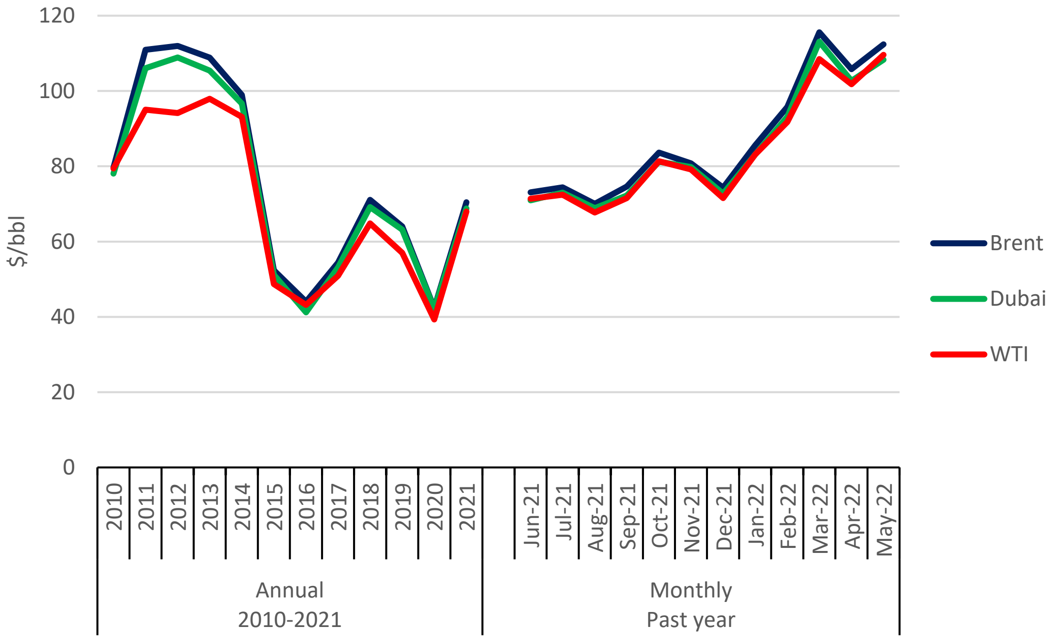
Source: BP, Statistical Review of World Energy 2022 (June 2022).

Historically, in a world that has not been aiming for decarbonization until relatively recently, abundance, practicality and affordability have been the main factors explaining the success of fossil fuels.

Fossil fuels remain abundant and practical, but they are not affordable anymore. Indeed, the combination of the COVID-19 pandemic recovery in 2021 with the major international geopolitical crisis caused by the invasion of Ukraine by Russia in February 2022 has considerable consequences on energy demand & supply thereby significantly increasing fossil fuel prices across the world. A severe issue, in energy importing countries particularly.

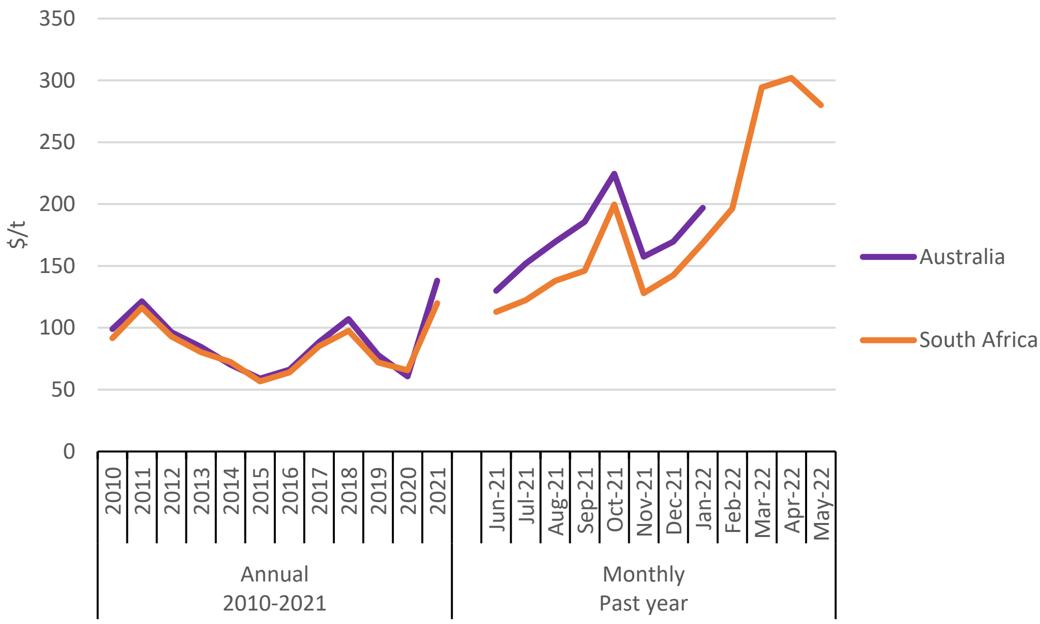
In May 2022, the prices of the three main international crude oil benchmarks were around $110/bbl (Chart 3 on next page), the prices of coal from South Africa (one of the world's main coal exporters for which data are available) – were at $280/t (Chart 4 on next page as well), and the prices of gas were close to $30/MBtu in Europe (Chart 5 on page 8). Given the current uncertainty surrounding fossil fuel markets, prices could remain high for a few years.

Chart 3: Crude Oil Prices



Source: World Bank, Commodity Markets – Annual and Monthly Prices (June 2022).

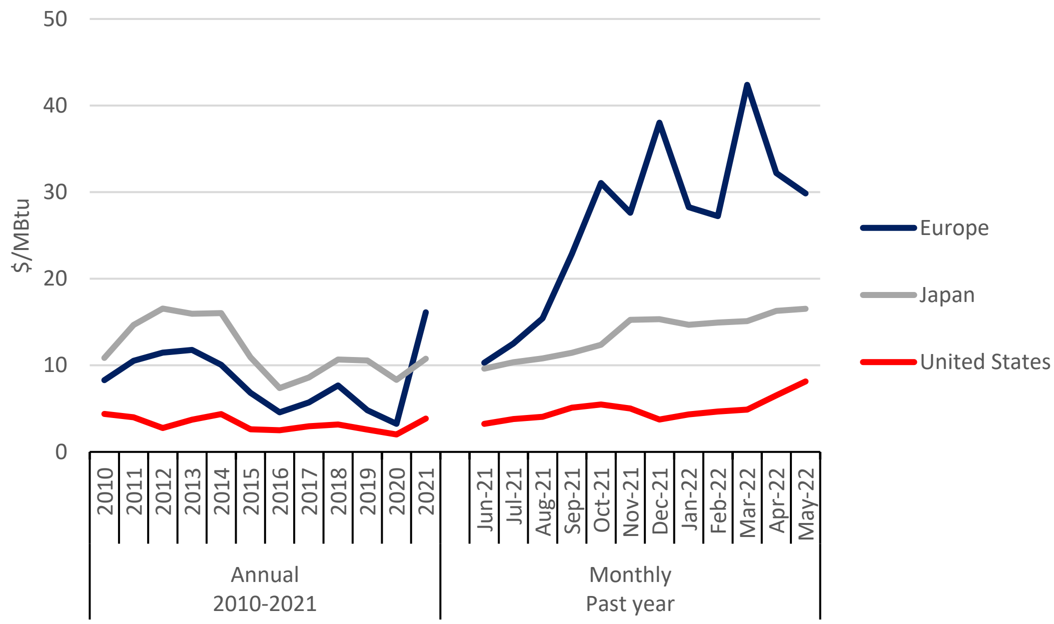
Chart 4: Coal Prices



Note: Data for Australia are not available for the period February-May 2022.

Source: World Bank, Commodity Markets – Annual and Monthly Prices (June 2022).

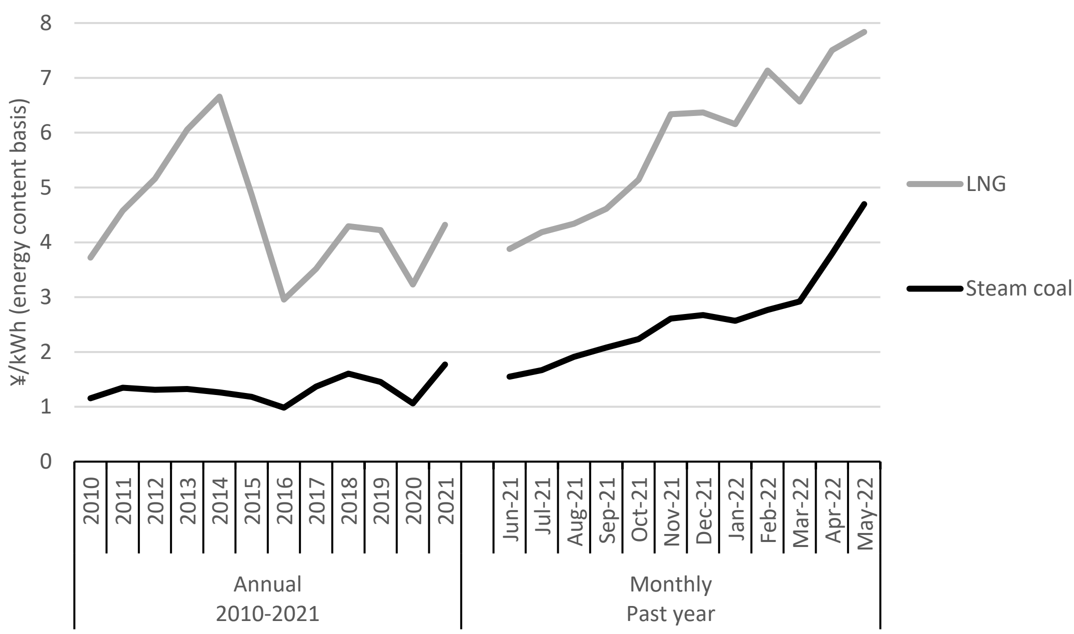
Chart 5: Gas Prices



Source: World Bank, Commodity Markets – Annual and Monthly Prices (June 2022).

Considering the main fossil fuels used for electricity generation, the monthly average prices of importing these fuels into Japan were at all-time highs in May 2022: Almost ¥8/kWh for liquefied natural gas (LNG), and ¥5/kWh for steam coal. Compared to June 2021, that is double for LNG and triple for steam coal (Chart 6).

Chart 6: Japan Steam Coal and LNG Import Prices



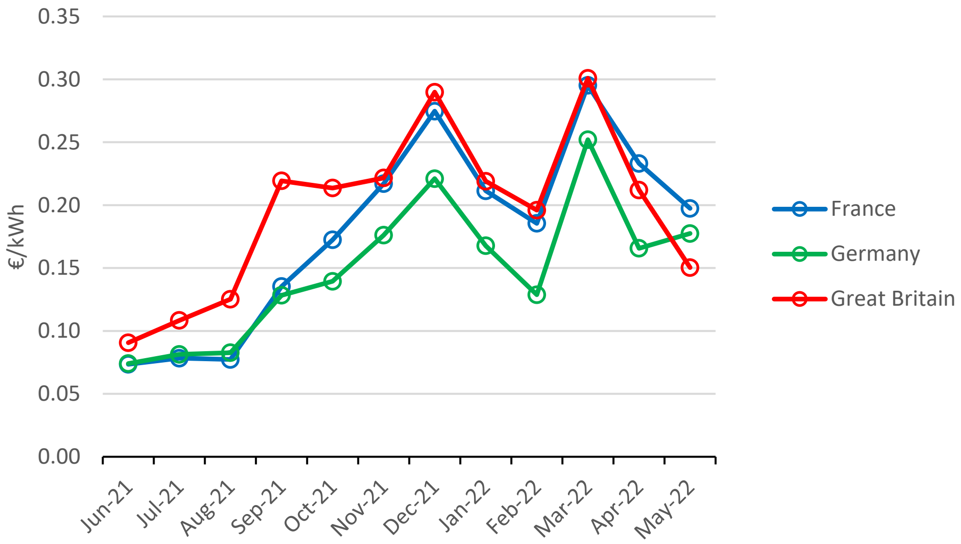
Source: Japan Ministry of Finance, Trade Statistics of Japan: Steam Coal and LNG (accessed June 29, 2022).

These numbers only indicate the prices of these fuels on an energy content basis, they are not fuel costs for electricity generation which should also take into account the electrical conversion efficiency of power plants: In Japan, around 55% for a recent combined cycle gas turbine and 40% for a recent ultra-supercritical coal-fired power plant. Fuel costs for electricity generation from LNG and steam coal should thus currently be about ¥14/kWh and ¥12/kWh, respectively.

Fossil fuel prices have a significant impact on electricity price formation. This is because of the merit order principle which ranks power plants on an ascending order of price based on their marginal costs. Those with the highest marginal costs set the power exchange prices. Typically, these are power plants burning fossil fuels, especially gas.

It then comes as no surprise that power exchange prices have dramatically increased in Europe (Chart 7) and in Japan in the past twelve months.

