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A study on level of possible conflict for developing offshore wind energies in Japanese territorial waters

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Abstract:

This study identified suitable areas within Japanese territorial waters for offshore wind energy, which could be considered to become "promising zones" recognized by a legal framework effected in 2019, and areas within these zones reflecting possibilities to face a few conflict with fishery groups, shipping agents, and local residents (minor conflict areas). Geographic Information System (GIS) analysis revealed that areas suitable for promising zones recognized by the legal framework covered 53,665 km^2 or 12% of Japanese territorial waters. However, when community concerns regarding the seascape, conflicts with fishery rights and shipping routes are comprehensively considered, the minor conflict areas are considerably limited especially for bottom-fixed wind turbines in nearshore areas. When the following conditions are considered; (a) the distance from shore is more than and equal to 10 km, (b) the shipping density is less than 3 ships/month, (c) not covered by fishery rights, the total area of minor conflict areas was only 7,213 km^2 or 2% of Japanese territorial waters. These areas correspond to a potential installation capacity of up to 5.3 GW for bottom-fixed and 37.9 GW for floating wind turbines. Although offshore wind energies are to play a vital role in reducing greenhouse gas emissions, when a target for offshore wind capacity is established in the future, consideration of a realistic target should be undertaken by taking into account areas with less concern for conflicts.

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1. Introduction

Based on the Paris Agreement, the Japanese government has set a target of reducing greenhouse gas emissions by 80% by 2050 [1]. In 2018, the Japanese Ministry of Economy, Trade and Industry renewed the country's medium- and long-term energy policy, called the "Strategic Energy Plan," and stated that photovoltaic and wind energy systems will be expanded to provide the nation's "main power supply" [2]. Because Japan is an island country, offshore wind energy is expected to play a major role in realizing this objective.

In 2019, Japan had an offshore wind energy capacity of 4.39 MW installed in harbors under the jurisdiction of the Port and Harbor Act [3]. However, there were no unified rules for the development of offshore wind energy systems in territorial waters outside harbors. Consequently, "the Act of Promoting Utilization of Sea Areas in Development of Power Generation Facilities Using Maritime Renewable Energy Resources" (hereinafter, the Act) came into effect in April 2019 [4]. The Act establishes a framework for coordination with stakeholders, allowing the development of "promotion zones" (*sokushin kuiki*) within territorial waters within 12 nautical miles (22.2 km) to enable 30 years of use by offshore renewable energy facilities. Under the current legal framework, including the Act, designating promotion zones requires two steps: (i) determining the "promising zones" (*yubo na kuiki*), which are candidate areas for future promotion zones according to the Act requirements (e.g. natural conditions, conflicts with shipping routes, connectivity to the electricity grid), and the opinions of a neutral third-party committee including academic standings, and; (ii) designating promotion zones from promising zones, which first requires gaining consent in a council consisting of local stakeholders such as fishery groups, shipping agents, second consulting ministers of the relevant departments, and mayors of the relevant municipalities.

The Act is expected to increase offshore wind energy systems in Japanese territorial waters by making the approval processes more efficient. However, in the process of (or after) designating these promotion zones, social conflicts have already arisen. For example, local residents or fishery groups have opposed the development of a promotion zone near Yurihonjo City, citing concerns regarding the seascape, noise, fisheries, and leisure use (e.g. surfboarding) [5]. An offshore wind energy project in Shimonoseki is yet to commence due to a lawsuit raised by a fishery group, despite initial planning occurring in 2009 [6]. As seen by these examples, if local stakeholders do not support nearshore wind projects, promotion zones may not be smoothly designated. Therefore, it is essential to identify the areas with a likelihood of facing several conflicts with stakeholders to smoothly coordinate interests for designating promotion zones. Furthermore, it is also important to clarify the extent of the areas that are available toward an ambitious target of reducing greenhouse gas emissions.

