Briefing Paper

Renewable energy potential in Japan and Germany

An overview of different renewable energy sources

Imprint

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Content

Executive Summary

This study examines the theoretical and technical potential of renewable energy sources in Germany and Japan, as well as practical constraints to their realization, based on findings from existing studies and reports. The analysis focuses on the volume of energy that could physically be generated and does not assess temporal correlations between supply and demand, grid integration, or flexibility options. With this scope in mind, both countries demonstrate the technical potential to cover their entire electricity demand with renewable sources, particularly solar PV and wind. However, the structure of their respective potentials and the main barriers to realization differ. Germany's strengths lie in its favorable geography for onshore wind and balanced solar PV applications, and solid potential for offshore wind, even though with limits by spatial constraints. Japan, meanwhile, holds immense technical potential for both solar PV and offshore wind, especially through floating technologies, but practical potential for onshore wind is limited because of the mountainous terrain, regulation, and social acceptance. Both countries must continue to innovate in policy, technology, and stakeholder engagement to fully realize their renewable energy ambitions.

Solar PV

Both Japan and Germany possess abundant solar resources, with technical potentials that far exceed their current electricity demand. Under technical conditions accounting for system efficiency, module configuration, and other factors such as air temperature, soiling and shading, only 2.95% of Germany's and 2.34% of Japan's total land area would suffice to cover each country's current electricity needs through utility-scale solar PV deployment alone. This calculation does not account for temporal mismatches between generation and demand, which would require storage or grid balancing. Germany has a slightly smaller, but less mountainous land area (about 357,000 km²) compared to Japan (about 378,000 km²). Japan benefits from higher average solar irradiation, resulting in a greater daily photovoltaic output per square meter (3.61 kWh/m² for Japan vs. 2.98 kWh/m² for Germany).

When also considering obvious physical obstacles (such as rugged terrain, forests, and urban or industrial areas) and practical constraints, both countries encounter significant land use, regulatory, and economic constraints. In Germany, technical solar PV potential estimates range from 1,070 GW (about 1,155 TWh) to over 3,150 GW (about 3,400 TWh), depending on whether building-integrated, agricultural, floating, and other innovative applications are included. For Japan, national-level studies estimate technical potentials from around 704 GW up to over 4,000 GW, with practical potentials likely much lower due to competition for land and other uses. Notably, apart from utility-scale PV, Japan's potential is heavily weighted towards agrivoltaics and floating PV, while Germany's is more balanced between building-integrated and agricultural solar.

Both countries now enjoy highly competitive generation costs for solar PV, with new solar projects being cheaper than coal or gas-fired power. Rapidly falling battery costs further improve the business case for solar. While Germany and Japan both face land-use conflicts, there are still ample potentials on commercial and residential rooftops. Still not widely applied approaches such as vertical agrivoltaics and flexible perovskite solar cells promise additional potential for solar PV in general and for overcoming issues of limited space for solar panels.

Onshore Wind

Germany and Japan both have substantial technical onshore wind potential, but the realizable potential differs strongly due to geographic and regulatory factors. Germany benefits from a larger proportion of suitable land area and more favorable wind conditions, especially in its northern regions. Technical and practical potential estimates for Germany range from 200 GW under the current political framework (2% of land area designation), up to 2,086 GW based on broader technical assumptions. If implemented, these capacities could translate to a yearly generation of between 770 TWh and 7,822 TWh, the latter far exceeding Germany's projected electricity demand for 2045.

In contrast, Japan's technical potential for onshore wind is estimated at around 264–286 GW, but strict land-use constraints, mountainous terrain, and environmental regulations sharply limit development options. Recent analyses suggest that only a small fraction of Japan's land might be available for wind projects, with practical deployable onshore wind capacity potentially as low as 25 GW under current conditions. The national industry target for 2050 is set at 40 GW, reflecting the significant challenges to large-scale deployment in practice. Annual generation from these capacities would cover only a modest, but still relevant share of Japan's total electricity needs.

Germany's favorable onshore wind conditions, regulatory progress and political support position it to achieve significantly higher practical deployment and electricity generation from onshore wind than Japan. Japan's realizable onshore wind potential is constrained by its challenging topography, land-use competition, and stringent regulations, making policy reform and infrastructure upgrades essential if it is to realize a greater share of its technical potential.

Offshore Wind

Offshore wind energy plays a crucial role in both Germany's and Japan's energy transitions. Germany benefits from shallow coasts and high average offshore wind speeds of 9–10 m/s in its marine areas, making it highly suitable for efficient fixed-bottom offshore wind installations. However, its marine area is relatively small, at about 57,000 km², with almost half under environmental protection. Germany's technical offshore wind potential is estimated at up to 203 GW (940 TWh/year), but practical potential is much lower due to spatial constraints, with estimates ranging from 50 to 84 GW—closely matching the government's target of 70 GW by 2045.

Japan, in contrast, has a vast combined exclusive economic zone (EEZ) and territorial waters of approximately 4.47 million km², with average wind speeds of 7–9 m/s, and some areas reaching up to 9.5 m/s. Due to Japan's steeply shelving coastlines, a significant share of its offshore wind potential lies in deep waters, making floating wind technology essential for large-scale expansion. Japan's technical offshore wind potential is vast, with studies suggesting up to 2,396 GW for floating turbines and 70–128 GW for fixed-bottom, equating to several thousand TWh/year. The practical potential, considering economic and spatial constraints, is estimated at 70 GW for fixed-bottom, which is similar to the estimates for Germany. Additionally, Japan's practical potential for floating turbines is estimated at 1,477GW by 2050.

By the end of 2024, Germany had installed 9.2 GW of offshore wind capacity, with current targets of 30 GW by 2030, 40 GW by 2035, and 70 GW by 2045. Japan's installed offshore wind capacity remains modest, with 253.5 MW operational as of early 2025. However, project pipelines are expanding rapidly, with government targets of 10 GW by 2030 and 30–45 GW by 2040. Recent legislative changes, such as opening the EEZ for offshore wind, are expected to accelerate deployment, particularly of floating wind farms. Germany's main limitations are spatial, with large, protected areas restricting further expansion. Japan's challenges are more technical and regulatory, including the need for floating wind technology, lengthy permitting processes, grid limitations, and the necessity to negotiate with established marine users such as fisheries.

Japan's offshore wind potential far exceeds its governmental targets as well as its current and projected electricity needs, while Germany's practical expansion is largely limited by available marine space.

Table 1: Electricity consumption and parameters for renewable energy potentials in Japan and Germany

	Germany	**Japan**
Electricity Consumption (2023)	521 TWh (2023)	903 TWh (2023)
Combined Currently installed Solar & Wind Energy Capacity	172 GW (Solar: ~99.3, Wind: onshore ~ 63.5; offshore ~ 9.2)	75.9 GW (Solar: ~70, Wind: onshore ~ 5.7; offshore ~ 0.3)
Combined 2030 Targets Solar & Wind Capacity	330 GW (Solar: 215, Wind: 115)	140–160 GW (Solar: 103–118, Wind: onshore 18; offshore 10)
Theoretical Solar PV Potential per day (Global Solar Atlas data)	2.98 kWh/m²	3.61 kWh/m²
Size of land area	357,000 km²	378,000 km² (more mountainous)
Average wind speeds (onshore)[1]	8.45 m/s	7.6 m/s
Mean power density wind (onshore)	595 W/m²	624 W/m²
Size of marine area	57,000 km² (EEZ: 32,991 km²)	4,470,000 km² (EEZ: 4,050,000 km²)
Range of average wind speeds (offshore)	9–10 m/s	7–9.5 m/s

[1] Average wind speeds in the 10% windiest areas of the respective country's surface at 100m hub height.

1 Introduction

Renewable energy potentials are a decisive factor for achieving climate neutrality, industrial decarbonization, and energy security in both Germany and Japan. As highly industrialized nations with ambitious climate objectives, both countries face significant challenges, including high energy import quotas and the need to transform complex industrial sectors. Unlocking and fully utilizing domestic renewable energy resources will be essential to reduce reliance on energy imports, meet emissions reduction targets, and secure a sustainable energy future.

This comparative briefing provides an overview of the renewable energy potentials in Germany and Japan, highlighting the opportunities and challenges each country faces on the path towards a resilient, low-carbon economy. The briefing summarizes the findings of potentials for different renewable energy sources for Japan and Germany from existing studies and reports. The assumptions underlying the determination of potentials sometimes differ significantly between sources. Results are sometimes only comparable to a limited extent. Generally, potentials can be divided into three different levels: 1) theoretical, or natural potential; 2) technical potential; 3) the practical potential. All three are explained in detail in the blue box on the right side.