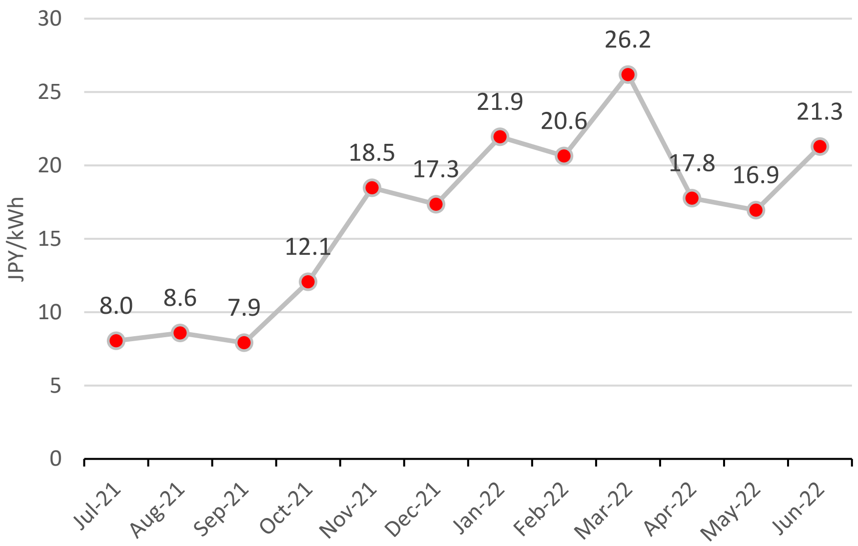
Chart 7: Monthly Average Day-ahead Power Exchange Prices France, Germany, and Great Britain June 2021-May 2022



Source: EPEX SPOT, Monthly Power Trading Results (July 2021-June 2022).

In the case of Japan, monthly average day-ahead power exchange prices increased from ¥8/kWh in July 2021 to ¥21/kWh in June 2022, a multiplication by a factor 2.6 (Chart 8 on next page).

Chart 8: Monthly Average Day-ahead Power Exchange Prices Japan July 2021-June 2022



Source: Japan Electric Power Exchange, Trading Information – Fiscal Years 2021 and 2022: Spot Market Trading Results (downloaded June 30, 2022).

Thus, being quite reliant on fossil fuel imports Europe and Japan must currently pay hefty prices to meet their energy needs. These high energy prices severely weaken their economies and expose their vulnerabilities to overseas fuel price fluctuations and supply disruptions.

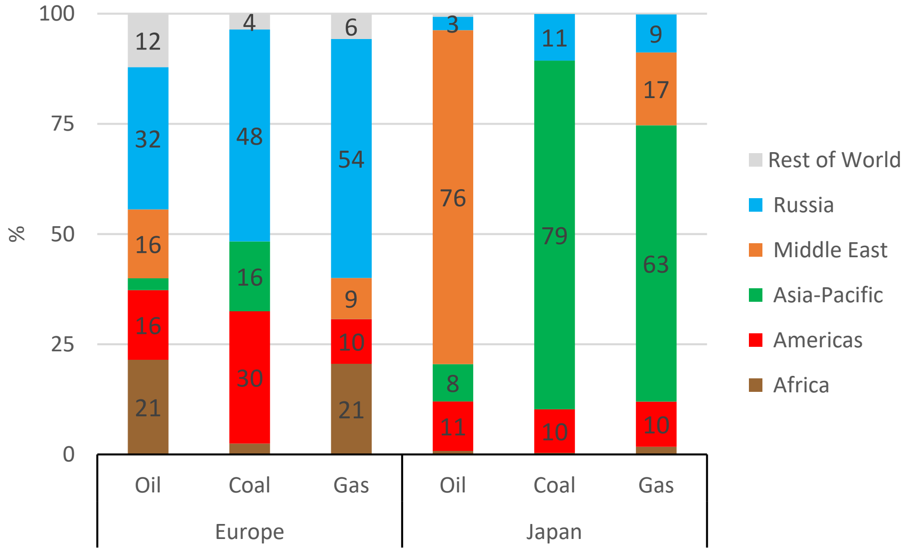
Because of recent high energy prices in Europe and Japan, industries are sometimes constrained to either curtail or stop production (e.g., steel producers, fertilizer manufacturers, glass makers…), households are increasingly confronted to energy poverty, and several energy suppliers went bankrupt.

As a result, governments had to intervene. Subsidies such as tax cuts and direct payments (i.e., from public authorities to customers to help them pay their energy bills) were among emergency measures implemented to protect and maintain social peace. However, these subsidies supporting largely fossil based energy consumption, are not sustainable solutions neither economically nor environmentally.

2) Problematic Geopolitical Dependence on Fossil Fuel Imports from Africa, the Middle East, and Russia

Europe and Japan’s vulnerability to fossil fuel imports sometimes further suffers from problematic geopolitical dependence towards countries either engaged in conflicts or facing instable domestic/regional situations jeopardizing trade relationships (Chart 9 and Map 1 on next page).

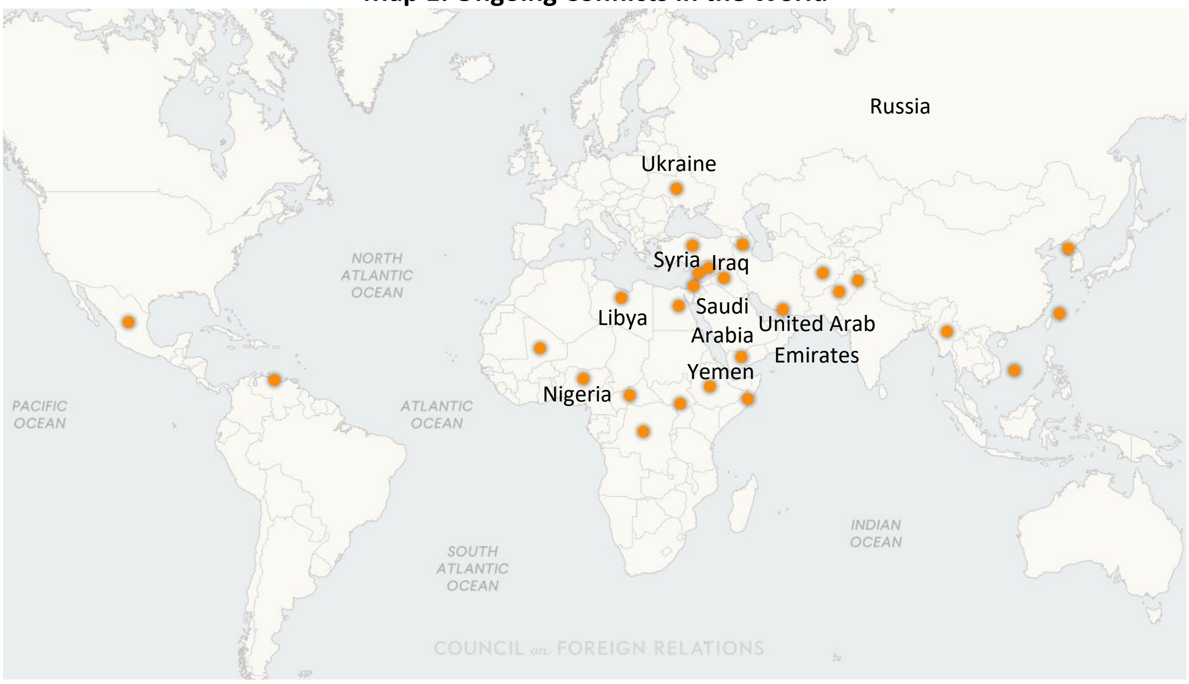
Chart 9: Europe and Japan Reliance on Fossil Fuel Imports by Geographical Area 2021



Note: Shares below 3% are not displayed for readability purposes.

Source: BP, Statistical Review of World Energy 2022 (June 2022).

Map 1: Ongoing Conflicts in the World



Note: Modified by Renewable Energy Institute; Selected countries' name added.

Source: Council on Foreign Relations, Global Conflict Tracker (accessed May 13, 2022).

For instance, Europe is very dependent on Russia for all its fossil fuel imports. Indeed, in 2021, Russia was Europe's first supplier for gas (54%), coal (48%), and oil (32%). The decision of Russia to invade Ukraine in February 2022 has put Europe in an extremely uncomfortable position. It has pushed Europe to look for alternatives to stop on the one hand financing an historical trade partner that has turned into a hostile belligerent, on the other hand being at the mercy of fuel supply interruptions.

Europe's dependence on Russia for fossil fuel imports is by far the most problematic, but it is not the only one.

Indeed, Europe's oil and gas imports from Africa and the Middle East may be threatened by instability. For example, Nigeria – Africa's first oil and third gas producer – is in the grip of terrorism because of the Islamic sect Boko Haram. Libya – Africa's second oil producer – is confronted with a civil war. Europe is also significantly dependent on oil imports from Iraq, another country where a civil war takes place.

Regarding the origins of fossil fuel imports into Japan, the situation is different from that of Europe.

For oil, Japan is much more dependent on imports from the Middle East, especially from Saudi Arabia and the United Arab Emirates. These two countries are spared from conflicts, but the region is characterized by instability and several civil wars are ongoing in neighboring countries (Iraq, Syria, and Yemen).

When it comes to coal and gas, Japan is mostly dependent on Asia-Pacific, and especially one country: Australia. Indeed, in 2021, Australia alone accounted for 65% and 36% of Japan's coal and gas imports, respectively. Though Australia is a friendly trade partner not facing any conflict, this high degree of reliance – somewhat reminding the interdependence between Europe and Russia – could be questioned from the point of view of strategic diversification because it is not desirable to excessively rely on one supplier.

Diversifying fossil fuel imports for Europe and Japan is possible, but this strategy is constrained by two limiting factors putting upward pressure on prices: reduced accessible supply resulting from the boycott of Russia and increased competition from emerging and developing economies to procure these fuels. For instance, it may be noted that after decades of being the world's largest LNG importing country, Japan has symbolically been overtaken by China in 2021.[1]

The European Union (EU) being aware of this issue recognized in its "REPowerEU Plan", its response to the hardships and global energy market disruption caused by Russia's invasion of Ukraine, that diversifying fossil fuel imports could only be one of the three solutions it needs to implement.[2] The other two are: energy efficiency & savings and renewable energy (RE). Regarding the latter, it is proposed to increase the target for the share of RE in the EU's total energy (i.e., including electricity, heating & cooling, and transport) from 40% to 45% by 2030. There is no dedicated target for the share of RE electricity, but it is at the heart of the RE expansion strategy, notably by approximately quadrupling solar PV installed capacity to almost 600 GW by the end of this decade.

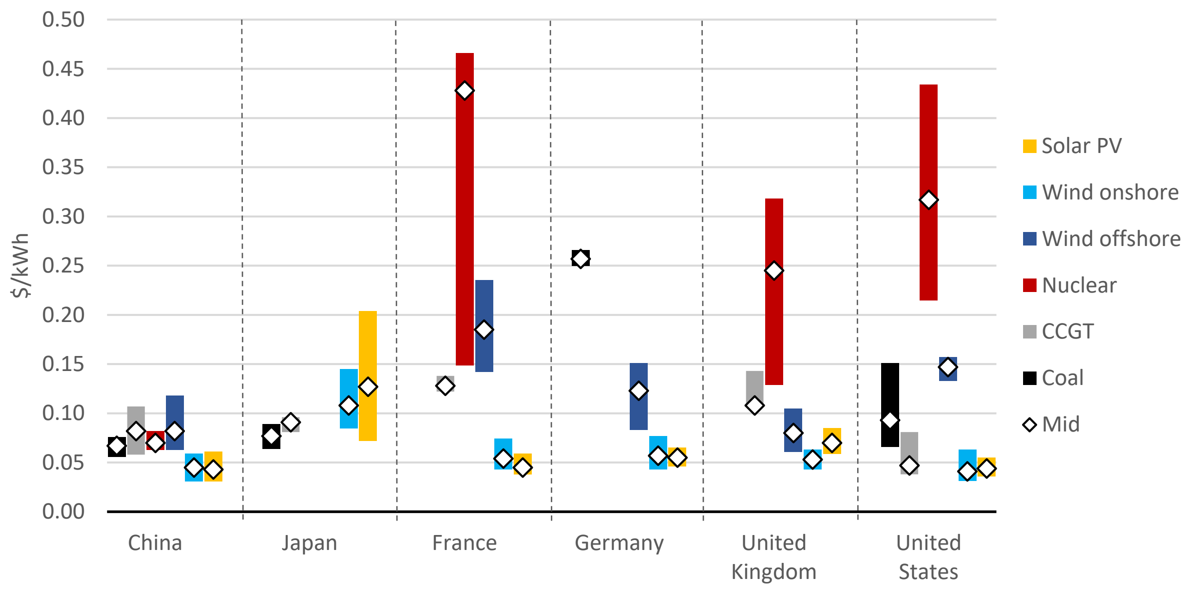
Chapter 2: Strengthening Energy Security by Accelerating Renewable Energy Electricity

On the one hand renewable energy resources are abundant and freely available across the world, on the other hand their cost competitiveness to generate electricity is proven. As a result, renewable energy electricity is the main supply-side solution to reduce fossil fuel consumption, thereby strengthening energy security and contributing to carbon neutrality objectives. Europe's three largest economies: France, Germany, and the United Kingdom as well as Japan have all granted key future roles to renewable energy electricity. However, depending on countries the level of ambitions for renewable energy differs. Indeed, while Germany aims for a challenging, but pragmatic 100% renewable energy electricity supply, France and the United Kingdom recently adopted new plans for both renewable energy and nuclear – the plans for the latter are questionable, and Japan wishfully intends to combine renewable energy with nuclear & fossil + carbon capture and storage – a pipe dream.

1) Renewable Energy Electricity: Key for Energy Security and Carbon Neutrality

RE electricity is already generally cost-effective today (Chart 10) and it is technically feasible to further electrify energy uses. Thanks to RE electricity there is thus a significant potential to reduce the need for fossil fuel consumption in many important sectors such as industries, buildings, and transport. This is excellent news for energy security and carbon neutrality, especially in fossil fuel importing countries.