To date, studies have assessed offshore wind energy potential globally [7], and in Europe [8], Africa [9], the UK [10], Ireland [11], China [12]-[13], the US [14]-[16], India [17]-[18], Thailand [19], Hongkong [20], Brazil [21], and Turkey [22] by considering area-specific constraints. In Japan, the Ministry of Environment (MOE) [23] determined that there are potential capacities of 332 GW for bottom-fixed wind turbines and 1,081 GW for floating wind turbines in an area of 141,276 km^2, excluding marine parks and locations where the average wind speed is < 6.5 m/s, locations that are ≥ 30 km from shore, and locations where the water depth is ≥ 200 m. Moreover, the International Energy Agency (IEA) [24] assessed a huge technical potential for Japan (9,074 TWh/year) of offshore wind energy in areas where the distance to the shore is 20–300 km and the water depth is > 1,000 m. This is approximately 10 times Japan's annual electricity demand in 2018 (896.5 TWh/year) [25]. Yamaguchi and Ishii [26] determined that the total potential for offshore wind energy along the coast within 30 km of the Kanto region was 287 TWh/year. Although these previous studies assessed the massive potential for offshore wind energy in Japan, they did not necessarily reflect the requirements of the Act, as they included installations outside Japanese territorial waters (i.e., > 22.2 km from shore) where the Act does not apply. Furthermore, these studies did not comprehensively consider conflicts with stakeholders such as fishery groups, shipping agents, and local residents.

Giving these facts, this study aimed to identify potential promising zones recognized by the Act and areas within these zones with a likelihood of facing several conflicts with fishery groups, shipping agents, and local residents. The results can be used for recognizing areas where it is expected to be less difficult to coordinate the interests of stakeholders, and for determining an appropriate target for offshore wind energy capacity. These stakeholder groups are especially important in designating promotion zones because they join councils or have previously opposed offshore wind projects in some areas. This study defined "potential promising zones" as areas covered by the requirements by the Act, and possible areas to become promising zones as candidate areas for future promotion zones. To understand offshore wind energy capacities with the likelihood of local acceptance, this study used a geographic information system (GIS) to estimate and visualize the total area available for offshore wind energy generation in Japan, selected only Japanese territorial waters within 22.2 km, and considered the legal constraints of the Act.

The remainder of the paper is structured as follows: Section 2 summarizes a procedure and estimation method for determining potential promising zones and minor conflict areas; section 3 defines the constraints in determining potential promising zones based on requirements of the Act, and assesses the levels of conflict within potential promising zones; section 4 presents the results and discussions, and; section 5 concludes with key findings and areas for future research.

2. Methods

2.1. Procedure for determining minor conflict areas

The following three steps were employed to identify potential promising zones recognized by the Act and areas within these zones with a likelihood of facing several conflicts with fishery groups, shipping agents, and local residents (Fig. 1). First, the Act specifies that only Japanese territorial waters should be selected for consideration. Some European countries, including the UK [27], Germany [28], and the Netherlands [29], permit the development of offshore wind turbines in the contiguous zone or exclusive economic zone (EEZ) outside their own territorial waters. However, the Act does not cover the Japanese contiguous zone and EEZ. Hence, this study focused on Japanese territorial waters, which are within 12 nautical miles (22.2 km) of the shore.

Second, the Act [30] requirements specify that non-conforming areas, i.e., areas not covered under the Act or guidelines (see details in subsection 3.1), should not be considered. Therefore, non-conforming areas were excluded from territorial water areas. The remained areas were defined as potential promising zones which could be designated to be promotion zones if consent from council members can be obtained.

Third, the potential promising zones were classified into three levels, depending on the degree of difficulty in gaining consensus with fishery groups, shipping agents, and local residents: (A) Major conflict area, (B) moderate conflict area, or (C) minor conflict area (see details in subsection 3.2). For this classification, this study considered fishery rights, shipping density, and the distance from shore. Among this classification, this study focused on minor conflict areas, where it is expected to be less difficult to coordinate stakeholder interests for designating promotion zones.