In a society, the regulatory framework and economic viability influence which share of the technical and geographically possible potential of a given technology is likely to be classified as feasible. It has to be mentioned, that not all of the sources quoted in this study strictly apply the introduced concepts. Sometimes, definitions of potentials are blended together or are not sharply separated. In these cases, context will be provided.

This overview concentrates on solar and onshore and offshore windenergy as the currently most viable and popular options for renewable capacity expansion. Both countries have potential for other renewable energy sources, which will only be briefly discussed in the following.

Japan, known for its significant tectonic activity and 110 active volcanoes, is considered to have one of the largest geothermal potentials in the world. Geothermal energy also has recently gained renewed attention in energy policy debates in Japan. In Germany, where geothermal energy is regarded as a promising element, particularly for the heating transition, project numbers are also increasing. Unfortunately, there is limited recent research on the specific geothermal energy potential in Japan, with many publications on this topic referring to an old study from 2008, which estimated a potential of 23 GW. This limits the comparability of Japan’s potential with that of Germany. For Germany, there is a sounder basis of research. Estimates state that up to 25% of Germany's total heating requirements could be covered by using geothermal energy (Christian Kluge et al. 2025).

Different level of potentials

1) Theoretical/natural potential: The first level takes the approach of using the totality of a country’s surface (or exclusive economic zone in the case of offshore wind) and its natural conditions, such as solar irradiation, wind speeds or water depths for calculating the potential of a given technology.
2) Technical potential: The second level looks at how much of the theoretical potential can be harvested with available technology considering factors such as conversion efficiency, system configuration, technically needed spacing between e.g. modules/windmills and in many cases also limitations due to physical obstacles for the installation of a respective renewable technology such as rugged terrain, forests, urbanized/industrial areas.
3) Practical potential: The third level considers limitations, which vary greatly depending on the study, and which comprise: physical obstacles for the installation of the respective renewable technology if not included in the technical potential; land use regulations, e.g. for nature conservation or cropland; government support and regulatory policies and the economic viability of a technology (Seitz et al. 2023).

As coastal nations, ocean energy (other than offshore wind) can be considered. The potential for different forms of ocean energy, like wave and tidal current energy, in Japan has been evaluated in several studies from 2011 - 2016. Japan's total marine theoretical energy potential is estimated at 1,327 GW, with the total estimated technical potential of annual energy production from ocean energy ranging from 82 to 260 TWh/year within Japanese sea areas less than 30 km from shore (Hirosuke Yamada and Kisaburo Nakata 2013). Another study by NEDO estimates the theoretical potential for wave energy at 195 GW, with technical potentials ranging from 5 GW to 25 GW, depending on technology development. For tidal energy, the estimate is 22 GW of theoretical potential and around 2 GW technical potential. For ocean current energy, NEDO estimates the largest theoretical potential at 205 GW, however with a limited technical potential of only 1.3 GW. The potential for wave power generation is considered to be concentrated primarily around Japan's northeastern coast. Additionally, tidal energy potential, whilst lower than wave energy, is concentrated around the southern regions of Japan. Ocean current energy shows significant promise, particularly from the Kuroshio Ocean Current running along Japan's eastern coastline (Guillaume Hennequin 2016; Ocean Energy Systems 2025). Despite these substantial technical potentials, ocean energy technologies currently face significant economic barriers. Average LCOE figures stand at EUR 0.27/kWh for wave energy and EUR 0.20/kWh for tidal energy (European Commission et al. 2024) – substantially higher than for established renewables such as utility-scale solar PV (EUR 0.033/kWh or USD 36/MWh; (BloombergNEF 2025)). This cost gap is further compounded by Japan's limited expertise across key parts of the marine energy supply chain, including project design, environmental impact assessment, and offshore technology operations (Guillaume Hennequin 2016; Ocean Energy Systems 2025). Given this cost gap and the very limited commercial deployment to date, ocean energy is unlikely to be a near-term cost-competitive option in Japan's energy mix. Nonetheless, its predictable generation profile may offer longer-term value in a highly renewable system, making targeted R&D investment and a supportive regulatory framework a worthwhile foundation for tapping into Japan's sizeable ocean energy resources.

For Germany potential for ocean energy is estimated as rather small. The reasons for this are the limited extent of the coastline and access to deep waters. A study from 2010 evaluated the theoretical potentials for all forms of ocean energy in Germany as negligible. Due to the shallow sea off the country’s shores, water and wave pressures are unable to supply the required primary energy for existing plants ((GKSS Forschungszentrum et al. 2010; Seitz et al. 2023).

The potential of hydropower will not be further discussed, as both Germany and Japan, have already realized most economically viable potentials in the past (Japan NRG 2023; Seitz et al. 2023).

2 Solar Power

2.1 Targets, Policy and status

In the following, the status of solar power expansion and political targets for solar technology will be introduced briefly for both countries and a connection between wider decarbonization efforts will be made.

2.1.1 Germany

German climate policy has the target of achieving climate neutrality by 2045 and the transformation of the energy sector is an essential part of the way towards this goal. In this context, the German government aims at a share of 80% of the electricity supply coming from renewable sources by 2030 (Bundesregierung 2023). In 2024, renewables already provided 54.4 percent of the electricity consumption (Umweltbundesamt 2025a). To achieve the 80% goal by 2030 the so-called "Easter-Package" from April 2022 contained a revamped Renewable Energy Sources Act (EEG), which also contains additional support for rooftop solar (Umweltbundesamt 2023; Bundesministerium für Wirtschaft und Energie 2023).

The Act also set a new solar expansion goal of 215 GW until 2030, which would more than double the installed peak capacity in Germany from 99.3 GW as of end 2024. Accounting for the remaining years until 2030, this would require an installation of approximately 19.3 GW of additional peak capacity per year. This target is ambitious, since the highest annual capacity additions in the past have been around 16.2 GW, achieved in 2024 (PV Magazine 2025). However, these capacity additions in 2024 of 16.2 GW would represent a new record, surpassing the previous record of 14.3 GW in 2023.

In summer 2025, the newly elected German government commissioned research institutes to assess the progress of the energy transition with regard to security of supply, affordability and the national and European climate protection targets (focusing on achievability, consistency and associated cost-efficiency). Based on the findings of the monitoring report, the Federal Ministry for Economic Affairs and Energy (BMWE) reaffirmed its commitment to the target of 80% renewable electricity supply by 2030. However, the Ministry now expects overall electricity consumption in 2030 to be lower than previously projected (Bundesministerium für Wirtschaft und Energie 2025b). Consequently, the volume of additional solar PV installations required to meet the 80% target could decrease. As of now, the BMWE has not yet indicated whether the specific solar expansion targets will be adjusted in light of these updated projections.

2.1.2 Japan

Japan aims to become climate neutral by 2050. This will require a fundamental shift in its energy supply. The country has announced goals to expand the share of renewables in electricity production, but also to reintroduce its fleet of nuclear power plants. Additionally, Japan plans to introduce carbon capture and storage technologies (CCS) and hydrogen to decarbonize the remaining thermal power generation capacities. Japan's power mix continues to be dominated by fossil fuels, though their share has slightly decreased in fiscal year (FY) 2023 compared to the previous year. The share of renewable energy increased marginally to 22.9%, primarily due to moderate capacity additions in solar PV, wind power (on- and offshore), and biomass. Solar PV accounted for 9.8% (Renewable Energy Institute 2025b; Ministry of Economy, Trade and Industry 2025).

Looking ahead, Japan sets its energy targets in the strategic energy plans (SEP). Under the 6th SEP for FY 2030, the aim is to increase the share of renewables in the electricity mix to 36–38%, with solar PV projected at 14–16%. In February 2025, Japan has released the 7th SEP with targets for FY 2040. The 7th SEP for the first time designates renewables as the country's main power source. The targets envisage renewables providing 40–50% of electricity, with solar PV contributing 23–29% (Agency for Natural Resources and Energy 2021, 2025).

There has been strong growth of solar PV in Japan since the accident at the Fukushima nuclear power plant in 2011. The high feed-in tariff (FIT) support accelerated the expansion to the third highest solar capacity worldwide in 2020. There was a slowdown in growth with the expiry of the FIT in FY 2021. The current installed capacity is around 70 GW (AC) (Statista 2024). For FY 2030, METI is aiming for a share of 14–16% of PV in the power generation mix, which roughly translate to capacity targets of 103.5 to 117.6 GW (AC, around 129–147 GW DC) (Ministry of the Environment, Japan 2025). Slight growth is expected over the next few years for rooftop solar systems in the residential and commercial building sector as well as through PPAs.