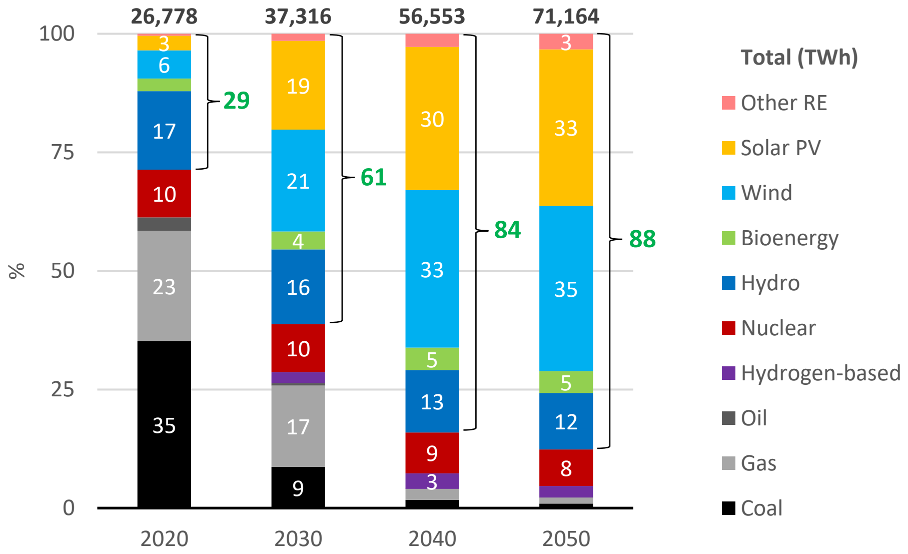
Chart 10: Levelized Cost of Electricity Selected Countries 2H 2021



Source: BloombergNEF, Levelized Cost of Electricity 2H 2021 (accessed May 16, 2022) [subscription required].

In this regard, in its flagship report "Net Zero by 2050: A Roadmap for the Global Energy Sector" published in 2021, the International Energy Agency (IEA) projects that nearly 90% of global electricity generation will come from RE in 2050 (Chart 11), against 29% in 2020.

Chart 11: World Gross Electricity Generation Mix Projections 2020-2050 – Net-Zero Emissions Scenario



Notes: Shares below 3% are not displayed for readability purposes."Other RE" includes concentrating solar power, geothermal, and marine.

Source: International Energy Agency, Net Zero by 2050: A Roadmap for the Global Energy Sector (revised October 2021).

In the same report, the IEA also forecasts that thanks to affordable and clean RE electricity, electrification of industries, buildings, and transport will significantly progress over the coming three decades. As a result, electricity will ultimately account for almost half of the world's total final consumption by mid-century, against 20% in 2020.

2) Key Points of the Three Main Types of New Power Supply Plans in Europe and Japan

To illustrate the futures of RE electricity in Europe and Japan the following section summarizes the key points of the new power supply plans of Germany "100% RE", France and the United Kingdom "RE & nuclear", and Japan "RE, nuclear & fossil + carbon capture and storage". All these plans have been presented in recent months and are theoretically carbon neutral compatible. Carbon neutrality is a climate and energy objective of upmost importance commonly shared by these four countries and which is targeted to be achieved by 2045 (Germany)-2050 (France, United Kingdom, and Japan).

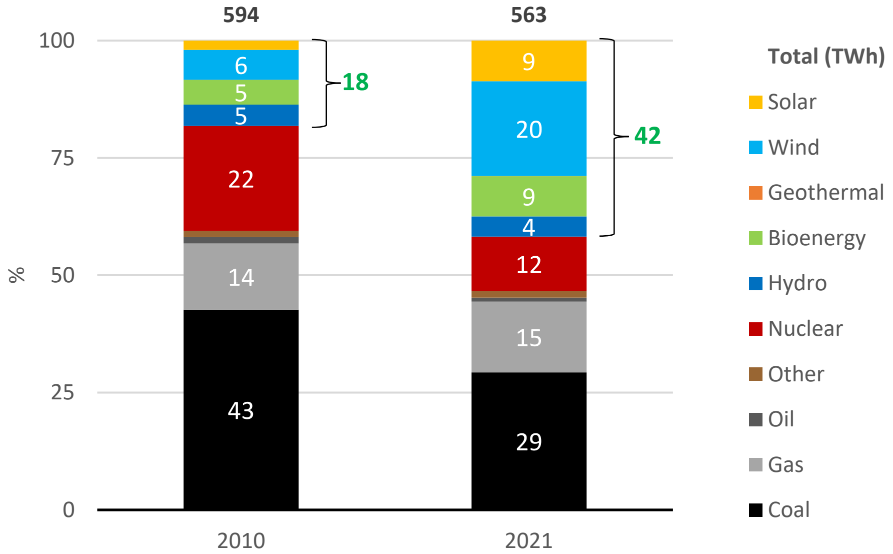
- <u>100% RE – Germany</u>

At the beginning of March 2022, just a week after the invasion of Ukraine by Russia, Germany demonstrated an outstanding reactivity by boldly announcing that it would pursue 100% RE electricity by 2035.

If successful, this strategy by making Germany free of both nuclear and fossil power would greatly strengthen the country's energy security and contribute to the objective of carbon neutrality. At the end of 2022, a first step in this direction should be accomplished with the permanent shutdowns of Germany's last three nuclear reactors.

In comparison to this new 100% RE goal, RE accounted for 42% of Germany's electricity generation in 2021, an increase of 24 percentage points since 2010 while total generation decreased by 5% (Chart 12).

Chart 12: Germany Net Electricity Generation Mix 2010 and 2021



Notes: Shares below 2% are not displayed for readability purposes. "Other" includes other non-renewable combustibles and unspecified.

Source: International Energy Agency, Monthly Electricity Statistics – May 2022 (downloaded May 16, 2022).

Thus, to achieve its new 2035 RE electricity goal, Germany will need to strongly accelerate the pace at which the country increases the share of RE in its electricity generation mix from 2.1 percentage points per year between 2010 and 2021 to 4.2 percentage points per year between 2022 and 2035, a quite demanding doubling.

This will be made more difficult by the fact that compared to the 2010-2021 period, the 2022-2035 period should see rising electricity consumption due to further electrification (i.e., from around 560 TWh in 2021 to 680-750 TWh in 2030 has been specified).

It may be noted here that these efforts will not stop in 2035 but continue well beyond because both energy security and decarbonization will require an electrification rate higher than that to be achieved by 2035.

Against this backdrop, the German Government also adopted new RE targets for solar photovoltaic (PV) and onshore wind cumulative installed capacity for the 2035-2045 horizon, notably (Table 2).

Table 2: Germany Solar and Wind Cumulative Installed Capacity 2021 and Targets 2035-2045 (GW)

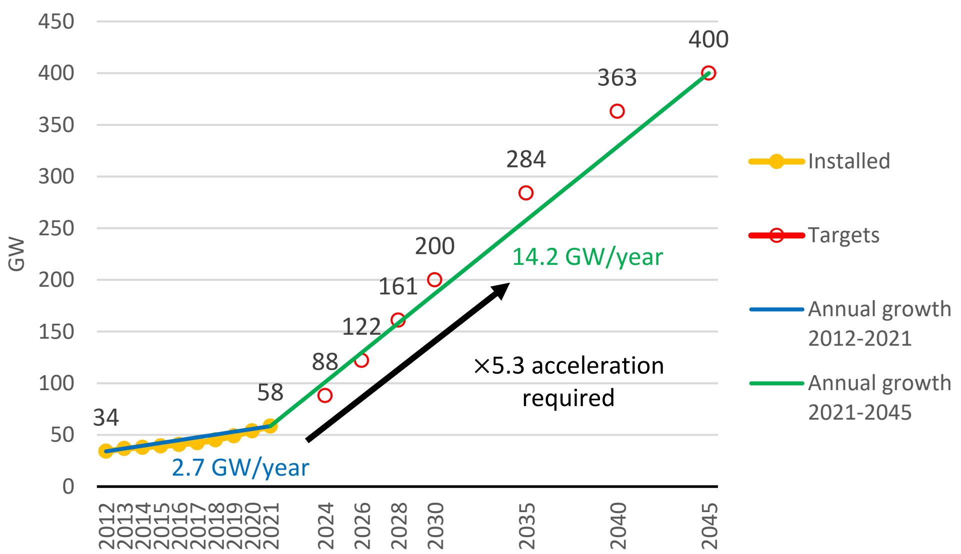
Technology	Cumulative installed capacity	Target		
	2021	2035	2040	2045
Solar PV	58	284	363	400
Onshore wind	56	152	160	n/a
Offshore wind	8	40	n/a	70

Note: The targets for offshore wind have been announced separately in December 2021 and are indicated for reference purposes only.

Sources: For installed capacity; International Renewable Energy Agency, Renewable Capacity Statistics 2022 (April 2022). For solar PV and onshore wind targets; Germany Federal Ministry for Economic Affairs and Climate Action, Draft Bill on Immediate Measures for an Accelerated Expansion of Renewable Energy and Other Measures in the Electricity Sector (March 2022) (in German). For offshore wind targets; Coalition Agreement between SPD, Alliance 90/The Greens and FDP, Dare to Make more Progress: Alliance for Freedom, Justice and Sustainability (December 2021) (in German).

Compared to those of onshore wind, the new targets for solar PV are particularly ambitious. Indeed, solar PV cumulative installed capacity is required to be increased by 14.2 GW per year between 2022 and 2045, against 2.7 GW per year between 2012 and 2021, a multiplication by a factor 5.3 (!) (Chart 13). This task is even more daunting that this steep increase will need to take place at a time when some old panels will also need to be replaced.

Chart 13: Germany Solar PV Cumulative Installed Capacity and Targets 2012-2045



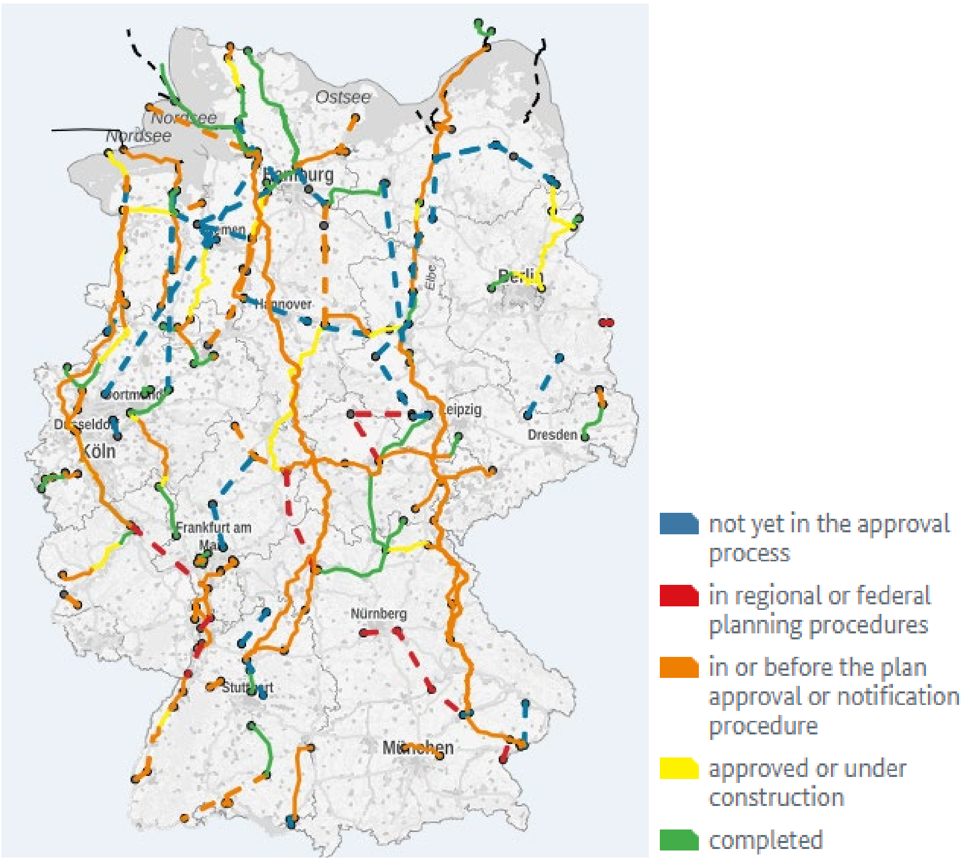
Sources: For installed capacity; International Renewable Energy Agency, Renewable Capacity Statistics 2022 (April 2022). For solar PV targets; Germany Federal Ministry for Economic Affairs and Climate Action, Draft Bill on Immediate Measures for an Accelerated Expansion of Renewable Energy and Other Measures in the Electricity Sector (March 2022) (in German).

To realize this big leap, the organization of pluriannual RE auctions will be a central policy tool of the German Government. For examples, between 2023 and 2028 a total of: 53 GW of solar PV and 58 GW of onshore wind capacity will be tendered.

Other key measures to be implemented to directly facilitate the expansion of RE in Germany will focus on: Making available new sites for solar PV and onshore & offshore wind, extending the participation of municipalities in solar PV and onshore wind projects, and improving policies to increase rooftop solar PV installations. Regarding the latter, as of March 2022, 10 out of 16 States had enacted or were planning/considering the obligation to install solar power generation facilities. The target of installation obligations varies from state to state, but three States had already begun to make it mandatory from January 2022, and four states, including the capital Berlin, are scheduled to make it mandatory from January 2023.[3]

At the same time, power grid expansion will also be speeded up as barriers are removed and planning and approval procedures are streamlined. The priority is to transmit electricity generated from wind power in the north of the country to demand centers located in the South. As of the end of 2021, there were 101 transmission expansion projects totaling 12,229 kilometers (km). Of these, 22 projects (1,934 km) had been completed, 7 projects (761 km) had been approved or were under construction, and 72 projects (9,534 km) were before or in the approval process (Map 2). Significant efforts will need to keep taking place in the coming years.

Map 2: Germany Grid Expansion Status December 31, 2021



Note: Legend translated by Renewable Energy Institute.