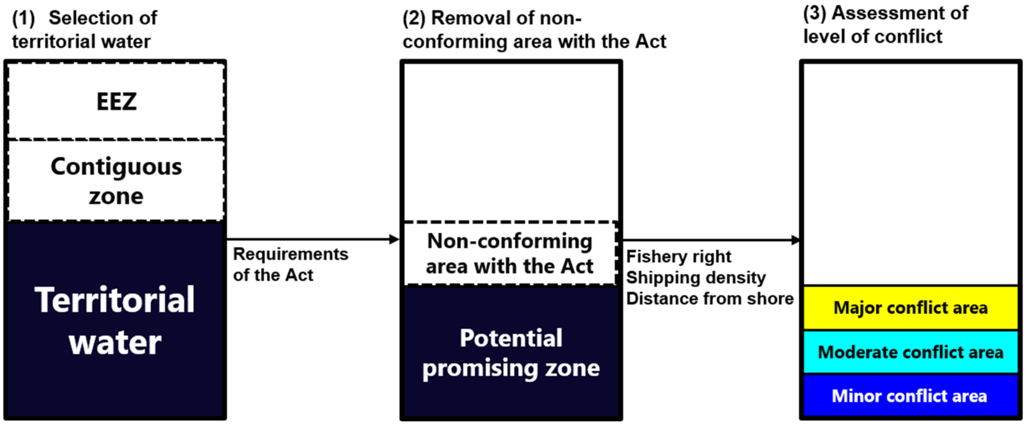


Fig. 1. Procedure for identifying potential promising zones and minor conflict areas.

2.2. Estimation method using a GIS-based approach

A GIS-based (ArcGIS Pro 10.6) approach was used to estimate the total area of the potential promising zone and the minor conflict areas; previous studies have used this approach to investigate offshore wind energy potential [7]-[23]. Japanese territorial waters were divided into a grid cell separated by 15 and 22.5 arcseconds for latitude and longitude, respectively. Each side of the grid cell was approximately 500 m long, with an area of approximately 0.25 km^2. Using public GIS data, seven data types were included for each grid cell (Table 1): (i) water depth, (ii) wind speed, (iii) shipping density, (iv) distance from shore, (v) legal area, (vi) nearest prefecture, and (vii) transmission network area developed by any of the ten general transmission and distribution business operators in Japan (Fig. 2). Using these data, the total area of the potential promising zone and the minor conflict areas were estimated.

Table 1. Data used in geographical information system (GIS) analysis.

Category	Type	Notes	Base data
Water depth	Numerical	Average water depth within the grid cell.	JODC-Expert Grid data for Geography [31]
Wind speed	Numerical	Annual average wind speed at 100 m.	Wind map “NeoWins” [32]
Shipping density	Numerical	Total number of passed ships with an automatic identification system (AIS) from Jan. 2014 to Dec 2014 within each grid cell.	AIS data (latitude/longitude) supplied by the Japanese Maritime Safety Agency
Distance from shore	Numerical	Minimum distance from the center of each grid cell to shore.	-
Legal area	Binary	Existence of legal area in grid cell (Y or N).	Costal lines [33] Natural park [33] Fishery right [33] Military training area [34]
Prefecture	Text	Nearest prefecture to the center of each grid cell.	-
Transmission network area	Text	Nearest transmission network area owned by any of the ten power transmission and distribution business operators to each grid cell.	-

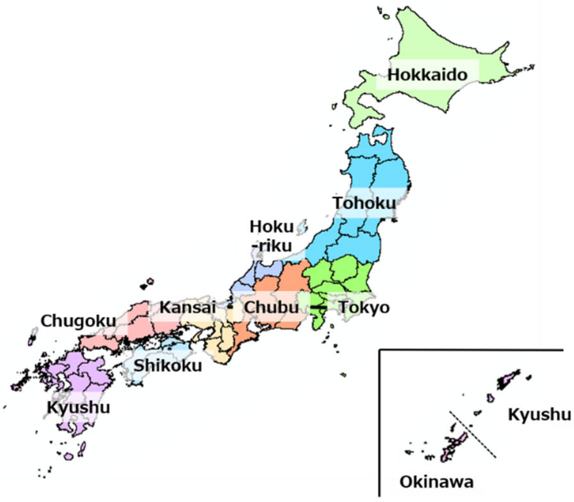


Fig. 2. Japanese electricity transmission network.