A focus is on perovskite solar cells, with around 20 GW of new photovoltaic systems based on perovskite solar cell (PSC) technology to be installed by 2040 throughout Japan. At the same time, the government wants to support Japanese manufacturers in the production of PSC modules to establish a competitive domestic supply chain. Due to their low weight and flexibility, Japan considers PSC modules as advantageous for being able to be installed in locations that are unsuitable for conventional modules (Emiliano Bellini 2024).

2.2 Potential according to Global Solar Atlas

In this part, the Global Solar Atlas, published by the World Bank, will be used to provide some basic context for the evaluation of both countries' solar potential.

2.2.1 Germany

The starting point for the consideration of overall solar potential is the natural or theoretical potential, referring only to the total amount of global horizontal irradiation received by a country. According to calculations from the World Bank's Global Solar Atlas, Germany's theoretical potential is on average 2.98 kWh/m² per day (World Bank Group et al. 2023). The strongest potential can be found in the south, as indicated in Figure 1 below.

A simplified calculation using Germany's total surface area of approximately 357,000 km² and the average natural potential results in a theoretical solar potential of 388,000 TWh per year. To put this in context, the German gross electricity consumption in 2024 was 521 TWh, which would be equivalent to about 0.14% of this theoretical potential (Enerdata 2023; Bundesnetzagentur 2025b; Umweltbundesamt 2025b).

However, solar power installations would not be able to harvest all this energy. Correcting for technical potential (e.g. considering the system configuration, conversion efficiency of PV modules and other factors such as air temperature, soiling and shading) and spacing between modules, the global solar atlas therefore calculates that 2.95% of Germany's total area would need to be converted to utility-scale solar to provide the equivalent of Germany's 2014 electricity consumption. Figure 1 on the right side shows the photovoltaic power potential in Germany considering the mentioned technical limitations.

Even apart from technical limitations, it is not realistic to assume that one would be able to harvest this maximum potential due to limitations in land use, which is why the global solar atlas adds two levels of additional limitations to these calculations to more realistically reflect the actual potential. On level 1, land with identifiable physical obstacles (such as rugged terrain, forests, urbanized/industrial areas) is removed, and on level 2, land possibly under land use regulations (e.g. nature conservation; cropland) is removed. This reduces the theoretically available area to 73.2% and 21.4% of the total land area of Germany, respectively.

This reduction in available space also impacts the theoretical average efficiency of solar panels in Germany. Taking technical limitations and the distribution of the available land into account, the atlas calculates a practical efficiency of 2.96 kWh/kWp per day for the land available under level 1. This would be equal to around 1,080 kWh per kWp per year, meaning that Germany would need

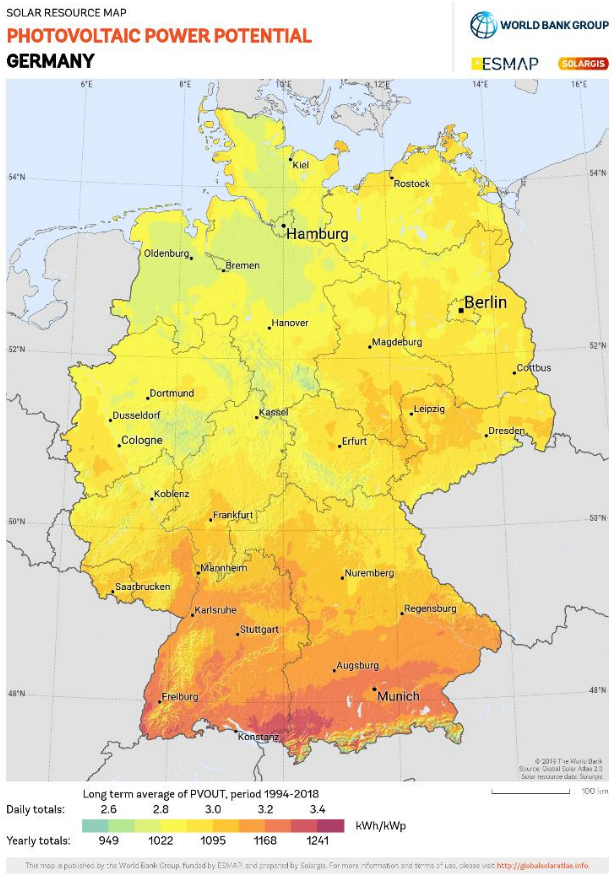

Figure 1: Photovoltaic power potential in Germany considering technical limitations

Map obtained from the "Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info/
The photovoltaic power potential shown here considers how much of the theoretical potential (solar radiation) can be harvested with available technology, considering factors such as conversion efficiency, system configuration, technically needed spacing between modules.

around 482 GW installed solar capacity to meet its 2024 electricity demand of 521 TWh through solar alone.

When using a simplified approach based on the assumptions made in the Global Solar Atlas regarding land use restrictions (level 2) and using the entire country's average solar irradiation for the 21.4% theoretically available, a technical potential of 7,438 TWh for solar PV can be calculated for Germany (Rechner Online 2023).

2.2.2 Japan

As in the case of Germany, the starting point for evaluating Japan's solar potential is the natural or theoretical potential, which refers to the total amount of global horizontal irradiation (GHI) received by the country. According to calculations from the World Bank's Global Solar Atlas, Japan's theoretical potential is on average 3.614 kWh/m² per day. With a total land area of approximately 377,970 km², a simplified calculation yields a theoretical solar potential of around 498,644 TWh per year (Solargis & World Bank Group 2020). For context, Japan's annual electricity consumption in 2023 was about 903 TWh (TheGlobalEconomy.com 2024), which would be equivalent to roughly 0.18% of this theoretical potential.

Figure 2: Photovoltaic power potential in Japan considering technical limitations

Map obtained from the "Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info/ The photovoltaic power potential shown here considers how much of the theoretical potential (solar radiation) can be harvested with available technology, considering factors such as conversion efficiency, system configuration, technically needed spacing between modules.

The Global Solar Atlas estimates that about 2,34% of Japan's land area would be required to meet the country's current electricity demand with utility-scale solar PV, assuming ideal technical conditions that consider technical limitations such as system configuration, conversion efficiency of PV modules, and factors like temperature, soiling, and shading.

Excluding land with obvious physical obstacles (such as rugged terrain, forests, and urban or industrial areas) the Global Solar Atlas calculates that 34.6% of Japan's land are available for PV (level 1). Applying further restrictions to account for possible land use regulations (e.g., cropland, nature conservation), reduces the theoretically available area to approximately 15.7% of Japan's total land area (level 2).

This reduction in available space also affects the practical efficiency and output of solar PV systems in Japan. Taking technical limitations and the distribution of available land into account (level 1), the Global Solar Atlas calculates an average practical output of around 3.45 kWh/kWp per day, or about 1,258 kWh/kWp per year. Using a simplified approach and assuming the entire country's average solar irradiation applies to the 15.7% of theoretically available land, a technical potential of approximately 78,287 TWh per year can be calculated for Japan. This means that Japan would need to install around 718 GW of solar PV capacity to meet its current electricity demand solely with solar energy (TheGlobalEconomy.com 2024).

2.3 Specific potential according to national level studies

As mentioned, it needs to be kept in mind that the global solar atlas calculations use a somewhat theoretical scenario assuming utility-scale solar under ideal conditions, only excluding land with clearly detectable limitations. Such overarching potential analyses are naturally not reflective of the practical conditions on the ground. To get a better sense of the technical and practical potential, a look at the diverse literature on the topic proves valuable. This chapter will summarize results from national level studies to give a more nuanced overview of the specific solar energy potentials of both countries.

2.3.1 Germany

The most important detail left unaddressed by the Global Solar Atlas' estimations concerns the various potential use-cases for solar energy. Thanks to its versatility, solar can be used in a multitude of circumstances, such as building-integrated solar, swimming solar on lakes and reservoirs or solar in mixed use with agricultural land. Fraunhofer ISE calculates the technical potential (excluding surfaces that cannot be used for the respective technology but not considering other regulatory and economic limitations) for these different applications in Germany and highlights in particular the high potential for building-integrated and agricultural solar. According to their calculations, the potential for the former amounts to 1000 GW and for the latter to 1700 GW. In addition, various other sources, such as swimming solar, solar alongside transportation infrastructure or solar in urban areas offer an additional 450 GW (Conexio GmbH 2021). Putting this overall estimate of 3150 GW or approximately 3400 TWh in the context of Germany's solar expansion goal, only around 7% of this technical potential would be needed to reach the 2030 expansion goal of 215 GW – not accounting for traditional utility-scale solar.