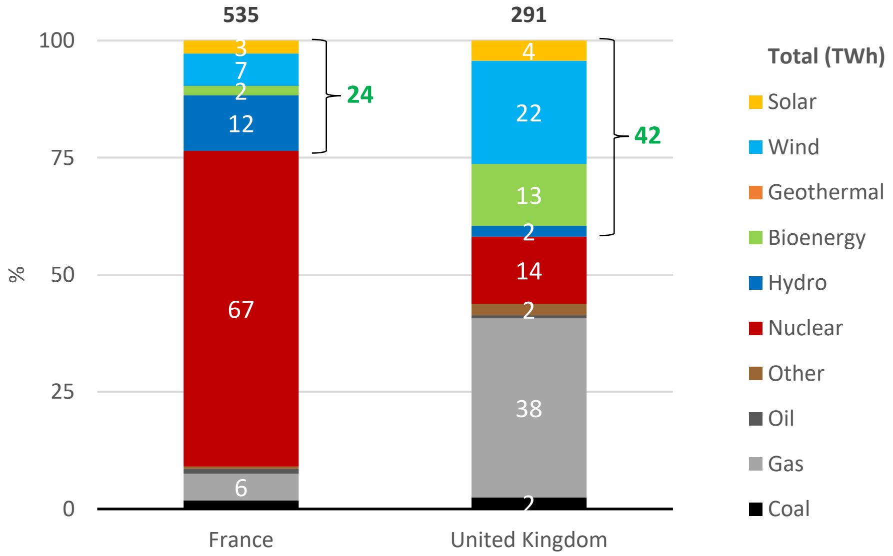
Source: Germany Federal Network Agency, Grid Expansion Status (accessed June 14, 2022) (in German).

Finally, it may be noted that in Germany, while RE grows an increased reliance on domestic coal power may temporarily be tolerated to strengthen energy security by reducing gas imports used for electricity generation. This fuel switching takes advantage of the fuel diversification opportunity offered by the German power system with both coal and gas power plants available. This situation should be terminated by the end of March 2024 to ensure greenhouse gas emissions from coal power are ultimately reduced.[4]

- RE & nuclear – France and United Kingdom

France and the United Kingdom face different situations today: France's electricity generation mix is largely dominated by nuclear (67%) and RE (24%) and that of the United Kingdom by RE (42%) and gas (38%) (Chart 14).

Chart 14: France and United Kingdom Net Electricity Generation Mix 2021



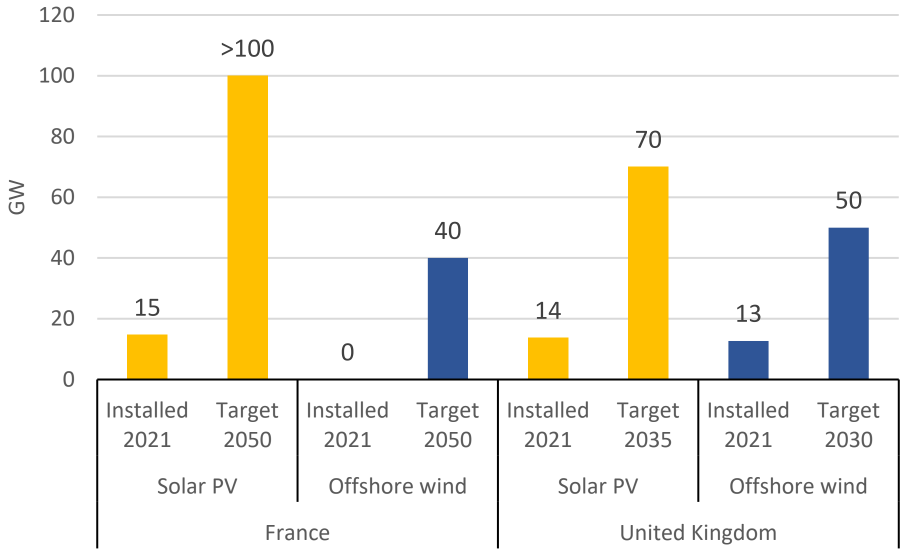
Notes: Shares below 2% are not displayed for readability purposes. "Other" includes other non-renewable combustibles and unspecified.

Source: International Energy Agency, Monthly Electricity Statistics – May 2022 (downloaded May 16, 2022).

These two countries, however, share a rather similar approach when it comes to their new power supply plans presented in February 2022 (France) and April 2022 (United Kingdom). Indeed, both announced increased ambitions for solar PV and offshore wind and a continued reliance on nuclear power, including lifetime extensions of existing reactors and the construction of new reactors.

Regarding cumulative installed capacity new goals: By 2050, France aims at exceeding 100 GW for solar PV and reaching 40 GW for offshore wind. And the United Kingdom targets 70 GW by 2035 and 50 GW by 2030, respectively. These targets will require substantial efforts to be met (Chart 15 on next page).

Chart 15: France and United Kingdom Solar PV and Offshore Wind Cumulative Installed Capacity 2021 and Targets 2030-2050



Sources: For installed capacity; International Renewable Energy Agency, Renewable Capacity Statistics 2022 (April 2022). For France's targets; France Government, France's New Energy Strategy (February 2022) (in French). For the United Kingdom's targets; United Kingdom Government. British Energy Security Strategy (April 2022).

Like in Germany, in France and the United Kingdom pluriannual auctions will be a key tool for governments to support further expansion of these RE technologies.

Other key measures in favor of RE will be: In France, to reduce regulatory barriers to speed up the realization of projects (because of complicated administrative procedures it currently takes 5 years to be authorized to build a solar PV project, and 7 years or more for a wind project) and to improve the consultation of stakeholders who may be negatively impacted by RE projects, which should be done by empowering local authorities and advancing the timing of consultation that sometimes takes place too late. And in the United Kingdom, to accelerate the development and deployment of offshore wind farms by cutting the time of this process (up to 13 years) by over half, which will partly be done by reducing consent time from up to four years down to one year, to maintain a 0% value-added tax on solar panels installed in residential accommodation until 2027, and to support solar PV that is co-located with other functions (e.g., agriculture, onshore wind, or storage) thereby maximizing the efficiency of land use.

It may be noted briefly here that onshore wind, due to the local and/or political oppositions it sometimes faces because of its visual impact, now gets less support than solar PV and offshore wind in France and the United Kingdom. For instance, France postponed its objective to quasi double its onshore wind installed capacity from 19 GW to 36 GW from 2030 to 2050, and the United Kingdom has not announced new targets for this technology.

Regarding nuclear power, the other pillar of France and the United Kingdom's new power supply plans, the key announcements recently made are certainly ambitious. They are also quite questionable.

France announced the intention of extending the lifetime of all existing nuclear reactors beyond 50 years. In France, reactors are granted 10-year operating licenses that can be renewed multiple times without limits if they are deemed safe by the nuclear watchdog. It may be noted here that the cost of the "grand carénage", the program aiming at refurbishing France's nuclear power fleet, enhancing reactor safety, and if conditions allow, extending their operating lifespan is estimated to about €50 billion over the period 2014-2025. This is a significant investment for the company in charge of it, Électricité de France, which net financial debt reached €43 billion (as of the end of 2021).[5]

Moreover, France also announced the construction of 6-14 large new reactors and some small modular reactors (SMRs) – without many details. In total, new reactors could account for an additional 25 GW by 2050, which compares with 61 GW (net capacity) of existing operational reactors.

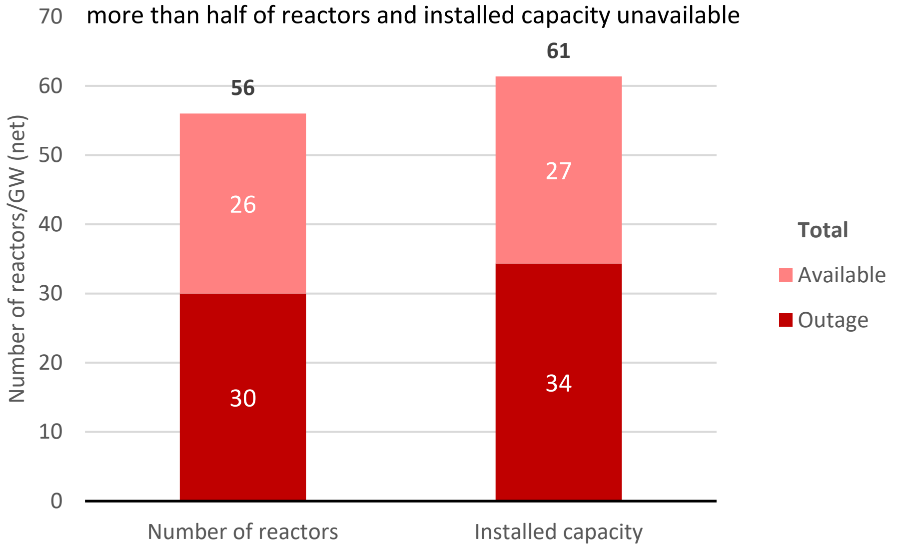
The United Kingdom announced the construction of 8 large reactors. To a lesser extent, the country also pursues SMRs. By 2050, The United Kingdom targets nuclear power capacity to increase from 7 GW to 24 GW (net capacity) (8 large reactors of 1.63 GW such as those under construction at Hinkley Point C should account for around 13 GW, the remaining increase of about 4 GW could be SMRs and/or power uprates of existing reactors) to cover 25% of the country's projected electricity consumption.

Before diving into the main problems of these plans, it may be clearly stated once and for all that both in France and the United Kingdom the focus is essentially on large reactors. In the coming decades, economically and technologically immature SMRs are unlikely to provide anything, but marginal contributions. Therefore, the following paragraphs only concentrate on plans for large reactors: existing and new.

Regarding the lifetime extensions of existing nuclear reactors, this option is often preferred because it is based on already built reactors which have generally been competitive to operate and sufficiently reliable and safe until now.

In the past few months, however, the ageing French nuclear reactor fleet (37 years old in average) has been struck by numerous outages. These outages were mainly due to the COVID-19 pandemic that has significantly disturbed reactor maintenance, and because of checks and repairs related to the recent discovery of cracked pipes in the safety injection systems of 12 reactors. Adding, to these issues, regular seasonal maintenance and refueling, and planned works to extend the lifetime of reactors resulted in more than half of the country's reactors and nuclear power installed capacity being temporarily offline during spring 2022 (Chart 16 on next page). As a result of these issues and with the combination of high fossil fuel prices, the cost of electricity on the French power exchange increased from €0.07/kWh in June 2021 to €.020/kWh in May 2022.

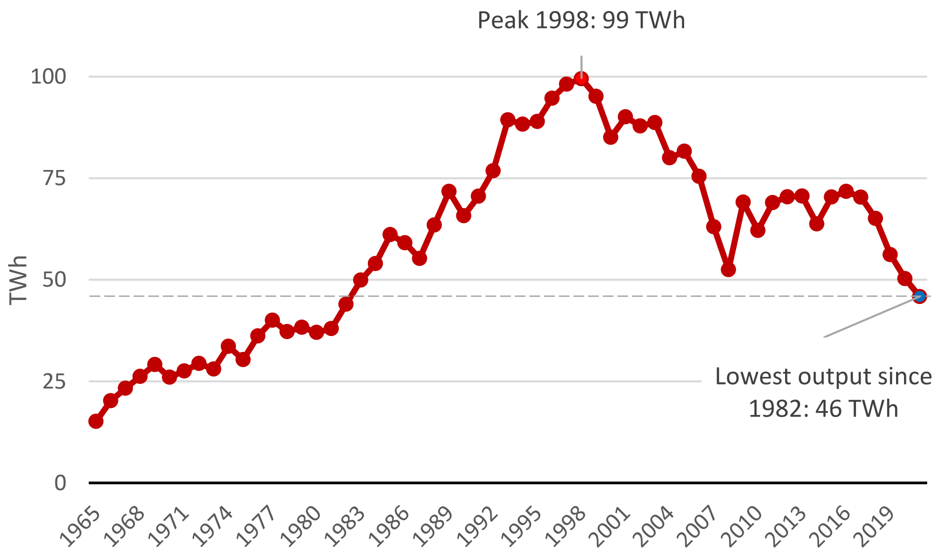
Chart 16: France Nuclear Power Availability May 17, 2022



Source: Réseau de Transport d'Électricité, [Downtime of Generation Resources](#) (downloaded May 17, 2022).

Furthermore, existing nuclear reactors in the United Kingdom suffered unplanned outages (i.e., suspension of on-load refueling, thermal sleeve repair, and securing a boiler tube leak safety case) in 2021.[6] These outages combined with the permanent closures of many reactors over the years resulted in the lowest output from nuclear power in the country in about four decades (Chart 17).

Chart 17: United Kingdom Gross Electricity Generation from Nuclear Power 1965-2021



Source: BP, [Statistical Review of World Energy 2022](#) (June 2022).

At the light of these recent reliability issues, it is difficult to be eager and envision a bright future for existing reactors in France and the United Kingdom.

Regarding the construction of new reactors, this option faces two insurmountable obstacles: costs and time.

In France, the only reactor currently under construction is Flamanville-3. This project is a complete industrial failure with endless delays and countless cost overruns.[7] Construction started in 2007 with commissioning scheduled for 2012 at a cost of around €4 billion. This reactor is still not operational and will not be before 2023 – at least an 11-year delay on a five-year project (!). Its cost has spiraled to about €15 billion, a multiplication by a factor 3.4 (!).

In the United Kingdom, two reactors are currently under construction Hinkley Point C-1 & -2. The construction of these twin reactors started in 2018 and 2019, respectively, with commissioning scheduled for 2025 in the case of the first unit. The project cost for the two reactors was then estimated at around £22 billion. The latest update on this project indicated that the first unit operation start date has been postponed to 2027 and that the project cost is now estimated at about £28-29 billion.[8]

As a result, it is also difficult to be enthusiastic about the prospects for new nuclear reactors.