3. Assumptions

3.1. Areas conforming with the Act requirements

The Act sets several requirements for identifying promising zones, and refer to natural conditions, conflicts with shipping routes, and connectivity to the electricity grid. The Japanese Ministry of Economy, Trade and Industry and the Ministry of Land, Infrastructure, Transport and Tourism published guidelines to interpret each requirement [30]. The non-conforming areas were identified by referring to the requirements in both the Act and the guidelines (Table 2).

Regarding the requirements of natural conditions (the Act, Art.8 Para.1 [1]), the guidelines specify that offshore wind energy projects could have business feasibility in areas where the average wind speed is ≥ 7 m/s. The guidelines also recommend the use of the wind map "NeoWins" developed by the New Energy and Industrial Technology Development Organization (NEDO) [32]. Consequently, NeoWins data was used in this study to remove areas where the annual average wind speed is < 7.0 m/s. Notably, this threshold differs from those used in previous studies, for example, the MOE (6.5 m/s) [23] or WindEurope (8.0 m/s) [8].

Areas with water depths ≥ 200 m were also excluded, corresponding to the threshold determined by the MOE [23]. This is the approximate depth of the continental shelf, and water depths increase markedly past this point. While the guidelines specify that current bottom-fixed offshore wind projects will be profitable in areas where the water depth is < 30 m, in this study it was assumed that floating wind turbines will be installed in the future. Indeed, the promotion zone in Goto City has been established in an area where the water depth is ≥ 100 m in anticipation of floating wind turbines.

Requirements regarding the hindrance of shipping routes and the use of harbors (the Act, Art. 8 Para. 1 [2]) specify that areas where large vessels often pass should be avoided and that a suitable interval between the shipping route and the promising zone is required. With this in mind, the study removed areas where the shipping density in a grid cell, defined by vessel traffic with an automatic identification system (AIS), was ≥ 31 ships/month (approximately 1 ship/day). Based on the International Convention for the Safety of Life at Sea (SOLAS), all passenger and non-passenger ships between 300–500 gross tons (i.e. medium–large vessels) are obliged to install an AIS. Several Japanese municipalities have conducted spatial planning for offshore wind turbines via demonstration projects by the MOE. However, the shipping density threshold used in the planning varied among projects. For example, Shinkamigoto Town [35] and Saikai City [36] excluded areas where the shipping density was ≥ 21 ships/month, whereas Aomori Prefecture [37] excluded areas with ≥ 31 ships/month. Notwithstanding, ≥ 31 ships/month was the maximum threshold among all zoning maps created prior to 2019. Spatial planning by Shinkamigoto Town considered an interval of 254 m from the area where vessels pass by estimating a turbine collapse impact zone [35]. Based on these assumptions, grid cell spaces where the shipping density was ≥ 31 ships/month were removed from consideration in this study.

Areas around isolated islands that are independent of the main electricity grid (the Act, Art. 8 Para. 1 [4]), the coastal preservation area (the Act, Art. 8 Para. 1 [6]), natural parks (the Act, Art. 3), and military training areas (the Act, Art. 3) were also excluded. The assumptions based on the Act are summarized in Table 2.

Table 2. Areas legally excluded from the potential promising zone.

Excluded area	Requirements in the Act	Description in guideline
Average annual wind speed < 7.0 m/s at 100 m	(VIII-1-i) Weather, marine, and natural conditions shall be suitable for generation.	Projects could have business feasibility in areas where the average wind speed is ≥ 7 m/s and where the water depth is < 30 m.
Water depth ≥ 200 m[*1]		
Marine traffic (with AIS) ≥ 31 ships/month within grid cell	(VIII-1-ii) Hindrance to shipping routes or harbor use shall be avoided.	Areas where large vessels often pass shall be avoided and a suitable interval between the area and the suggested promotion zone shall be required.
-[*2]	(VIII-1-iii) Promotion areas and harbors shall be integrally utilized.	Harbors should be within or near promotion areas for efficient installation and operation.
Areas that are isolated from the main electricity grid	(VIII-1-iv) Connection to the electricity grid shall be assured.	Connection to the main electricity grid should be feasible.
-[*2]	(VIII-1-v) Hindrance to fisheries shall be avoided.	Confirmation from fishers in a council including a fishery industry organization is required.
Coastal preservation areas	(VIII-1-vi) Fishing ports[*3], harbors[*3], coastal preservation areas, and low-water line conservation areas[*4] shall not be included.	Confirmation from the heads of administrative organizations is required to ensure these areas do not overlap with the promotion zone.
Natural parks	(III) Offshore wind development shall be harmonized with the marine environment and security needs.	Confirmation from the heads of administrative organizations is required to ensure protection of: (i) the marine environment, (ii) marine security, and (iii) harmonization with other measures or policies.
Military training area		

*1 Assuming the installation of floating wind turbines in the future despite the description in the guidelines.