A literature review by the German Foundation Climate Neutrality (Stiftung Klimaneutralität) using mostly older sources gets to a practical economically usable solar potential of 300-350 GW for free standing solar, including agri-solar and floating solar, 400 GW for rooftop and 320 GW for facade solar. This results in an overall potential of 1,070 GW or approximately 1,155 TWh (Stiftung Klimaneutralität 2021). Even though being slightly lower, these values are somewhat comparable to the Fraunhofer estimates, with estimates for building-integrated solar being 720 and 1,000 GW, respectively.

Another study focusing exclusively on rooftop solar for single- and two-family homes estimates a technical potential of up to 38.6 TWh p.a. for this category, even though the authors assume that a part of this potential is not economically viable. The study also looks at opportunities for rooftop solar in the agricultural and food retail sectors. There, the potential is estimated to be 3.8 TWh p.a. (Prognos 2016). This would be equal to a capacity potential of roughly 36 and 3.6 GW, respectively.

The relevance of solar, in particular roof-top solar becomes apparent from the findings of a study analyzing different scenarios for Germany's climate neutrality in 2045 written as part of the Ariadne project (Ariadne 2021). Regarding potential scenarios for Germany to become climate neutral by 2045, rooftop solar plays a central role, with a combination of renewable sources scenario requiring almost all available rooftops to be covered with solar power.

Regarding solar thermal, Fraunhofer ISE quotes other studies assuming a potential of around 30 TWh per year until 2050 (Wirth et al. 2021).

It is also relevant to take a look at the costs of solar PV, which the Fraunhofer ISE study estimates to be 2-7EuroCt per kWh (Wirth et al. 2021). A more recent study by Fraunhofer ISE estimates costs to be between 3.1 and 5.7EuroCt per kWh for utility-scale solar and 11-13EuroCt per kWh for small-scale rooftop solar (Wirth 2023). The estimates of the Global Solar Atlas are similar with an average of 11 USDCt per kWh (2016), which is roughly equal to 10 EuroCt.

2.3.2 Japan

A comprehensive study (Cheng et al. 2022) identifies over 4,000 GW of solar PV technical potential in Japan using geographic information system analysis. The analysis incorporates: land use data, protected area data, wave height data, rooftop area data, as well as meteorological data, together with technical characteristics of PV modules. This leads to a technical potential estimation comprising diverse applications. The results include potentials for ground-mounted PV (3 GW), building-mounted PV (101 GW), floating PV on inland rivers, lakes and reservoirs (376 GW), floating PV on the Japanese inland sea (234 GW), and a very high potential for agrivoltaics (3,402 GW). The authors also point out that the practical potential would be substantially lower, e.g. due to competition from other land- or water-use activities for the large identified agrivoltaics and floating PV potential. Nonetheless, Cheng et al. arrive at the conclusion, that only 20% of the calculated available area would need to be utilized for the different applications of solar PV to supply 100% of the electricity demand in Japan.

The PV Outlook 2050 by the Japan Photovoltaic Energy Association (Japan Photovoltaic Energy Association 2024) presents an overview of various estimations for Japan's solar PV potential. According to JPEA's own analysis from the PV Outlook 2050, the technical potential for solar PV capacity in Japan is 2,380 GW (DC). This figure again comprises the largest share with 1,593 GW from agrivoltaics. In addition, it includes 391 GW from rooftop solar on commercial buildings, 240 GW from residential rooftops, 87 GW from floating PV, 43 GW from ground-mounted installations and 27 GW from innovative installation types, such as solar panels on electric vehicles. These estimates are based on statistical data and expert interviews, which helped identify available locations and suitable installation areas to deduce technical potential.

JPEA did not provide figures for practical potential. However, it sets the following targets for the expansion of solar photovoltaic (PV) capacity in Japan: aiming for 125 GW by 2030, 173 GW by 2035, and 400 GW by 2050. As the main hindering factors, JPEA identifies grid constraints and land availability as the principal challenges to achieving these goals. Increased sector coupling and applications like building integrated PV or vertical agrivoltaics are named as potential solutions to overcome these issues.

To validate its findings, JPEA also cross-referenced its estimates with studies from other organizations, including the New Energy and Industrial Technology Development Organization (NEDO) and the Japanese Ministry of the Environment (MOE). In an older study from 2013, NEDO estimates Japan's solar PV potential at 704 GW, including 438 GW from agrivoltaics, 50 GW from commercial rooftops, 91 GW from residential rooftops, 73 GW from floating PV, and 52 GW from ground-mounted systems (Japan Photovoltaic Energy Association 2024).

The MOE's analysis from 2020 concludes a technical solar PV potential of 2,746 GW, which encompasses 2,447 GW from agrivoltaics, 206 GW from residential rooftops, 51 GW from commercial rooftops, 36 GW from ground-mounted PV, and 5 GW from floating PV. The MOE further estimates a possible introduction amount, defined as the amount of energy resources expected to materialize when certain conditions regarding business profitability are set, ranging from a rather small practical potential of around 38 GW to a larger of 406 GW (Ministry of the Environment, Japan 2020b).

Collectively, these studies highlight the vast potential for solar PV in Japan, while also underscoring the significant constraints that must be addressed to turn potential into practical capacity – including limited land availability, grid integration challenges and economic viability considerations.

Globally, solar PV has become the most competitive new generation technology. According to BloombergNEF's Levelized Cost of Electricity Report (2025), the global benchmark LCOE for fixed-axis utility-scale solar photovoltaic projects reached a record low of USD 36 per MWh in 2024 (≈ JPY 5,580/MWh; ≈ EUR 33/MWh; or USD 0.036/kWh; JPY 5.6/kWh; EUR 0.033/kWh). Based on BloombergNEF data, a Renewable Energy Institute's analysis from 2025 highlights that this is about half the cost of coal and gas-fired power, and a fraction of the cost of nuclear or fossil plants with carbon capture. in Japan, new solar PV (without battery storage) is now as cost-competitive as existing coal plants, while solar PV with battery storage is comparable to combined-cycle gas turbines. The rapid decline in battery storage costs—down 33% in 2024 alone—further enhances the economic case for solar, enabling reliable integration of renewables at scale. Despite these positive trends, Japan's pace of solar PV deployment has slowed, with only 2.5–4 GW of new capacity added in 2024—well below leading countries like China, the US, and India. This highlights the need for stronger policy support and greater public awareness to fully realize the cost and sustainability benefits of solar PV. With vast untapped potential on rooftops and farmland, and ever-lower costs, Japan stands at a pivotal moment to accelerate its solar transition (Romain Zissler 2025).

2.4 Comparison

The overview for solar PV potentials demonstrates that both Germany and Japan possess abundant solar resources, with technical potentials far exceeding their current electricity demand and diverse application opportunities ranging from rooftops to agrivoltaics. Theoretically, using just a fraction of the countries' total surface area—approximately 2.95% for Germany and 2.34% for Japan—would be sufficient to supply all their current electricity needs through solar PV alone, assuming ideal conditions and utility-scale deployment. Japan's larger surface area (about 378,000 km² vs. Germany's 357,000 km²) leads to a higher total theoretical solar energy potential in absolute terms, and Japan also benefits from higher average solar irradiation, resulting in a higher theoretical average daily photovoltaic power output per square meter (3.61 kWh/m² for Japan vs. 2.98 kWh/m² for Germany).

When considering technical and practical potentials, both countries face significant land use, regulatory, and economic constraints. Estimates for Germany's technical solar PV potential ranges from 1,070 GW (about 1,155 TWh) to over 3,150 GW (about 3,400 TWh), depending on the inclusion of building-integrated, agricultural, floating, and other innovative applications. For Japan, national-level studies estimate technical potentials from around 704 GW up to over 4,000 GW. Notably, Japan's potential is heavily weighted toward agrivoltaics and floating PV, while Germany's is more balanced between building-integrated and agricultural solar.

In terms of economics, both countries now enjoy highly competitive generation costs for solar PV, with new solar projects in Japan and Germany being cheaper than coal or gas-fired power and rapidly falling battery costs further improving the business case for solar. In summary, Germany and Japan are both well positioned to leverage solar PV as a cornerstone of their renewable energy transitions. While their respective potential differs in structure and scale, both countries can, in principle, cover their entire electricity demand with solar PV using only a small portion of their land, provided that technical, regulatory, and societal challenges are effectively addressed.