Finally, four additional important observations related to nuclear power in Europe may be shared:

With regards to energy security, neither France nor the United Kingdom mines natural uranium – the necessary fuel to generate nuclear based electricity. The issue of uneven geographical distribution of natural uranium is like that fossil fuels. Indeed, globally, uranium mining is largely dominated by one country: Kazakhstan which produced 45% of the world's natural uranium in 2021[9] (and uranium enrichment is largely dominated by another country: Russia which had 43% of the world's enrichment capacity in 2020[10]). As a result, both France and the United Kingdom need to rely on uranium imports. For example, France essentially relies on imports from Niger, Kazakhstan, Uzbekistan, and Australia to meet its natural uranium needs (France then often enriches uranium by itself).

With regards to funding, because the heavy initial investments required for new reactors are unbearable for private companies, European governments have opened the door to non-European state-owned companies. This is a source of commercial and diplomatic disputes because of suspicions among stakeholders. For instance, China General Nuclear Power Group holds a 33.5% share in the Hinkley Point C project in the United Kingdom. In 2018, the United States Government warned the United Kingdom explicitly against partnering with this Chinese company because of evidence that the business was engaged in taking civilian technology and converting it to military uses.[11]

With regards to radioactive waste, after generating electricity from nuclear power for more than six decades neither France nor the United Kingdom has a deep geological repository operational yet.

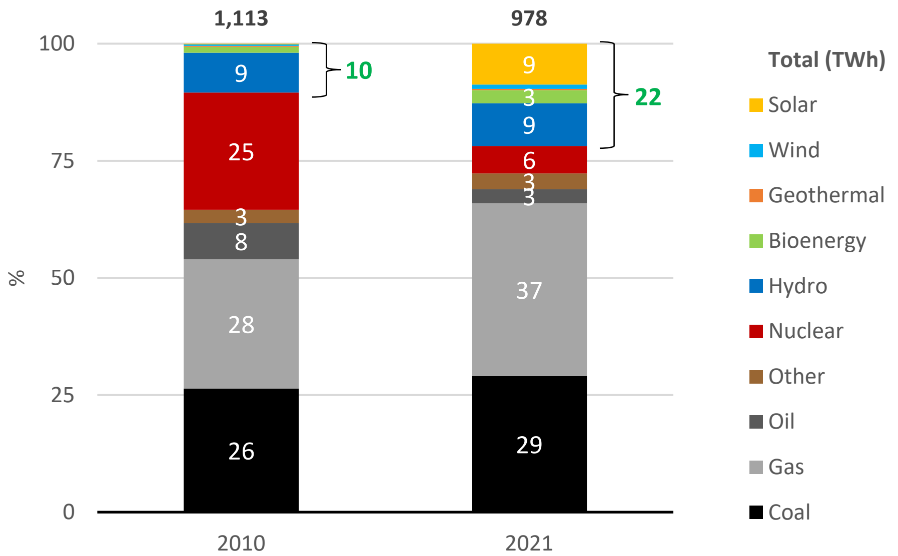
With regards to radiation threats, the recent shelling of the Zaporizhzhia nuclear power plant by Russian forces in Ukraine has now empirically demonstrated that nuclear power plants can become battlefields with all the risks it involves.[12]

- <u>RE, nuclear & fossil + carbon capture and storage – Japan</u>

Since Fukushima nuclear accident in 2011, Japan's electricity generation mix has deeply changed (Chart 18). According to IEA's statistics, the share of nuclear decreased from 25% in 2010 to 6% in 2021. In the meantime, that of RE increased from 10% to 22% primarily thanks to the massive deployment of solar PV: from 4 GW to 74 GW in the period considered following the introduction of a generous feed-in tariff scheme in 2012. In addition, the share of gas rose from 28% in 2010 to 37% in 2021. essentially because it substituted oil which share declined from 8% to 3%.

Moreover, it is important to note that total electricity generation significantly decreased in Japan between 2010 and 2021: a reduction of 12% thanks to impressive energy efficiency & savings efforts.

Chart 18: Japan Net Electricity Generation Mix 2010 and 2021



Notes: Shares below 2% are not displayed for readability purposes. "Other" includes other non-renewable combustibles and unspecified.

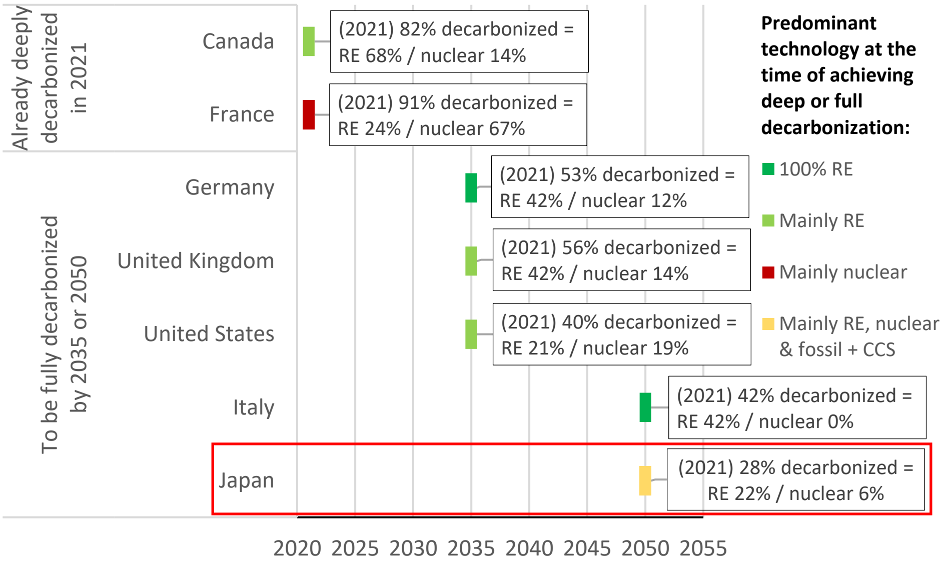
Source: International Energy Agency, Monthly Electricity Statistics – May 2022 (downloaded May 16, 2022).

Japan's "Green Growth Strategy Through Achieving Carbon Neutrality in 2050", originally formulated in December 2020, targets a fully decarbonized power sector by 2050. This should be realized thanks to an electricity generation mix consisting of RE 50-60%, nuclear & fossil + carbon capture and storage (CCS) 30-40%, and hydrogen & ammonia 10%.[13]

Before considering the situation of each of these technologies in Japan, it may first be noted that targeting a fully decarbonized power sector by 2050 is terribly unambitious. Indeed, among the Group of Seven (G7), all countries – with the exceptions of Italy and Japan – have either already deeply (i.e., about 80-90%) decarbonized their power sector (Canada and France) or aim to fully decarbonized it by 2035 (Germany, United Kingdom, and United States) (Chart 19 on next page).

Of the G7 countries, Japan had by far the least decarbonized power sector in 2021 (only 28%), but this delay is not an excuse to keep lagging behind, especially as it comes to the expense of the country's energy security.

Chart 19: G7 Countries Towards Deep or Full Decarbonization of the Power Sector



Sources: Full decarbonization objectives; collected by Renewable Energy Institute from various national sources of information. For 2021 progress; International Energy Agency, Monthly Electricity Statistics – May 2022 (downloaded May 16, 2022).

Another interesting point that should inspire Japan when considering its future electricity generation mix is that RE will be in almost all G7 countries – France being the exception – the undisputed cornerstone of power sector decarbonization. Indeed, both Germany (2035) and Italy (2050) are aiming for 100% RE, and in Canada, the United Kingdom, and the United States decarbonization will mainly be achieved thanks to RE. In the case of the United States, the Department of Energy's "Solar Futures Study" published in September 2021, projects that in decarbonization scenarios RE will account for about 80-85% of the country's electricity in 2035.[14]

This trend is due on the one hand to the success of RE expansion on the other hand to poor prospects for nuclear, with a lot of ageing existing reactors and very few new reactors actually under construction to replace them in the five countries not phasing out this technology (Table 3 on next page).

The average age of nuclear reactors in these countries is 38 years whereas the expected standard lifetime for a nuclear reactor is 40 years. Old reactors are sometimes affected by lengthy outages for repairs. The examples of French and British reactors have already been mentioned on pages 20-21. It may also be mentioned here that in Japan, the reactor Takahama-3 (38 years), temporarily shut down on March 1, 2022, for a periodic inspection, does not have a determined resumption date of power generation due to damage of some heat transfer tubes of steam generators.

Finally, it may be briefly added that even if all existing reactors were to be granted lifetime extensions and reactors under construction were to come online in the five countries considered, the increase in electricity generation from nuclear power in the coming decade would remain quite limited compared to today's level. That is because in a best-case scenario only about new 10 GW would be added on top of existing 220 GW, a mere 5% increase. In the meantime, the growth in electricity generation from RE will certainly be much bigger.

Table 3: Poor Prospects for Continuous Use of Nuclear Power G7 Countries

Technology	Existing reactors			New reactors (under construction)	
	Number of reactors	Gross installed capacity (GW)	Average age (years)	Number of reactors	Gross installed capacity (GW)
Canada	19	14.6	39	0	0
France	56	64.0	37	1	1.7
Japan	33	33.1	31	2	2.8
United Kingdom	11	7.8	37	2	3.4
United States	92	100.0	42	2	2.5
Total	**211**	**219.6**	**38**	**7**	**10.3**

Source: International Atomic Energy Agency, Power Reactor Information System: Country Statistics – Updated June 28, 2022 (accessed June 29, 2022).

Focusing solely on Japan again, starting with RE. A target of 50-60% for RE by 2050 is clearly unambitious, especially when compared to that of Germany to achieve 100% RE by 2035.

For Japan to become more ambitious towards its great RE potential, it will need to: Revitalize its solar PV expansion that has been losing momentum since 2016 (annual additional capacity decreased from 9.2 GW per year in the period 2012-2015 to 6.7 GW per year in 2016-2021, including only 5.5 GW per year in 2020-2021), finally make onshore wind take off (only 4 GW of cumulative installed capacity in 2021), and meet the upper range of its 2040 offshore wind target of 45 GW.[15]

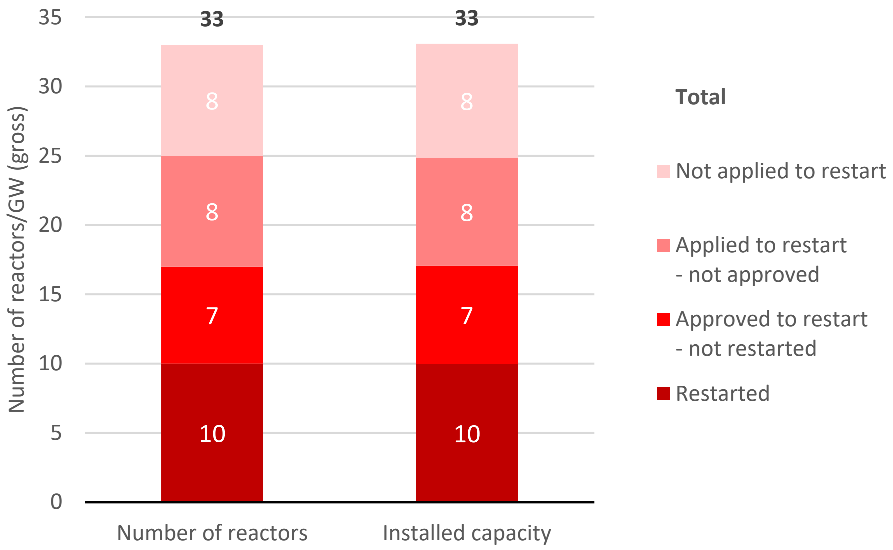
More specifically, in complementary reports published in 2020 and 2021: "Proposal for 2030 Energy Mix in Japan (First Edition): Establish a Society Based on Renewable Energy"[16], "Verification of Electricity Supply-Demand Balance and Costs in 2030"[17], and "Renewable Pathways to Climate-Neutral Japan: Reaching Zero Emissions by 2050 in the Energy System"[18], Renewable Energy Institute drew paths towards 100% RE futures in Japan and made several key recommendations to realize such futures.

The first of these recommendations is to increase Japan's RE 2030 target to at least 45% (against 36-38% currently) to be on track for 100% RE electricity by 2050. Other important recommendations include significantly increasing the capacity of solar PV (524 GW by 2050) and onshore & offshore wind (88-144 GW and 63-199 GW, respectively). It may be noted that the role of rooftop solar is highlighted as well as the importance of timely strengthening interconnections between the windy northeastern regions of Japan (i.e., Hokkaido and Tohoku) and the rest of the country so that electricity generated from wind can be transported and consumed where it is needed. Batteries and green hydrogen (i.e., from RE) capacity will also need to be actively developed.

Being more ambitious and successful in meeting higher RE ambitions is critical for Japan to stop entertaining the nuclear & fossil + CCS pipe dream.

Regarding nuclear power, since Fukushima accident 22 reactors have been permanently shut down in Japan, a considerable decline. These closures were mainly decided because upgrading the safety of reactors was not economically viable and/or technically feasible. As of the beginning of June 2022, of the remaining 33 existing reactors (total installed capacity of 33 GW), only ten reactors (10 GW) had restarted commercial operation following the official approval by the Nuclear Regulation Authority. Seven reactors (7 GW) had received the official approval to restart but had not restarted. Eight reactors (8 GW) had applied to restart but not received the approval to do so. Finally, eight reactors (8 GW) had not even applied to restart (Chart 20). Furthermore, three reactors (4 GW) were under construction [the International Atomic Energy Agency – unlike the Japan Atomic Industrial Forum – does not count as "under construction" Tokyo Electric Power Company's Higashidori reactor, which construction started in January 2011 and was halted because of the Great East Japan Earthquake. This is because the first major placing of concrete for the base mat of the reactor building has not been made.].

Chart 20: Current Status of Existing Nuclear Reactors Japan June 7, 2022



Source: Japan Atomic Industrial Forum, Current Status of Nuclear Power Plants in Japan (June 2022).