*2 This study did not establish the excluded area based on requirements in VIII-1-iii and VIII-1-v because of the difficulty in identifying the specific area to be excluded.

*3 Fishing ports and harbors were not removed in this study because these areas are under the legal jurisdiction of the Port and Harbor Act and the Fishing Port Act.

*4 Low-water line conservation areas were not considered because their total area is very small.

3.2. Assessment of conflict level

The levels of conflict within potential promising zones were assessed in this study, and areas were classified as major, moderate, or minor conflict areas. Three stakeholder groups were considered; fishery groups, shipping agents, and local residents (Table 3), as they are especially important to designate promotion zones because they join councils or they have previously opposed offshore wind projects in some areas.

To date, conflicts with local residents have occurred owing to noise or seascape concerns when large promotion zones have been planned nearshore. For example, for a planned 700 MW promotion zone in

Yurihonjo City, the distance to shore is 0–5 km owing to the depth of the water [38]. Consequently, local residents in Yurihonjo City have opposed the development of this promotion zone and require a minimum wind turbine distance of 10 km offshore. Additionally, in Shimonoseki City, a 60 MW offshore wind project 1.5 km from the shore was proposed prior to the Act; local residents opposed the project and required a minimum wind turbine distance of 10 km offshore [39].

Therefore, the levels of conflict with local residents according to the distance from the shore were investigated in this study. Previous studies have shown that the required distance to alleviate seascape concerns is greater than that of noise concerns [35], [36]; consequently, the conflict threshold distance was determined based on seascape concerns. In an MOE guidelines, the effect on the seascape can be theoretically described using the visual angle from the shore to the top of the wind turbine. The guidelines specify that wind turbines can negatively affect the seascape when the visual angle is > 1–2º [40]. Accordingly, it is possible that a 180-m high offshore wind turbine installed 5–10 km offshore could negatively affect the seascape. Although the height of offshore wind turbines varies, current planned turbines in each promotion zone are large turbines of up to 10 MW. Therefore, in this study, areas at distances of 0–5, 5–10, and > 10 km offshore were defined as major, moderate, and minor conflict areas, respectively. This classification is supported because local residents in Yurihonjo City and Shimonoseki City required a minimum wind turbine distance of 10 km offshore. Furthermore, data from other countries has shown that most conflict with local residents mostly occurs when offshore wind projects are proposed within 10 km of the shore [41].

As for conflict with shipping agents, areas where the shipping density is ≥ 31 ships/month were excluded from potential promising zones; however, areas where marine traffic is less dense may still pose a concern. For example, Shinkamigoto Town and Saikai City excluded areas where the shipping density is ≥ 21 ships/month following consultation with the coast guard [35], [36]. Moreover, regular weekly vessels may pass in areas where the shipping density is ≥ 4 ships/month. Accordingly, marine traffic areas with a density of 21–30 ships/month were specified as major conflict areas in this study, whereas areas with a density of 4–20 and 0–3 ships/month were classified as moderate and minor conflict areas, respectively.

Quantifying the level of conflict with fishery cooperatives has previously been carried out using the “marine product catch” as an indicator [40]; however, owing to a lack of data, this study quantified the conflict level according to fishery rights. In Japan, fishers have a strong legal basis to refuse the developments in areas covered by fishery rights based on the Fishery Act. For example, fishers have the right to claim losses caused by developments and to seek injunctions over the development. Therefore, it is impossible to establish promotion zones in areas covered by fishery rights without consent from fishers. In some planned promotion zones, compensation for fishery cooperatives based on the electricity generated by offshore wind projects has been proposed [42]. However, such compensation will raise project costs, and the surcharge collected from electric consumers through feed-in tariffs (FIT) will be indirectly utilized for local fishery cooperatives. While it is possible to establish promotion zones using compensation, careful consideration regarding the funding source will be required. However, the rights maintained by fishers under the Fishery Act may make it difficult to gain consent from fishery cooperatives. With this consideration, areas covered by fishery rights were specified as major conflict areas in this study.