3 Onshore Wind Power

3.1 Targets, Policy and status

In the following, we will introduce the countries' targets for onshore wind expansion and the plans for and status of implementation.

3.1.1 Germany

As with the other renewable expansion targets, the adjusted Renewable Energy Sources Act (EEG 2023), set new targets for onshore wind energy expansion as well. To achieve an almost completely decarbonized electricity, mix by 2035, the overall capacity for onshore wind is to be expanded to 115 GW by 2030 and further to 157 GW by 2035 and 160 by 2040. Therefore, yearly onshore wind capacity additions of approximately 10 GW are required. Whether the current government will adjust the onshore wind targets established in the EEG in light of the conclusions drawn from the monitoring report in September 2025 has yet to be determined.

By the end of 2024, 63.5 GW of onshore wind energy were installed in Germany (Bundesnetzagentur 2025c). In 2024, the net-expansion of new wind energy capacity has been 3.3 GW, which was significantly higher than in previous years and demonstrates substantial progress towards the required installation numbers. The upwards trend has intensified strongly through the implementation of regulatory adjustments made by the government, with approvals for nearly 15 GW of onshore wind capacity issued in 2024 - a record figure almost 90% above the capacity approved in 2023 (Bundesnetzagentur 2025c). Of the total electricity generation in 2024 (431.7 TWh), 26% were supplied by onshore wind energy, making it the largest single source of electricity generation in Germany (Bundesnetzagentur 2025a; SMARD - Bundesnetzagentur 2025).

3.1.2 Japan

Under the 7th SEP, wind power (onshore and offshore combined) is projected to account for 4–8% of the electricity generation mix by FY2040(Agency for Natural Resources and Energy, 2025).

The Japanese government set a capacity goal in 2023 for the year 2030 of around 18 GW of onshore wind capacity (Cornwall Insight 2023; Climate Integrate 2024). As of the end of 2024, Japan had installed approximately 5.7 GW of onshore wind capacity (Japan Wind Power Association 2024), with annual additions still lagging behind the pace required to meet the long term targets. Key factors hindering the expansion of onshore wind in Japan include complex and lengthy permitting procedures, grid access limitations, and local opposition related to environmental and landscape concerns. The country's mountainous terrain and fragmented land ownership also make it difficult to identify and develop suitable sites for large-scale onshore wind farms. Nevertheless, the government's strengthened targets and policy measures in the 7th Strategic Energy Plan also demand to accelerate the expansion of onshore wind in pursuit of a decarbonized power system (Renewable Energy Institute 2025a; Ember Climate 2024; Agency for Natural Resources and Energy 2025; Climate Integrate 2025). The focus of recent policy updates has been on offshore wind, but onshore wind remains an option, especially in northern Japan. Japan biggest onshore wind farm recently started commercial operation in April 2025, with an installed capacity of 147 MW (Sumitomo Corporation 2025; Ember Climate 2024; Renewable Energy Institute 2025a).

3.2 Overall potential in Germany and Japan

Compared to solar energy, many more variables go into calculating overall wind energy potentials of a country. Fluctuating wind patterns, turbine heights and rotor diameter sizes make theoretical wind energy potential harder to calculate. Calculating scientifically sound overall potential for wind, both on- and offshore, thus requires a much bigger set of variables than for solar, some of which are not openly available. To account for these nuances, this study will rely on the assumptions made in the baseline studies introduced below. Many of them do not give an overall theoretical potential but only technical and practical potential reflecting the various levels of limitations.

The data presented in the Global Wind Atlas (Davis et al. 2023) can provide some context for the comparison of Germany's and Japan's onshore wind energy potential. Figure 3 and 4 on the next page, showcase the onshore wind power potential in Germany and Japan.

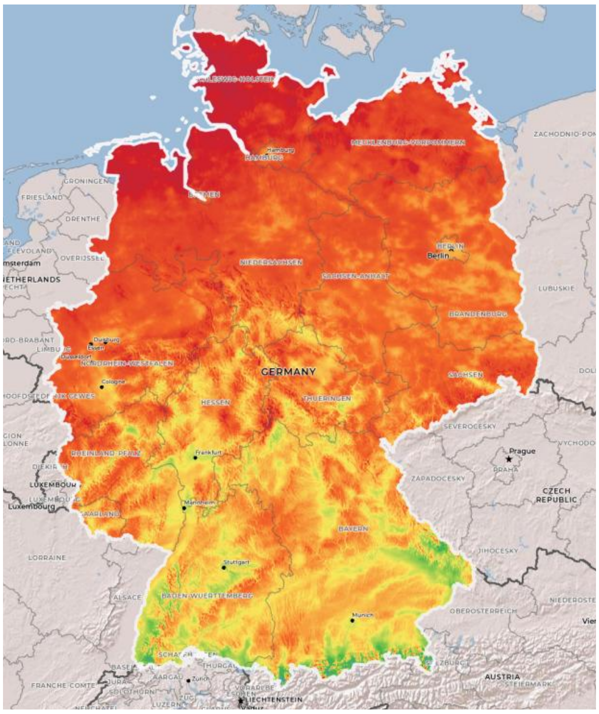

Figure 3: Onshore wind power potential in Germany

(mean wind speed at 100 m, darker shades indicating higher wind speeds)

Map obtained from the "Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info/en/area/Germany

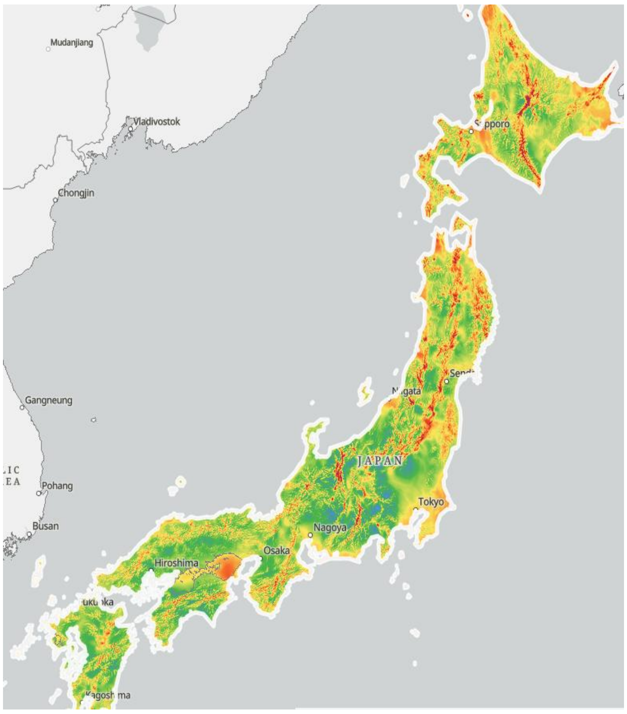

Figure 4: Onshore wind power potential in Japan

(mean wind speed at 100m, darker shades indicating higher wind speeds)

Map obtained from the "Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info/en/area/Japan

At a height of 100 meters above the ground (an average turbine's height), the mean power density for the 10% windiest areas of the respective country is 595 W/m² for Germany and 624 W/m² for Japan. Average wind speeds in these areas are 8.45 m/s in Germany and 7.6 m/s in Japan. While Germany benefits from slightly higher mean wind speeds, Japan's windiest regions exhibit a higher mean power density (DTU Wind and World Bank Group 2025a, 2025b). As visible in Figure 3, the wind speeds in Germany are generally higher in the northern part of the country. In Japan, the highest wind speeds can be found along the mountain ridges in the middle of the islands of Honshu and Hokkaido, as well as along the coastlines, especially along the eastern and northern coastlines (see Figure 4). Hokkaido overall seems to have the highest potential for onshore wind.

3.3 Specific potential according to national level studies

In this part, studies indicating the various levels of onshore wind potentials for both countries will be introduced and context regarding the respective study's assumptions will be provided.

3.3.1 Germany

As with solar energy, the theoretical potential of the total surface area of a country for onshore wind energy capacity and generation is in practice limited by various factors.