Considering the 2050 horizon, by optimistically assuming: The restart of all existing reactors and granting them all 60-year operating licenses, the commissioning of reactors under construction, and without announcements of new constructions, it is possible to project 21 reactors (23 GW) will be operational at the end of 2050. Also, considering the two reactors Kashiwazaki Kariwa-2 & -5 (2 GW combined) – two reactors which will be closed during 2050 and which outputs are estimated on a pro-rata basis of their operational hours in that year, and by making the hypothesis of a 70% capacity factor across the entire fleet (a little higher than prior to Fukushima accident), the amount of electricity to be generated from nuclear power may be calculated to be less than 150 TWh. Finally, selecting the lower range of Japan's forecasted future electricity demand (1,300 TWh) – to maximize the share of nuclear power in the country's electricity generation mix – it is possible to calculate a share of 11% for this technology. Undoubtedly it will be lower.

This means that the Japanese Government to meet its target of 30-40% for nuclear & fossil + CCS plans to massively rely on the latter.

Though CCS can help reducing greenhouse gas emissions from electricity generation in coal and gas power plants, this strategy is a complete nonsense when it comes to energy security because it implies to keep relying on fossil fuel imports.

Beyond this major issue, in a new report entitled "Bottlenecks and Risks of CCS Thermal Power Policy in Japan", Renewable Energy Institute identified five other important reasons to think this strategy is nothing more than a dead-end and should be abandoned immediately:[19]

First, the introduction of fossil + CCS for electricity generation is stagnant and the technology has a very limited and poor track record. Second, this immature technology is not close to achieve complete decarbonization yet (capture rate of 60-70% only). Third, Japan does not have suitable geographical conditions for greenhouse gas emissions sequestration. Fourth, the cost of generating electricity from fossil + CCS is high and uncompetitive with those of solar and wind. And fifth, there are risks related to planning to export Japanese emissions overseas, in particular to RE blessed Southeast Asia.

Finally, meeting the target of generating 10% of Japan's electricity from hydrogen & ammonia is rather uncertain. That is because today this technology is immature and costly (see also "decarbonized thermal" on page 34). Regarding the cost, according to Japan's "Basic Hydrogen Strategy", determined in December 2017, the country aims to cut the unit hydrogen power generation cost to ¥17/kWh around 2030.[20] In comparison, a recent auction for solar PV in Japan delivered lowest price of ¥9/kWh in March 2022[21], and the first auction for offshore wind lowest price of ¥12/kWh in December 2021[22].

In addition, the origin of the hydrogen & ammonia Japan wants to promote should be clarified. In the context of energy security and carbon neutrality, RE based or "green" hydrogen & ammonia should certainly be prioritized

As a result, given the severe difficulties nuclear & fossil + CCS are confronted with, and the uncertainties surrounding hydrogen & ammonia, the Japanese Government should rapidly substantially ramp up its ambitions for RE.

Chapter 3: Challenges and Solutions for an Energy Security based on Renewable Energy Electricity

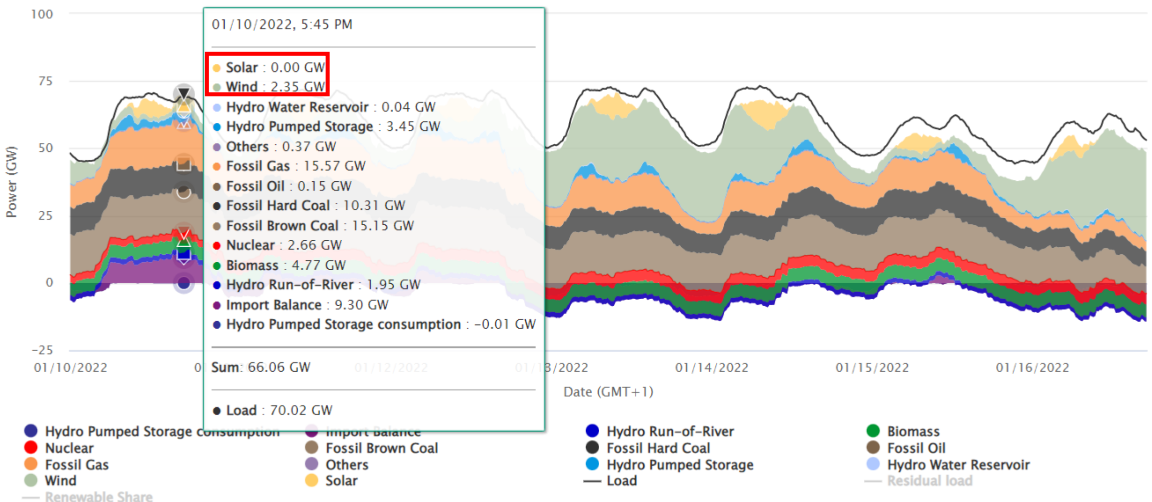
A renewable energy electricity-based energy security comes with two main challenges: improving demand & supply flexibility of the power system and hedging against the risks of geographical concentrations of critical minerals and of clean energy technologies manufacturing capacity. Neither the former nor the latter lacks solutions. For instance, to improve flexibility six complementary solutions are highlighted in this chapter: demand response, interconnections, pumped storage hydro, batteries, decarbonized thermal, and market operations. And to hedge against the risks of geographical concentrations four solutions are advanced: recycling, optimizing efficiency, substituting materials, and expanding domestic manufacturing capacity.

1) Improving Demand and Supply Flexibility

It is well-known that solar and wind outputs fluctuate depending on weather conditions and the time of the day. In that regard, two extreme opposite situations can punctually happen: either electricity generation from RE is "insufficient" or it is "excessive". The following two paragraphs and charts briefly present and illustrate these situations.

In Germany on January 10, 2022, at 5:45 PM, despite more than 120 GW of solar and wind capacity being installed across the country, the actual combined output of these two technologies was only 2 GW (Chart 21). At that time, Germany mostly relied on brown and hard coal (25 GW), gas (16 GW), and imports (9 GW) to meet its electricity consumption. Considering energy security and carbon neutrality, the challenge here is to deploy domestic and clean alternatives playing the "backup" roles of coal and gas.

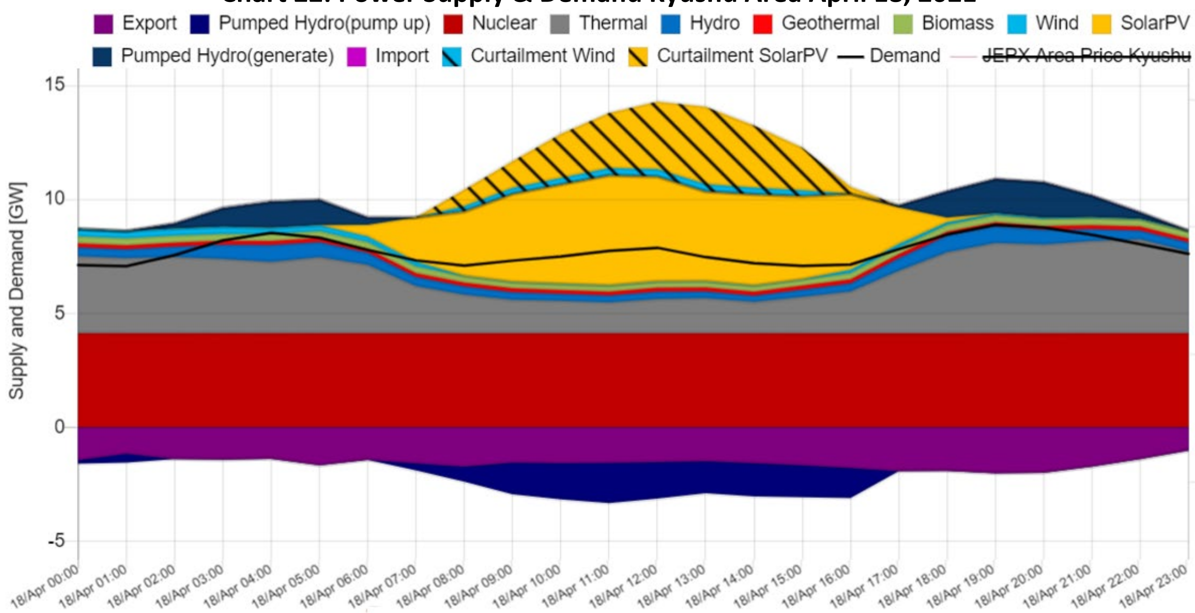
Chart 21: Germany Electricity Generation Week 2 2022



Source: Fraunhofer Institute for Solar Energy Systems, [Energy-Charts – Power, Electricity Production](#) (accessed May 20, 2022).

In Kyushu, Japan on April 18, 2021, at 1 PM, a record 3.7 GW curtailment of solar PV and wind power took place (Chart 22). At that time, flexibility was mainly provided by thermal power plants by reducing their output and by pumped storage power plants which instead of generating electricity consumed electricity to pump water up and store it for later use. It may be noticed that the output of nuclear power remained stable throughout the day at around 4.1 GW, higher than solar PV and wind curtailment. This is because in Japan, contrarily to major economies where the merit order principle truly prevails (e.g., Europe and the United States), a controversial curtailment rule unduly favors higher marginal costs nuclear power over solar and wind. In the Japanese context where nuclear reactors are not flexibly operated (which can, however, technically be done as demonstrated by the French example), the challenge here is to avoid wasting cheaper and cleaner RE electricity by either storing or exporting it to areas where it could be consumed.

Chart 22: Power Supply & Demand Kyushu Area April 18, 2021



Source: Renewable Energy Institute, Statistics – Charts & Map (accessed June 9, 2022).

There are six clearly identified energy security and carbon neutral compatible solutions to the challenges of RE “insufficient” and “excessive” generation: Demand response, interconnections, pumped storage hydro, batteries, decarbonized thermal, and market operations.

- Demand response

Demand response is an opportunity for electricity consumers to adjust their load to alleviate power supply constraints. Based on price signals consumers can either increase or decrease their demand. Demand response has been existing for decades and is becoming more sophisticated to be always more valuable in fast evolving power markets.

In Europe, France and the United Kingdom, for examples, annually organize auctions in which demand response can participate to help securing flexible capacity. Regarding the latest round for such auctions: In November 2021, French Réseau de Transport d'Électricité (i.e., transmission system operator) announced that 2.4 GW of demand response capacity were awarded contracts for 2022 (for comparison purposes, France's peak demand was 88.4 GW in 2021).[23] And in February 2022, the British National Grid Electricity System Operator announced that 0.5 GW of demand response capacity won contracts for 2022/2023 (peak demand of 47.1 GW in 2021).[24]

Japan also sees growing activity for demand response. For instance, 4 GW of demand response capacity are awarded contracts for 2024 in the framework of the capacity market – a mechanism to provide reserve power in severe peak time (peak demand of 163 GW in 2021).[25]

Though this subsection focuses on demand response, it may be added here that demand side policies under the umbrella of energy efficiency & savings are the quickest and cheapest ways to address the energy crises the world faces by directly reducing unsustainable fossil fuel consumption.

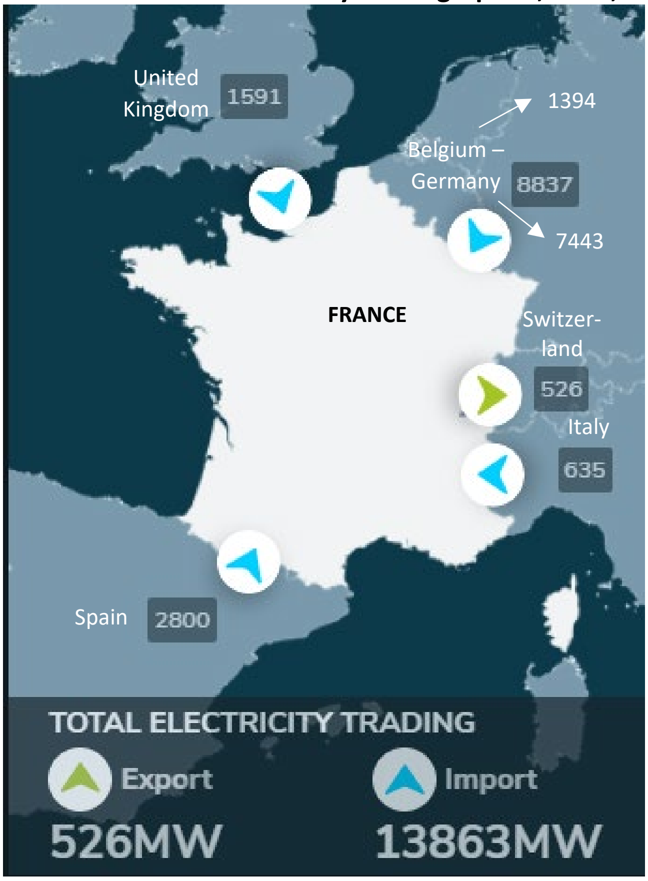
Therefore, improving the efficiency of heating & cooling systems, industrial processes, transportation means, and appliances & products, as well as the insulation of buildings, should certainly always be prioritized.

To go beyond these efficiency gains it is also everyone's responsibility to adapt a lifestyle which without sacrificing comfort enables further energy savings. These actions may typically include temporarily adjusting thermostats by just one degree Celsius, walking or cycling instead of driving for short distances, teleworking to avoid commuting when professional situation allows it.