Table 3. Conflict level classifications within potential promising zones.

	Distance	Shipping density	Fishery rights
Major conflict	0–5 km (visual angle: > 2°)	21*–30 ships/month	Inside fishery rights
Moderate conflict	5–10 km (visual angle: 1–2°)	4–20 ships/month	None (all fishery rights related
Minor conflict	> 10 km (visual angle: < 1°)	0–3 ships/month (< 1 ship/week)	conflicts area considered to be major conflict area)

* Corresponds to the threshold set by local spatial planners in Shinkamigoto Town based on consultation with the coast guard.

3.3. Offshore wind turbine technological assumptions

The type of foundation used for offshore wind turbines differs depending on water depth and can generally be classified as either bottom-fixed or floating [43]. In this study it was assumed that bottom-fixed wind turbines are installed in areas where the water depth is < 60 m, whereas floating wind turbines are installed in water depths between 60–200 m. Floating wind turbines are currently at the demonstration stage and have been demonstrated in water depths of 100 m and 120 m in Goto City [44] and Fukushima [45], respectively.

Offshore wind turbines are arranged at intervals to reduce wake loss and maximize plant level profitability. In this study, an installation density of 6.0 MW/km^2 was used, based on the actual average installation density in the North Sea [46]. During this study it was noticed that the natural conditions differ between Japanese territorial waters and the North Sea; however, as there are very few installed offshore wind systems in Japan, the layout in the North Sea was used as a reference. This installation density differs from previous studies regarding offshore wind energy potential. For example, WindEurope assumes an installation density of 5.36 MW/km^2 based on 212-m high turbines spaced over $9D\times6D$, where D is the diameter of turbine [8]. Furthermore, Musial [14] assumed a density of 5.1 MW/km^2 based on a 155-m rotor diameter spaced over $7D\times7D$, whereas the Japanese MOE [23] uses 10 MW/km^2 based on 1-MW turbines spaced over $10D\times3D$ and onshore wind turbine configurations. The turbine size assumed by the MOE is considerably smaller than that of current offshore wind turbines, and offshore wind conditions differ significantly to those onshore. Consequently, a smaller installation density was used in this study than that used by the MOE. Based on the above, technological assumptions of offshore wind turbines including installation density, exclusion areas, and potential conflict area are summarized in Table 4.

Table 4. Offshore wind turbine technological assumptions.

Exclusion (non-conforming area with the Act)		Annual average wind speed < 7.0 m/s Water depth ≥ 200 m Shipping density ≥ 31 ships/month Isolated area from the main electricity grid Natural park Coastal preservation area Military training area
Potential conflict area	Major	Inside fishery rights (all fishery rights related conflicts area considered to be major conflict area) Shipping density 21–30 ships/month Distance from shore 0–5 km
	Moderate	Shipping density 4–20 ships/month Distance from shore 5–10 km
	Minor	Shipping density 0–3 ships/month Distance from shore > 10 km
Installation density		6.0 MW/km^2