A Fraunhofer study conducted in 2012 looks at technically and geographically (excluding physical obstacles) viable areas for wind energy turbines and classifies three levels of possible restrictions in said areas: areas without regulatory restrictions, areas in forests without nature protection requirements and those under nature protection. When all technically and geographically viable areas are included, 22% of Germany's land surface would be usable for wind energy, allowing the country to install wind turbines with a capacity of 1,500 GW. When only considering areas without any geographic or nature preservation restrictions, the potentially usable area would still be 8% of the country, leading to a possible capacity of 722 GW (Fraunhofer-Institut für Windenergiesysteme 2012).

Another study by Umweltbundesamt identifying all technically suitable areas using geo information system data demonstrates Germany’s onshore wind energy potential in relation to the various possible minimum distances to be kept between wind energy sites and buildings. The study finds that with a minimum distance requirement of 600 meters, 13.8 percent of Germany’s total surface area could be used for wind turbines. This would allow for the installation of 1,190 GW of wind energy capacity, providing around 2,900 TWh of power per year. Increasing the minimum distance by 200 or 400 meters would shrink the available surface area to 9.1 percent or 5.6 percent respectively (Lütkehus et al. 2013). Overall, the omission of some of the most important economic and regulatory factors in the study significantly diminishes the applicability of the findings to an actual political and social context.

A study by Fraunhofer IEE from 2022, using more advanced geoinformation data sets, differentiates areas regarding “conflict risks” by looking at factors standing in the way of wind energy usage. Conflict risk factors reflect the possible interference of wind energy plants with matters of nature or landscape protection. When disregarding said factors for conflict risk and incorporating all areas technically and geographically viable for wind energy use, 26% of Germany’s surface area could be used for the installation of 2,086 GW of wind energy capacity. However, more importantly, when considering only areas with “very low” to “medium” conflict risk for practical viability, 5.6% of the total area would be available for wind power turbines. This could translate to a wind power capacity of 366 GW and an annual generation of 971 TWh. Additionally, if old turbines were replaced by technically more advanced new ones (repowering), a further 39 GW providing 109 TWh/a of electricity could be added without designating further areas (Pape et al. 2022).

A focus in the political debate in Germany surrounding wind energy lies on the designation of land area. The German government has set a binding target that 2% of the country’s land area must be designated for onshore wind energy by 2032. This is also enshrined in the Onshore Wind Act, which mandates federal states to make sufficient land available for wind energy development. The law also sets interim targets: 1.4% of the land must be designated by 2027, increasing to 2% by 2032 (Bundesnetzagentur 2023). With the availability of 2% of the country’s surface, erecting onshore wind turbines with a capacity of roughly 200 GW would be possible, generating 770 TWh/a (Fraunhofer-Institut für Energiewirtschaft und Energiesystemtechnik 2022).

Onshore wind could thus supply around 57% to 77% of Germany's overall electricity demand is expected to rise significantly by 2045 due to increased electrification across all sectors. According to the monitoring report on the energy transition from September 2025, climate-target-compatible scenarios project a wide range of demand between roughly 700 and 1,600 TWh/a - largely depending on assumptions regarding sufficiency measures, hydrogen usage and industrial structure – with a median of approximately 1,255 TWh/a. (EWI & BET 2025).

As demonstrated in some of the studies, using more areas than reflected in the 2%-goal would be technically, ecologically and economically viable for wind energy generation. A utilization of these areas could further strengthen the role onshore wind energy plays in Germany’s energy transition.

3.3.2 Japan

The potential for onshore wind energy in Japan seems to be significantly constrained by various geographical, regulatory, environmental, and social factors. Recent discussions in Japan focus predominantly on solar PV and offshore wind energy. This is also reflected in a smaller number of studies on onshore wind potential in Japan.

The Japanese Ministry of Environment (MOE) assessed in a study from 2020 that around 280 - 286 GW of onshore wind capacity is technically possible in Japan. The study employed geographic information system (GIS) analysis and considered multiple constraining factors including annual average wind speed requirements, topographic limitations, legal constraints, and land-use constraints. The study's prominence in the literature reflects the limited availability of other detailed technical potential assessments for Japan's onshore wind resources (Ministry of the Environment, Japan 2020a; Obane et al. 2020). Also based on study results by the MOE, the REI see Japan’s total technical potential at 264 GW for onshore wind, assuming wind speeds of at least 6.5 m/s (Renewable Energy Institute 2023b).

Another detailed GIS-based study by Obane et al. (2020) provides a more realistic assessment of available land area for onshore wind. The study found that only about 0.9% of Japan's contiguous land area would be available for wind and solar deployment after accounting for legal, environmental, and practical constraints. Of this limited area, 72% is subject to competition between wind and solar or other land uses. The study concludes that, even under optimistic assumptions, practical deployment may be limited to around 25 GW for onshore wind, unless significant changes are made to land use policy, infrastructure, and public engagement. Japan's mountainous topography presents a particular challenge for onshore wind development. Unlike countries with large flat areas, Japan's complex terrain affects not only the physical placement of turbines but also influences wind patterns and turbulence. The Obane et al. study found that most available areas for renewable energy development in Japan are not flat, which presents challenges for ensuring the safety and efficiency of wind power systems (Obane et al. 2020).

An older assessment from the JWPA of 2014 estimates Japan's technical onshore wind potential at approximately 144 GW (Renewable Energy World 2014). In its JWPA Wind Vision 2023, however, the association only sets a target of 40 GW onshore wind for 2050, potentially resembling more of practical potential from the perspective of the JWPA (Japan Wind Power Association 2023).

In summary, the realizable potential for onshore wind energy in Japan seems to be significantly constrained by the country's mountainous terrain, strict environmental regulations, and social acceptance challenges. Addressing these constraints through policy innovation, improved grid infrastructure, and meaningful community engagement will be essential for realizing a greater portion of Japan's wind energy potential.

3.4 Comparison

As evident from the preceding analysis, Germany possesses a considerably higher practical and technical potential for onshore wind energy compared to Japan. The country benefits from a larger proportion of suitable land area and more favorable wind conditions, particularly in the northern regions. Consequently, the technical and practical potentials for onshore wind calculated in various studies are higher for Germany than for Japan. For Germany, estimates lie between 200 GW, which is based on the current political framework of the designation of 2% of land area, and 2,086 GW. If implemented, these capacities could translate to a yearly generation of between 770 TWh and 7,822 TWh. Thus, with the current political framework the practical onshore wind potential could supply more than half of Germany’s expected electricity demand in 2045 of around 1,255 TWh/a. The technical potential exceeds the projected electricity demand many times over.

In contrast, Japan’s technical potential for onshore wind is estimated at around 264–286 GW, but strict land-use constraints, mountainous terrain, and environmental regulations sharply limit what can be developed. A recent analysis suggests that only a small fraction of Japan’s land is realistically available for wind projects, with practical deployable onshore wind capacity potentially as low as 25 GW under current conditions. The national industry target for 2050 is set at 40 GW, reflecting the significant challenges to large-scale deployment in practice. Annual generation from these capacities would cover only a modest share of Japan’s total electricity needs. However, it must be noted that the study base is limited and allows for limited conclusions.

In summary, while both countries have substantial technical onshore wind potential, Germany’s favorable geography, regulatory progress, and political support position it to achieve much higher practical deployment and electricity generation from onshore wind than Japan. Japan’s realizable onshore wind potential is constrained by its challenging topography, land-use competition, and stringent regulations, making policy reform and infrastructure upgrades essential if it is to realize a greater share of its technical potential.

4 Offshore Wind Power

4.1 Targets, Policy and status

In the following, an overview over the current levels of implementation, the wider political framework and future goals concerning the expansion of offshore wind energy in Germany and Japan will be given.

4.1.1 Germany

The German government targets to reach 30 GW of offshore wind capacity by 2030, 40 GW by 2035 and 70 GW by 2045 (Bundesministerium für Wirtschaft und Energie 2025a). This would correspond to a generation of 220 TWh in 2045. To reach these goals, tender volumes were increased, and planning simplifications were introduced by law. As of the end of 2024, 9.2 GW of offshore wind energy capacity were installed (Bundesnetzagentur 2025c), contributing 6% (25.7 TWh) to Germany's overall electricity generation (Bundesnetzagentur 2025a). While offshore expansion was slowing down almost to zero in 2021 due to higher commodity prices and an unfavorable regulatory framework, regulatory adjustments in the 2022 amendment of the Offshore Wind Energy Act have led to a significant uptick in project development. The 30 GW target set for 2030 is expected to fall slightly short, reaching 27 GW. However, the target for 2035 might be achieved earlier than planned (Stiftung Offshore Windenergie 2025; Deutsche Windguard 2024).