- Interconnections

Interconnections enable to transport electricity across different geographical areas. It is then possible to match a local deficit in an area with a surplus in another area. Again, this solution is well-established – especially in Europe where across the continent countries trade electricity cross-border. In Chart 21 (on page 28) the example of Germany importing power due to low output from RE was illustrated. Hereinafter the case of France currently affected by low nuclear power output due to outages (see pages 20-21) and as a result importing a record amount of power from neighboring countries is shown. On April 3, 2022, at 1:30 AM, France imported close to 14 GW from Belgium-Germany (about 8.8 GW aggregated/breakdown: 1.4 GW from Belgium and 7.4 GW from Germany), Spain (2.8 GW), the United Kingdom (1.6 GW) and Italy (0.6 GW). At that time, France only exported a small volume of power to Switzerland (0.5 GW) (Map 3 on next page). France's net imports thus exceeded 13 GW, covering 22% of the country's demand at that time.

Map 3: France Cross-Border Electricity Trading April 3, 2022, at 1:30 AM



Note: Modified by Renewable Energy Institute; Selected countries' name and breakdown of imports from Belgium-Germany added.

Sources: For screenshot; Réseau de Transport d'Électricité, eCO$_2$mix – Cross-Border Electricity Trading (accessed May 23, 2022). For breakdown of imports from Belgium-Germany; European Network of Transmission System Operators for Electricity, Transparency Platform: Scheduled Commercial Exchanges – France-Belgium & France-Germany (accessed June 14, 2022).

This example is another good illustration of how international interconnections can contribute to energy security.

In the context of a conflict this positive example may be counterbalanced with the risk of supply interruption. In May 2022, Russia stopped power exports to Finland, officially over failed payments because of Western sanctions rather than retaliation.[26] Therefore, this risk can never be completely excluded. However, it can be mitigated by diversifying alternatives. This is the case of Finland which is not only interconnected with Russia, but also Estonia, Norway, and Sweden.

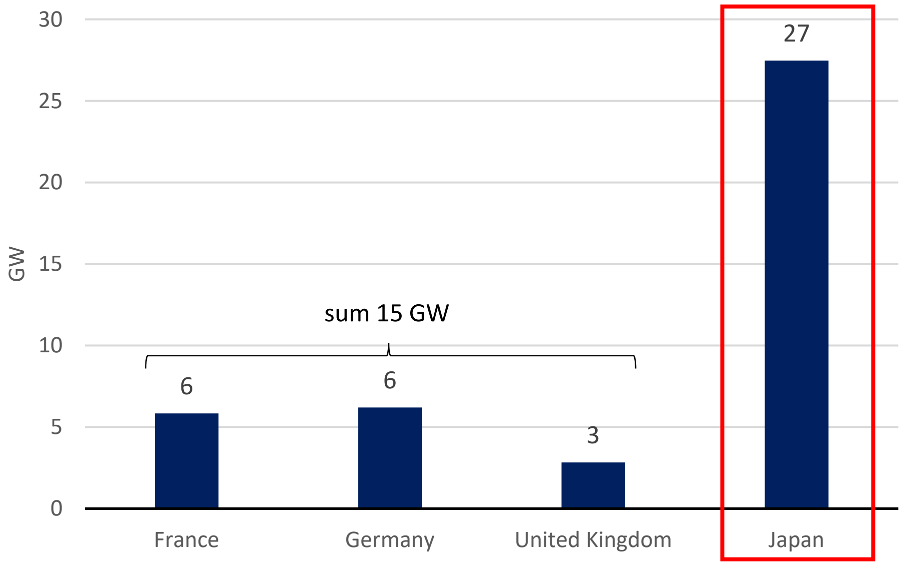
Considering Japan's isolated geographical situation and complicated diplomatic relationships in Northeast Asia it is difficult to imagine the country being interconnected with its close neighbors (China, Russia, North Korea, and South Korea) anytime soon. This is regrettable given the expected economic and environmental benefits of such projects as well as their technical feasibility. Nonetheless, developing and reinforcing Japan's domestic interconnections such as those between the islands of Kyushu and Honshu, those between the islands of Honshu and Hokkaido, and those between East and West Japan, will certainly be useful to improve the flexibility of the Japanese power system. A power system which, in terms of electricity demand, is roughly as big as those of France and Germany combined or three times bigger than that of the United Kingdom.

- <u>Pumped storage hydro</u>

Pumped storage hydro is another mature technology providing flexibility to power systems. When supply exceeds demand water is pumped from a lower elevation reservoir to a higher elevation reservoir to be stored. When demand exceeds supply stored water is released to generate electricity. Typically, the storage duration of pumped storage hydro is 5-175 hours.[27]

It may be noted here that Japan thanks to its advantageous topography and natural conditions for pumped storage hydro is a global leader in the deployment of this technology: About 27 GW installed in 2021 – #2 behind China. This is roughly twice more the pumped storage hydro capacity of France (6 GW), Germany (6 GW), and the United Kingdom (3 GW) combined (Chart 23).

Chart 23: France, Germany, United Kingdom, and Japan Pumped Storage Hydro Installed Capacity 2021



Source: International Hydropower Association, Hydropower Status Report 2022 (June 2022).

In Japan, there are two main ways pumped storage hydro is used. First, to balance RE fluctuations in areas with significant penetration of low marginal cost RE (e.g., solar PV). That is for example the case of Kyushu area introduced on page 29. Second, in preparation of meeting peak demand, in areas where penetration of low marginal cost RE is limited (e.g., Tokyo) electricity generated from expensive fossil power plants is used to pump water and store it before releasing it when necessary. Prior to Fukushima accident, when there were more nuclear reactors operational, nuclear power plants played the role of thermal power plants due to their lower marginal costs. In future power systems dominated by solar PV and wind which have lower marginal costs than both thermal and nuclear power plants, RE will completely replace these two technologies to be combined with pumped storage hydro.

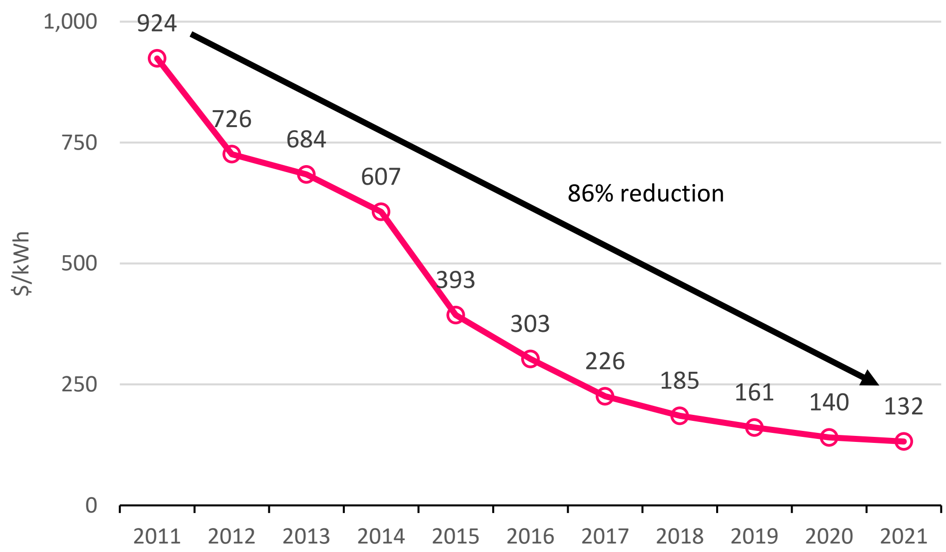
However, because of environmental and social constraints prospects for expansion of pumped storage hydro are often limited in developed economies. Indeed, pumped hydro storage projects require two large dams which impact natural life and local populations.

- Batteries

Batteries also offer the possibility to strategically store electricity. Today's most widely used lithium-ion battery technology can usually store electricity for less than four hours and are particularly well-suited to deliver fast response requirements.[28] Compared to the three flexibility solutions previously presented batteries are less mature but their growth is rapid: In 2020 alone, a record-high 5 GW of batteries were installed across the world bringing the global cumulative installed capacity to 17 GW (for comparison purposes, global cumulative installed capacity of pumped storage hydro was 159 GW in 2020).[29]

The success of batteries largely results from cost reductions owing to the widespread adoptions of electric vehicles (EVs). Indeed, between 2011 and 2021, while the world's stock of EVs increased from less than 1 million to more than 16 million, the cost of batteries decreased from $924/kWh to $132/kWh – an 86% reduction (Chart 24).[30]

Chart 24: Average Pack Price of Lithium-ion Batteries 2011-2021



Source: International Energy Agency, Critical Minerals Threaten a Decades-long Trend of Cost Declines for Clean Energy Technologies – May 18, 2022 (accessed May 24, 2022).

Germany, the United Kingdom, and Japan are dynamic markets for battery storage. In Germany, behind-the-meter installations are increasing with prosumerism as a driving force.

In the United Kingdom, power market service opportunities to meet fast response requirements is stimulating the growth of the technology. Finally, in Japan, which is prone to natural disasters, resilience is a key asset of battery storage and around 1.4 GW of batteries have been installed between 2015 and 2020.[31] These new installations can cover a little less than 1% of the country's peak demand.

In the future, in addition to liquid lithium-ion batteries which are mainstream today, solid-state lithium-ion batteries are expected to emerge (they could be introduced in EVs from the late 2020s onwards). These next-generation batteries hold the promises to be safer, have a double utilization range (i.e., capacity), and be shorter to charge (only one-third of the time of liquid lithium-ion batteries).[32] In 2020, Toyota already conducted test drives of a solid-state battery prototype vehicle.[33] Also in 2020, Toyota together with Panasonic started a joint venture, Prime Planet Energy & Solutions to develop solid-state batteries, with limited production by 2025 targeted.[34]

- <u>Decarbonized thermal</u>

Decarbonized thermal power plants are to be fueled by decarbonized gases as for example hydrogen. Considering energy security and carbon neutrality these gases should ideally be domestic and "green" (i.e., based on RE). At times of "excessive" RE electricity generation which results in low power prices, the production of green gases may be increased and stored for later use. This should further contribute to solve the flexibility issue.

Green hydrogen power plants are not fully cost competitive yet, neither for load following nor for peaking.[35] It is essential that the cost of producing the fuel using electrolyzers decreases and that new-generation combustors for hydrogen-fired turbines able to burn efficiently with low nitrogen oxide emissions becomes widely available. Therefore, tough the potential of decarbonized thermal is intriguing its contribution is not expected to be significant before 2030.

As for empirical developments, as of spring 2022, some decarbonized thermal projects were moving forward around the world. Among these, a (carbon-free) hydrogen power plant project led by the companies erex and Hydrogen Technology started operation in Japan in April 2022.[36] The plant only uses hydrogen (produced by reacting igneous rocks and water) as a fuel, it is small 320 kW and the cost of generating electricity is high ¥58/kWh. In the future, by building a larger-scale power plant (50-100 MW) the cost is expected to decrease to ¥17/kWh or lower.[37]

- <u>Market operations</u>

Finally, the last solution identified to improve flexibility of power systems is to be smarter when it comes to market operations. Conservative mindsets think that the variability of RE is an intrinsic weakness of these technologies and that other technologies are therefore necessary to solve the challenge of flexibility. This is ignoring that RE themselves can partly contribute to answer the flexibility question.

For example, wind power, one of Spain's main power sources with a share of 23% in the country's electricity generation mix in 2021 is hardly curtailed: only 0.3% in 2020 (latest year for which data could be found).[38] One of the important reasons for this achievement is that wind power actively participates in the country's balancing market which means wind power, just like conventional power plants, must adjust its output depending on system real-time needs, in other words: be flexible. In comparison to curtailment that only focuses on temporarily reducing undesirable wind power output at times of "excessive" generation, participating in the balancing market requires wind power to provide a continuously optimized output for the system needs, this implies a smooth production profile allowing to ramp up and down as necessary. This reduces the need for backups because wind power directly contributes to flexibility. This is possible thanks to sophisticated forecasts and automatic controllability. It may also be noted that solar PV does not participate in the Spanish balancing market, and it is rarely curtailed.

2) Managing Geographical Concentrations of Critical Minerals & of Clean Energy Technologies Manufacturing Capacity

Though RE resources are largely domestic, the critical minerals used to produce RE and other clean energy technologies and the manufacturing capacity of these technologies may not be. As a matter of fact, both critical minerals and clean energy technologies manufacturing capacity are geographically concentrated. This is a challenge for an energy security based on RE electricity, but again solutions exist to overcome this challenge.

RE electricity (e.g., solar panels, wind turbines…) and other clean energy technologies (e.g., batteries, hydrogen…) require a wide range of minerals and metals. The type and volume of minerals needs vary widely across the spectrum of clean energy technologies (Table 4 on next page).

Table 4: Critical Mineral Needs for Selected RE Electricity and Other Clean Energy Technologies

Clean Technology	Copper	Cobalt	Nickel	Lithium	REEs	Chromium	Zinc	PGMs	Aluminum
Solar PV	High	Low	Low	Low	Low	Low	Low	Low	High
Wind	High	Low	Moderate	Low	High	Moderate	High	Low	Moderate
Hydro	Moderate	Low	Low	Low	Low	Moderate	Moderate	Low	Moderate
Bioenergy	High	Low	Low	Low	Low	Low	Moderate	Low	Moderate
Geothermal	Low	Low	High	Low	Low	High	Low	Low	Low
Electricity networks	High	Low	Low	Low	Low	Low	Low	Low	High
EVs & battery storage	High	High	High	High	High	Low	Low	Low	High
Hydrogen	Low	Low	High	Low	Moderate	Low	Low	High	Moderate

Notes: "REEs" = rare earth elements (e.g., neodymium, dysprosium, praseodymium, terbium...) and "PGMs" = platinum group metals.