4. Result and discussions

4.1. Potential promising zones

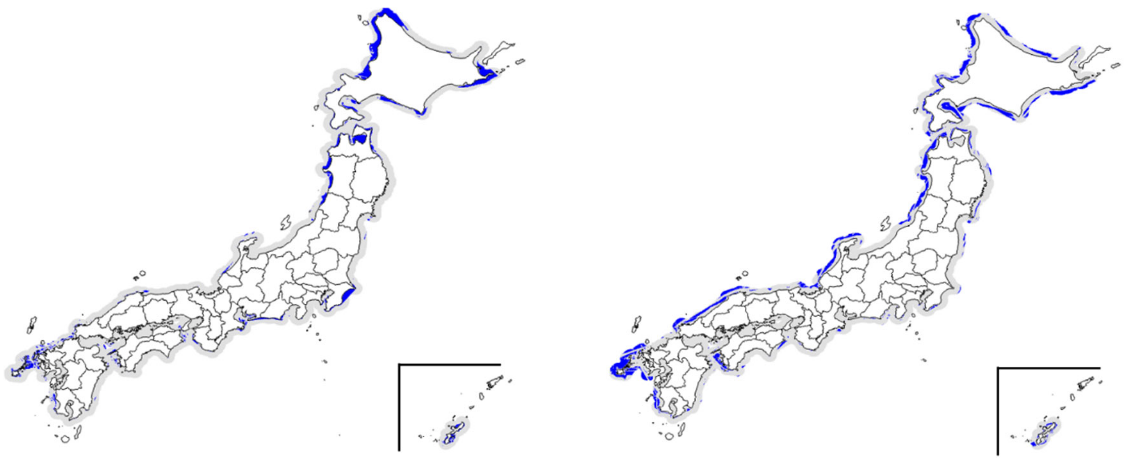
Using a GIS-based approach, potential promising zones and exclusion areas based on the Act were estimated (Table 5) using GIS data for areas 50 km from the major Japanese islands. Areas isolated from the main electricity grid (approximately 220,000 km^2) occupied over half of the total area of Japanese territorial waters (approximately 430,000 km^2 [47]). Furthermore, if the non-conforming area is removed (156,333 km^2), the remaining potential promising zone is 53,665 km^2, or 12% of Japanese territorial waters.

Fig 3 highlights the potential promising zone around Japan. Areas with water depths < 60 m are primarily concentrated around Hokkaido, Tohoku, Tokyo, and Kyushu and comprise a total area of 22,372 km^2. Areas with water depths between 60–200 m equate to a total area of 31,293 km^2. Based on the assumptions used in this study, these areas have potential installation capacities of up to 134.2 GW for bottom-fixed and up to 187.8 GW for floating wind turbines; the total capacity (322.0 GW) is only one-fifth of the possible installation capacity determined by the MOE (1,413 GW) [23]. These differences can be attributed to the altered thresholds of the maximum distance from shore (30.0–22.2 km), minimum annual average wind speed (6.5–7.0 m/s), and maximum shipping density (0–31 ships/month), considering the requirements of the Act. However, it is unrealistic to assume complete installation in potential promising zones, especially when possible social conflicts, economic restrictions, and grid access are considered.

Table 5. Breakdown of Japanese territorial waters in terms of suitability for offshore wind promotion [km^2].

Area	Water depth			Total
	0–60 m	60–200 m	≥ 200 m	
Potential promising zones	22,372	31,293	0	53,665
Excluded areas* (except for near isolated islands)	68,713	45,437	42,182	156,333
Annual average wind speed < 7.0 m/s	53,600	18,333	5,725	(77,658)
Water depth ≥ 200 m	-	-	42,182	(42,182)
Shipping density ≥ 31 ships/month	22,499	32,003	18,287	(72,789)
Coastal preservation area	4,704	44	2	(4,749)
Military training area	462	474	1,536	(2,472)
Natural parks	14,361	1,062	82	(15,505)
Excluded area (near isolated islands)	(approximately 220,000)			
Total	(approximately 430,000)			

*Some areas will overlap.



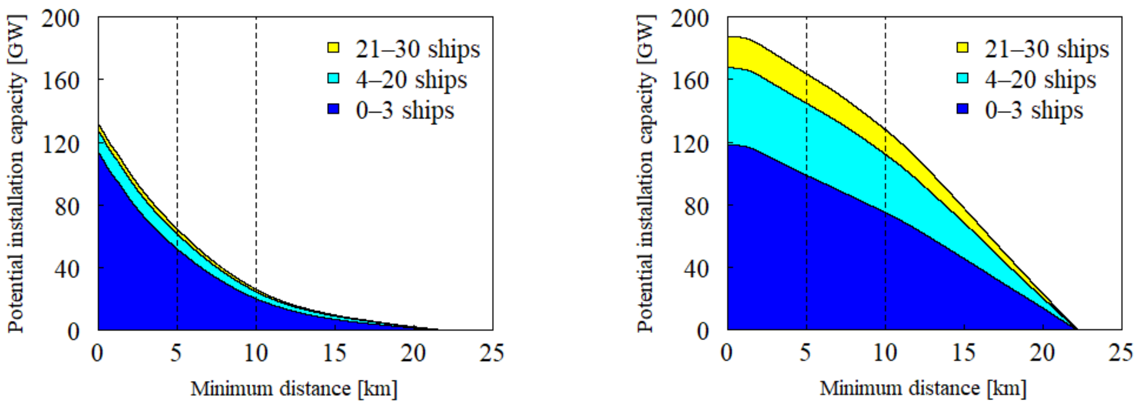
(A) Water depth 0–60 m (22,372 km^2) (B) Water depth 60–200 m (31,293 km^2)