The conclusions drawn in the September 2025 monitoring report also have implications for the expansion of offshore wind energy. In response to the revised projections for electricity demand in 2030, the BMWE has announced concrete plans to adjust the targets for offshore wind capacity in the coming months (Bundesministerium für Wirtschaft und Energie 2025b).

4.1.2 Japan

Japan is rapidly building momentum in offshore wind, with a particular focus on floating wind technology. The country targets 10 GW of offshore wind by 2030 and up to 30 to 45 GW by 2040. The long-term development is expected to be further supported by the 7th Strategic Energy Plan by the goals of 4-8% of wind power by 2040 in the power mix. While Japan's installed offshore wind capacity remains modest with 253.5 MW as of early 2025, project pipelines have rapidly expanded following the government's 2040 targets and the introduction of competitive auctions. In 2024, the country awarded over 1 GW of offshore wind capacity through its auction process. If all awarded projects from the first three offshore wind auction rounds are realized, Japan could achieve 5 GW of offshore wind capacity by 2030 and 9 GW by 2034. The country's future success will depend on maintaining clear regulatory processes, investing in supply chain capacity and port infrastructure, and ensuring predictable timelines (Global Wind Energy Council 2025).

The business environment has faced challenges such as inflation, yen depreciation, and supply chain uncertainties, leading some major players to review their portfolios. However, the opening of the EEZ is widely expected to reinvigorate the sector. The passage of the Exclusive Economic Zone (EEZ) Bill in 2025 marks a significant legislative milestone, enabling floating offshore wind development beyond territorial waters. This unlocks nearly 4 million square kilometers of sea space previously off-limits for such developments (Buljan 2025; The Maritime Executive 2024). This legislative change is expected to significantly accelerate offshore wind deployment, especially through deep-water floating wind technology, given Japan's often citied limited shallow-water areas.

The commissioning of the 16.8 MW Goto floating wind farm, which won Japan's first floating wind auction in 2021, has been delayed to 2026 due to technical issues. Nevertheless, the government has set aside a JPY 85 billion subsidy to support two large-scale floating demonstration projects, with new 15 MW turbines being tested in Akita and Aichi Prefectures (Global Wind Energy Council 2025).

4.2 Overall potential in Germany and Japan

According to the Global Wind Atlas (Davis et al. 2023), offshore wind speeds are higher in German waters than in Japanese waters. In the German sea, average wind speeds of between 9 and 10 m/s are the norm, while in Japanese waters, average wind speeds typically range between 7 and 9 m/s, with some areas—particularly off the coast of Hokkaido and in the Sea of Japan—reaching up to 9.5 m/s (DTU Wind and World Bank Group 2025a, 2025b). These wind speeds are considered suitable for efficient offshore wind power production, especially when compared on a global scale. Figures 5 and 6 show the offshore wind potential of Germany and Japan respectively, differentiated by wind speeds, the potentially available area and water depth (indicating whether fixed or floating are viable options). While the German coast reaches higher average wind speeds overall, Japan possesses a much larger marine area for potential offshore wind development, with a marine area (territorial waters + EEZ) of approximately 4,470,000 km². In contrast, Germany's marine area covers only about 57,000 km². Additionally, almost half of Germany's marine area is protected for marine biodiversity, while the proportion of fully protected areas in Japan is relatively limited compared to the overall size of Japan's marine area. Due to the shallow water depths of the German marine areas, only fixed-bottom offshore wind installations are needed. Japan's coastal geography, on the other hand, is characterized by significant water depth variations. While some shallow areas suitable for fixed-bottom offshore wind installations exist, particularly along parts of the north and north-western coasts, most of Japan's marine area is deep water, necessitating the use of floating wind technology. The rapid drop-off in seabed depth close to shore, especially along the Pacific coast, means that floating offshore wind turbines are essential for exploiting much of Japan's wind energy potential further from the coastline.

4.3 Specific potential considering national circumstances and outlook

In this part, theoretical, technical and practical potentials of offshore wind energy expansion in both countries as evaluated by different studies will be shown.

4.3.1 Germany

A study from 2009 looks at the offshore wind potential available within 100 kilometers of each country's shoreline. Despite working with the assumption of wind turbines' technical standard of 2009, the study finds an impressive total offshore wind potential of 940 TWh per year for Germany (Lu et al. 2009). However, given the limited size of Germany's marine area and the vast area under nature protection, this potential seems far from implementable.

An analysis by the Global Wind Energy Council from 2021 finds that within 200 kilometers off the German shoreline, 203 GW of fixed-bottom wind energy capacity could be installed. The potential is a technical one, focusing on turbine planting densities of 3 MW per km^2 for wind speeds between 7–8 m/s and 4 MW per km^2 for wind speeds greater than 8 m/s (Global Wind Energy Council 2021).

In the following, the findings of several studies on the practical potential for offshore wind in Germany are presented. These potentials generally exclude areas under nature protection, shipping routes, zones adjacent to cables or pipelines, and those reserved for military or research purposes.

An article by the German Institute for Economic Research references a study from 2017 stating that Germany's marine area offers a practical potential of 84 GW of offshore wind energy capacity (Deutsches Institut für Wirtschaftsforschung 2018). A similar capacity potential of 82 GW is identified by a 2022 study from Fraunhofer IWES. In this scenario, Germany could receive an annual power yield of 292 TWh (Fraunhofer-Institut für Windenergiesysteme 2022).

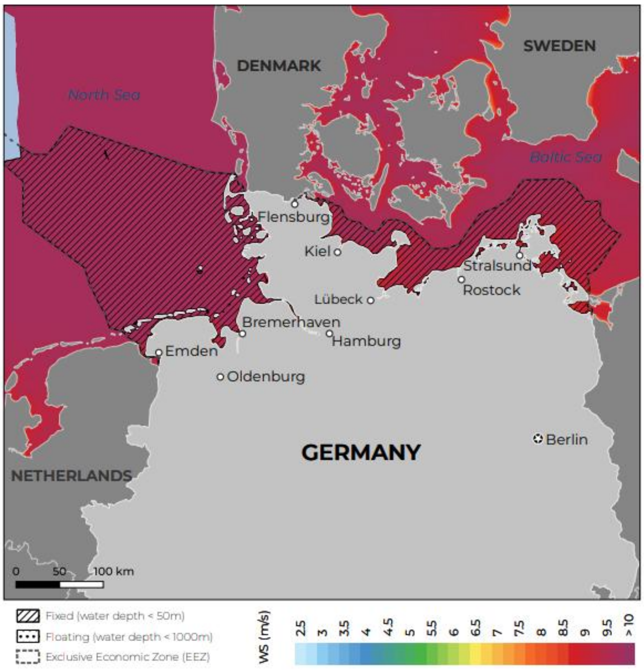

Figure 5: Offshore wind energy potential in Germany

Maps obtained from Global Wind Energy Council (2021) under: https://www.gwec.net/policy/offshorewind/oreac#technicalresourcesmap

Agora Energiewende states that most net-zero scenarios for Germany assume an installed offshore wind energy capacity of between 50 and 70 GW by 2050, generating some 200 to 280 TWh per year. Increasing the capacity further would lead to decreasing yields because the winds would be unable to regenerate due to the smaller spaces in between wind parks (Agora Energiewende et al. 2020).

As various scenarios have indicated, achieving Germany's net-zero target would require generating between 190 and 280 TWh per year from offshore wind energy (Stiftung Klimaneutralität 2022). Some of the studies analyzed above suggest that the existing practical potential could even allow for a slightly larger expansion

4.3.2 Japan

Japan's offshore wind energy potential is listed among the highest in the world, with both floating and bottom-fixed technologies considered. The country's steeply shelving coastlines mean that floating offshore wind offers enormous long-term opportunity.