Relative importance of minerals for a particular clean energy technology

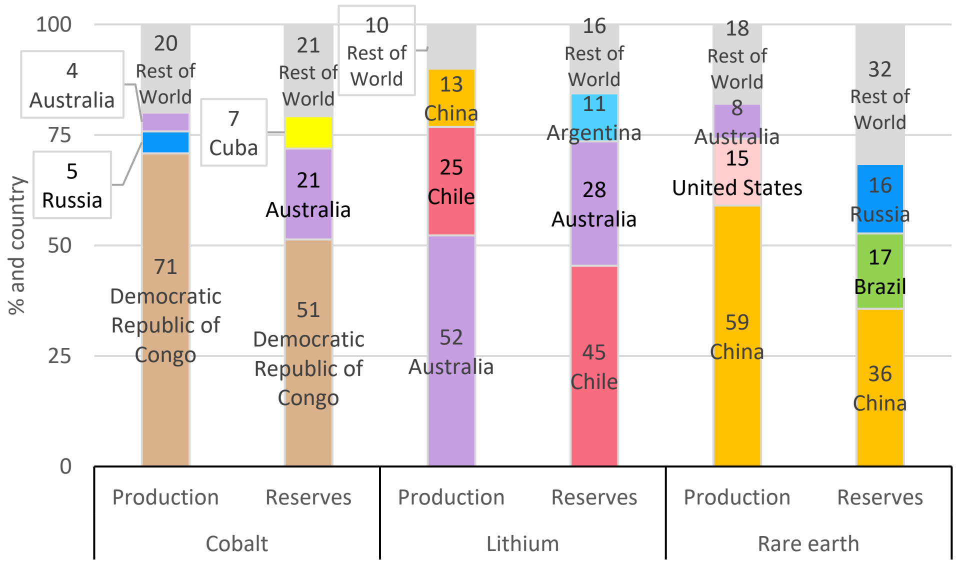
High Moderate Low

Source: International Energy Agency, The Role of Critical Minerals in Clean Energy Transitions (revised March 2022).

For instance, the relative importance of copper and aluminum is high for solar PV. In the case of wind, copper, rare earth elements, and zinc are very important. Copper is the single most important critical mineral for bioenergy. The relative importance of nickel and chromium is high for geothermal. Considering EVs & battery storage, copper, cobalt, nickel, lithium, rare earth elements and aluminum are very important.

Unfortunately, the production and the reserves of these critical minerals are often geographically concentrated in a few countries. Indeed, when it comes to cobalt, lithium, and rare earth elements, for examples, between 68% and 90% of the production and of the reserves of these minerals are concentrated in three countries only in each case (Chart 25).

Chart 25: Cobalt, Lithium, and Rare Earth Elements Production and Reserves Top-3 Countries and Rest of World 2021

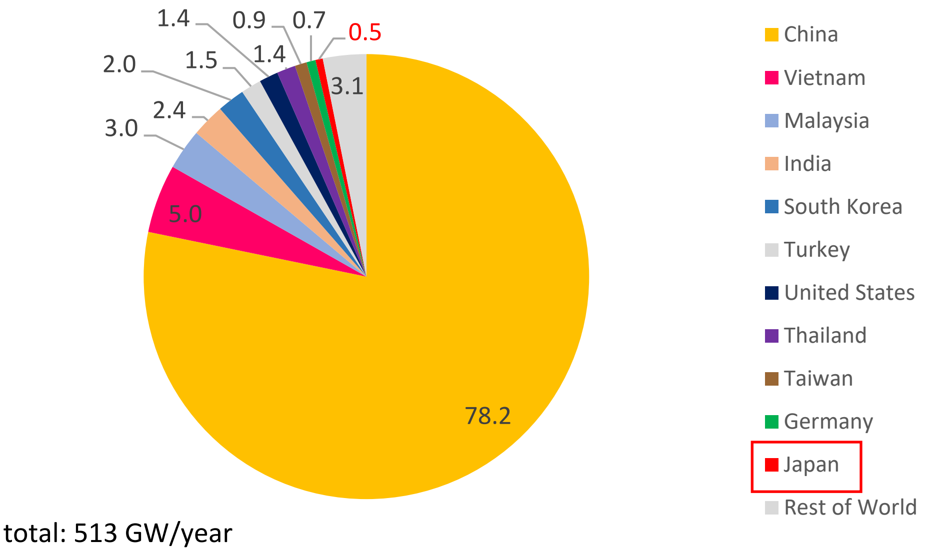


Source: BP, Statistical Review of World Energy 2022 (June 2022).

It may be briefly noted here that in the case of cobalt, the Democratic Republic of Congo – the world's top producer and the country with the largest reserves – is facing political instability which implies some supply risks for EVs & battery storage.

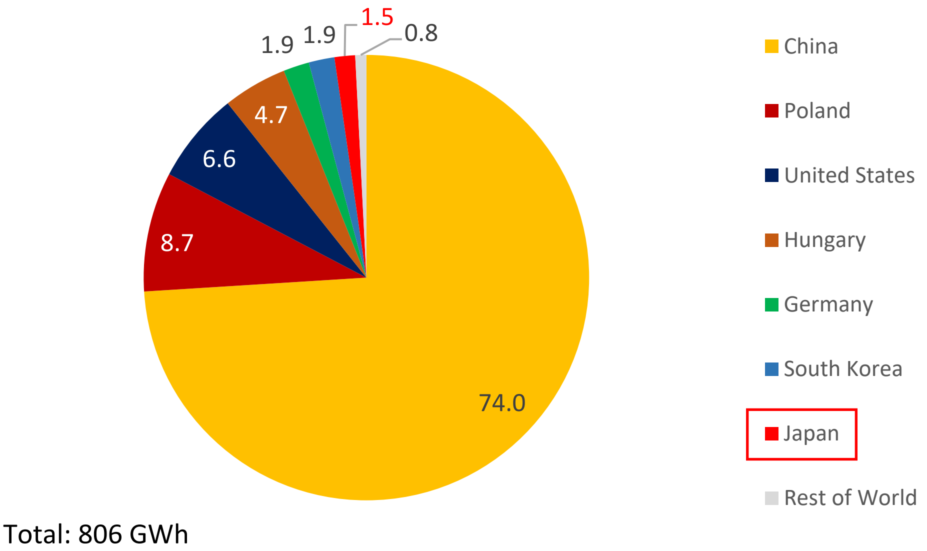
Regarding clean energy technologies manufacturing capacity now, it is also sometimes geographically concentrated. Indeed, a single country – China – largely dominates at least two key clean energy technologies manufacturing capacity with market shares of approximately three-quarters: solar PV modules (78% of global manufacturing capacity) and battery cells (74%) (Chart 26 and Chart 27).

Chart 26: Solar PV Modules Manufacturing Capacity by Country 2021 (%)



Source: BloombergNEF, Solar PV Equipment Manufacturers – Updated May 4, 2022 (accessed May 25, 2022) [subscription required].

Chart 27: Battery Cells Manufacturing Capacity by Country 2021 (%)



Source: BloombergNEF, Battery Cells Equipment Manufacturers – Updated February 23, 2022 (accessed May 25, 2022) [subscription required].

From an energy security perspective, this domination is problematic. Even more because the behavior of the Chinese political regime, notably diplomatic – but not only, raises serious concerns. For instance, the criminal treatment by Chinese authorities of the Uyghur minority – sometimes used into forced labor to make solar panels – is scandalous and unacceptable.[39]

There are four clearly identified energy security and carbon neutral compatible solutions to the challenges of geographical concentrations of critical minerals and of clean energy technologies manufacturing capacity: recycling, optimizing efficiency, substituting materials, and expanding domestic manufacturing capacity. In addition to these four solutions, opening new mines and diversifying suppliers of critical minerals and of clean energy technologies is also important. These approaches are very traditional. For instance, economies like those of Europe and Japan are quite familiar with diversifying suppliers given their extensive experiences in diversifying fossil fuel and uranium imports.

- Recycling

Though the recycling of clean energy technologies is not mainstream yet, initiatives are ongoing to reuse waste from these technologies. This will reduce the need for new raw critical minerals and hence dependencies towards countries mining these minerals. For now, recovering materials remains rather impractical, but progress is taking place.[40]

For example, in the case of a wind turbine, components such as the tower, gearbox, and generator are readily recyclable. However, blades are more challenging to recycle because they are typically made from a composite of glass fiber and epoxy or another thermoset resin. The cross-linked polymers cannot be melted down and recycled. It is necessary to cut up the blades, and then mechanically break them into smaller bits until they reach a size that contains fibers of a desired length for the material's next life (e.g., high-performance composite panels to be used for commercial and industrial buildings) (Chart 28).

Chart 28: Example of Wind Turbine Blade Recycling

from old wind turbine blade to new composite panel for construction

Source: Global Fiberglass Solutions, Homepage (accessed May 30, 2022).

To some extent, it is also possible to recycle solar panels and batteries. Regarding the latter, cobalt, which can be important for EVs & battery storage and which production and reserves are concentrated in the Democratic Republic of Congo, may notably be reclaimed.

- <u>Optimizing efficiency</u>

Optimizing the efficiency of clean energy technologies also reduces the need for critical minerals because more efficient technologies require less raw materials to provide the same output.

For instance, the average efficiency of solar panels (i.e., the percentage of solar energy that is being converted into useable electricity) used to be around 15% in 2010, but thanks to advancements made in the field of photovoltaic technology, efficiency of panels now exceeds 20%.[41] Research & development efforts in this direction should keep being pursued.

- <u>Substituting materials</u>

Innovations may simply replace critical minerals, which is an even more effective way to reduce the need for these minerals.

For example, rare earth elements (e.g., neodymium, dysprosium, praseodymium, terbium…) which can be important for wind turbine generators and battery EV motors and which production and reserves are concentrated in China may be substituted by control software and power electronics made of silicon, the most abundant solid element on Earth.[42]

- <u>Expanding domestic manufacturing capacity</u>

Finally, expanding domestic manufacturing capacity for clean energy technologies is another solution to manage the concentration of clean energy technologies manufacturing capacity in a few countries.

On the negative side, this may not be the lowest cost option, but clean energy technology do not need to be insanely cheap, they need to be affordable. On the positive side, building factories on its own territory benefits to a country by creating local employment and tax revenues and by decreasing the costs associated with the risks of energy insecurity.

In this regard, three interesting actions may be noted:

First, the “EU Solar Energy Strategy” announced in May 2022, as part of the “REPowerEU Plan”, aims at a massive deployment of solar PV which is seen as a chance to reinforce the EU’s industrial leadership by expanding its manufacturing base.[43] The EU currently imports most of the solar PV it installs, and heavily relies on China: 75% of the EU’s solar panel imports in 2020. The EU recognizes that this level of supply concentration weakens its energy security. Therefore, the EU will pursue the expansion of its solar PV manufacturing base on the back of its vibrant innovation and competitive market. The EU will also step in to ensure that solar PV products are sustainable and up to the standards demanded by EU consumers. In this framework, the EU will ensure the availability of an abundant skilled workforce and launch a European Solar PV Industry Alliance. The Alliance will bring together industrial actors, research institutes, consumer associations and other stakeholders with an interest in the solar PV sector. It will work to identify and coordinate investment opportunities, project pipelines and technology portfolios and establish pathways for the solar industrial ecosystem in Europe.

Second, the invocation by the President of the United States, Joseph Biden, of the Defense Production Act to accelerate domestic manufacturing of clean energy in June 2022.[44] This Act may be invoked to strengthen national security. In this case, invoking it allows the federal Government to invest in companies that can build clean energy facilities, expand clean energy manufacturing, process clean energy components, and install clean energy technologies for consumers. Necessary funding is appropriated by Congress. The five technologies included in the invocation referred to are: (1) solar PV, (2) transformers & grid components, (3) heat pumps, (4) building insulation, and (5) electrolyzers, fuel cells & platinum group metals.

Third, the draft of Japan's "Battery Industry Strategy", formulated in April 2022, stresses the importance of securing a manufacturing base for batteries.[45] This strategy recognizes that there are risks in the supply chain of mineral resources and materials which support battery cell production as the supply chain may depend on certain countries. It also warns that Japan is losing competitiveness and there is a risk of increasing dependence on foreign countries. Therefore, it is necessary to strengthen the domestic supply chain, including manufacturing infrastructure. As a result, this strategy sets the goal of 150 GWh of liquid lithium-ion battery manufacturing capacity in Japan by 2030. To meet this objective investment in domestic manufacturing base for batteries and materials through public-private partnerships will be strengthened.

Conclusion

Europe and Japan's current reliance on fossil imports is not sustainable from economic, geopolitical, and environmental perspectives. Since it makes them vulnerable it should be greatly reduced.

Because renewable energy is abundant and available domestically and because generating electricity from it is cost competitive, accelerating renewable energy electricity should be embraced to strengthen energy security in a carbon neutral compatible way. Pursuing 100% renewable energy electricity like Germany is challenging – especially in a short period of time because of the steep acceleration required, but it is certainly more pragmatic than to rely on struggling nuclear power like France and the United Kingdom, or on unproven carbon capture and storage like Japan.

An energy security based on renewable energy electricity also comes with challenges. On the one hand, demand and supply flexibility must be improved. On the other hand, the current geographical concentration of critical minerals, as well as that of some clean energy technologies manufacturing capacity must be reduced. However, solutions to these challenges exist.

Realizing an energy secure and carbon neutral future will not be an easy task but starting with the right vision and being fully aware of the multiple possibilities available should put Europe and Japan on the right track.

List of Abbreviations

bbl: Barrel

CCS: Carbon capture and storage

EJ: Exajoule

EU: European Union

EV: Electric vehicle

GW: Gigawatt

GWh: Gigawatt-hour

IEA: International Energy Agency

km: kilometer

kWh: Kilowatt-hour

LNG: Liquefied natural gas

MBtu: Million British thermal unit

MW: Megawatt

RE: Renewable energy

SMR: Small modular reactor

t: Ton

TWh: Terawatt-hour

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July 2022

Renewable Energy Institute

11F KDX Toranomon 1-Chome Bldg., 1-10-5 Toranomon, Minato-ku, Tokyo 105-0001　TEL：03-6866-1020

info@renewable-ei.org
www.renewable-ei.org/en