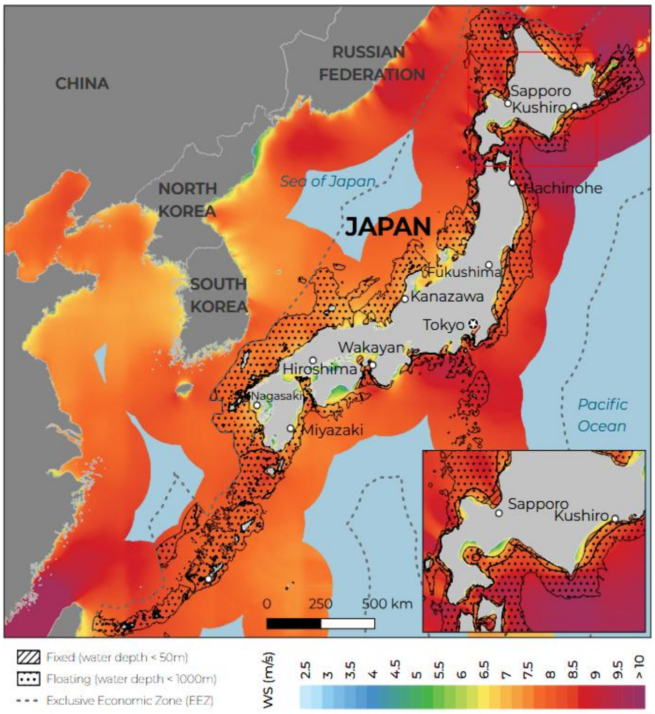

Figure 6: Offshore wind energy potential in Japan

Maps obtained from Global Wind Energy Council (2021) under: https://www.gwec.net/policy/offshorewind/oreac#technicalresourcesmap

The Global Wind Energy Council (GWEC) estimated in its global offshore wind report 2022, that there is potential for around 128 GW capacity for fixed bottom projects in shallow waters, and 424 GW for floating offshore wind in deeper waters. This was based on data from the NEDO offshore wind information system, without giving further details on the methodology. The IEA estimated in 2019 that Japan's total technical potential for offshore wind generation is over 9,000 TWh/year, with the majority of the technical potential in the EEZ (International Energy Agency 2019; Zero Carbon Analytics 2023).

The study by Cheng et al. provides a more comprehensive assessment of Japan's technical offshore wind potential. Using a detailed geographic information system (GIS)-based resource assessment the analysis highlights that the majority of Japan's future offshore wind capacity will need to be based on floating wind turbines in the EEZ. The authors find that Japan possesses offshore wind resources vastly exceeding its national electricity needs. The study concludes that Japan has 14 times more solar and offshore wind resources than required to supply 100% renewable electricity for the country, even when accounting for technical and spatial constraints. Areas considered optimal for the development of offshore wind in the study were typically 30 km from the coast, with annual mean wind speeds of 7.5 m/s at 150 m hub height and sea depths of 100 m. The total technical offshore wind potential for these high-scoring sites is estimated at 2,138 GW, equating to 8,428 TWh of annual electricity (Cheng et al. 2022).

According to the Japan Wind Power Association (JWPA), Japan's total, technical offshore wind potential is approximately 552 GW, comprising bottom-fixed potential of ~128 GW (water depth 10-50m) and floating potential of ~424 GW (water depth 100-300m). The bottom-fixed capacity breaks down to 55.1 GW in 7.0-7.5 m/s wind speeds, 42.8 GW in 7.5-8.0 m/s, and 22.5 GW in 8.0-8.5 m/s, whilst floating capacity includes 86.4 GW in 7.0-7.5 m/s wind speeds, 197.8 GW in 7.5-8.0 m/s, and 84.7 GW in 8.0-8.5 m/s, with the remaining capacity located in areas with wind speeds between 8.5-9.5 m/s. The analysis assumes annual average wind speeds of 7.0 m/s or higher and minimum project capacity of approximately 120 MW per project. The analysis represents an update from JWPA's February 2018 assessment which estimated bottom-fixed potential at ~91 GW based on 10-40m water depths, which were now expanded to 10-50m (Japan Wind Power Association 2020).

A 2024 analysis by the Mitsubishi Research Institute (MRI) provides one of the most detailed breakdowns of technical and practical potentials. According to MRI, Japan's total technical offshore wind potential is 70 GW for fixed-bottom and 2,396 GW for floating turbines. When considering only areas suitable for low-cost generation, below 10 yen/kWh (around 0,06 EUR/kWh), the practical potential is 70 GW for fixed-bottom and 1,477 GW for floating by 2050. These figures incorporate natural factors such as wind speed and water depth, as well as social and economic constraints like shipping lanes and fishing rights. The report highlights that Japan's national targets, 30–45 GW by 2040, represent only a small fraction of this vast technical resource (Mitsubishi Research Institute, Inc. 2024).

The Renewable Energy Institute (REI) conducted a comprehensive geospatial analysis, providing estimates of technical offshore wind energy potential based on wind speed and water depth conditions for sea areas where both datasets are publicly available. The analysis stressed that actual project development must consider natural and social environmental conditions, local community agreement particularly from fishing industries, detailed meteorological and oceanographic investigations, environmental impact assessments, and maritime spatial planning considerations. Therefore, at least a business feasibility criterion in the study sets minimum wind speed thresholds: ≥7.5 m/s annual average for bottom fixed and ≥8.0 m/s annual average for floating, to reflect the increased costs. For fixed-bottom offshore wind (water depth <50m), this resulted in an impressive 176 GW potential in the territorial sea with wind speeds ≥7.5 m/s, or 81 GW with wind speeds ≥8.0 m/s. For floating offshore wind (water depths 50-200m), the potential varies significantly by area and wind speed criteria. In the territorial sea only, the potential is 381 GW (wind speed ≥8.0 m/s). When expanded to territorial sea plus contiguous zone (12 nautical miles from the territorial sea into the EEZ), this increases to 542 GW (wind speed ≥8.0 m/s). The study estimates that fixed-bottom development of 50 GW would achieve an average capacity factor of 40.1%, generating approximately 175.6 TWh annually, while floating development of 100 GW (50-200m depth) would achieve an average capacity factor of 43.0%, generating approximately 376.9 TWh annually (Renewable Energy Institute 2023a).

Despite these impressive technical and partially practical potentials, realizing Japan's offshore wind ambitions is hampered by several interlinked challenges. The permitting and consenting process for new projects is often lengthy and complex, with timelines of three to five years not uncommon, due to the need for consensus among local governments, fishing communities, and other stakeholders. Grid integration is another major barrier, as Japan's transmission infrastructure is fragmented and often insufficient to absorb large volumes of new offshore wind generation, particularly in remote coastal regions. Moreover, the strong legal protection of fishing rights under Japanese law means that developers must engage in extensive negotiations and may face demands for compensation or even legal challenges from local fisheries. High capital and operational costs, especially for floating wind technology, and the need for ongoing technological innovation and supply chain development further add to project risks and uncertainties. Addressing these challenges will require not only regulatory streamlining, but also significant investment in grid upgrades and the creation of robust coexistence frameworks with marine users (Coca 2024; DLA Piper 2025).

4.4 Comparison

Germany benefits from high average offshore wind speeds of 9–10 m/s in its marine areas, making it highly suitable for efficient fixed-bottom offshore wind installations. However, its marine area is relatively small, at about 57,000 km², with almost half under environmental protection. In contrast, Japan has a vast marine area of approximately 4.47 million km², around 78 times the size of the German marine area, but average wind speeds are slightly lower at 7–9 m/s (with some areas reaching up to 9.5 m/s). Due to Japan's steeply shelving coastlines, a significant share of its offshore wind potential lies in deep waters, making floating wind technology essential for large-scale expansion.

Germany's technical offshore wind potential is estimated at up to 203 GW (940 TWh/year). However, practical potential is much lower due to spatial constraints, with estimates ranging from 50 to 84 GW—closely matching the government's target of 70 GW by 2045. Japan's technical offshore wind potential is vast, with studies suggesting up to 2,396 GW for floating turbines and 70–128 GW for fixed-bottom, equating to several thousand TWh/year. The practical potential, considering economic and spatial constraints, is estimated at 70 GW for fixed bottom, which is similar to the estimates for Germany, and 1,477 GW for floating turbines by 2050.

By the end of 2024, Germany had installed 9.2 GW of offshore wind capacity. The government has set targets for 30 GW by 2030, 40 GW by 2035, and 70 GW by 2045, but has announced that these targets will be revised in light of lower than previously projected electricity demand in the coming years. Japan's installed offshore wind capacity remains modest, with 253.5 MW operational as of early 2025. However, project pipelines are expanding rapidly, with government targets of 10 GW by 2030 and 30–45 GW by 2040. Recent legislative changes, such as opening the EEZ for offshore wind, are expected to accelerate deployment, particularly of floating wind farms.

Germany's main limitations are spatial, with large, protected areas restricting further expansion. Japan's challenges are more technical and regulatory, including the need for floating wind technology, lengthy permitting processes, grid limitations, and the necessity to negotiate with established marine users such as fisheries. Japan's offshore wind potential far exceeds its governmental targets as well as its current and projected electricity needs, while Germany's practical expansion is largely limited by available marine space.

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5 List of Figures