Fig. 3. Potential promising zone for offshore wind energy in Japan according to the requirements of the Act.

4.2. Minimum distance from shore and shipping density

Conflict with local residents is more likely when offshore wind development occurs near the shore. Therefore, in this study, the potential installation capacity was estimated according to a minimum distance from the shore (Fig. 4), which considerably reduces the potential installation capacity of bottom-fixed wind turbines compared to floating wind turbines. In Japan, the water depth increases markedly with distance from the shore. Although the assessed potential installation capacity of bottom-fixed wind turbines is 134.2 GW, only one-quarter of this capacity can be installed if turbines are required to be installed 10 km offshore and with a visual angle slope of < 1° (Fig. 4[A]) as demanded by local residents in Yurihonjo City and Shimonoseki City. Hence, based on a low risk of social conflicts, the development and installation of floating wind turbines is important.

While it is possible to install more floating wind turbines than bottom-fixed wind turbines in areas where the distance from the shore is ≥ 10 km, the areas available for floating wind turbine promotion zones are restricted by marine traffic (Fig. 4[B]). If floating wind turbines are to be installed only in areas where the shipping density is 0–3 ships/month, then the potential installation capacity is reduced by two-thirds. Conflict with shipping agents has not been raised as a critical issue during discussions with councils aimed at determining promotion zones for bottom-fixed wind turbines. However, if floating wind turbines are to be installed in the future, then obtaining consent from shipping agents is likely to be important.



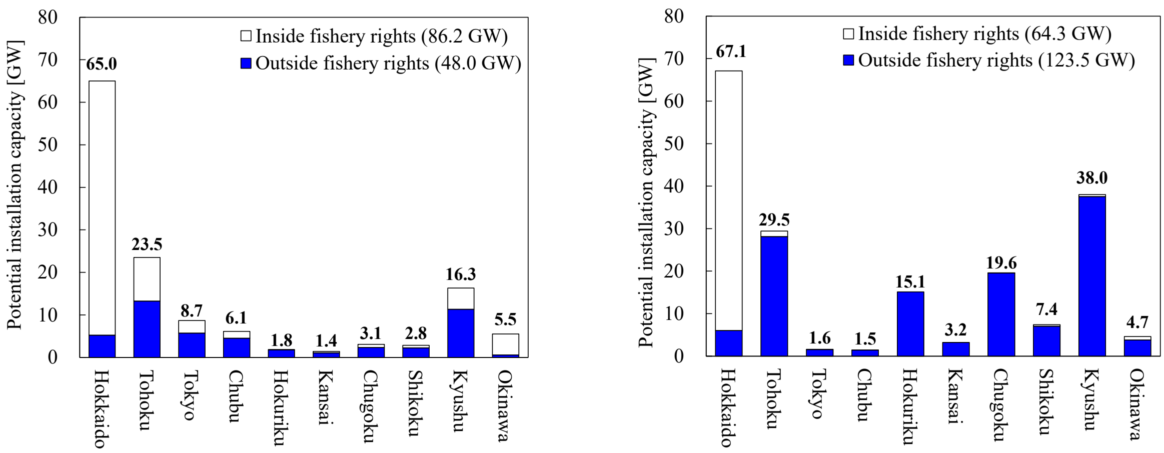
(A) Bottom-fixed wind turbines (B) Floating wind turbines

Fig. 4. Potential installation capacity according to the minimum distance from the shore and monthly shipping density [GW].

4.3. Fishery rights

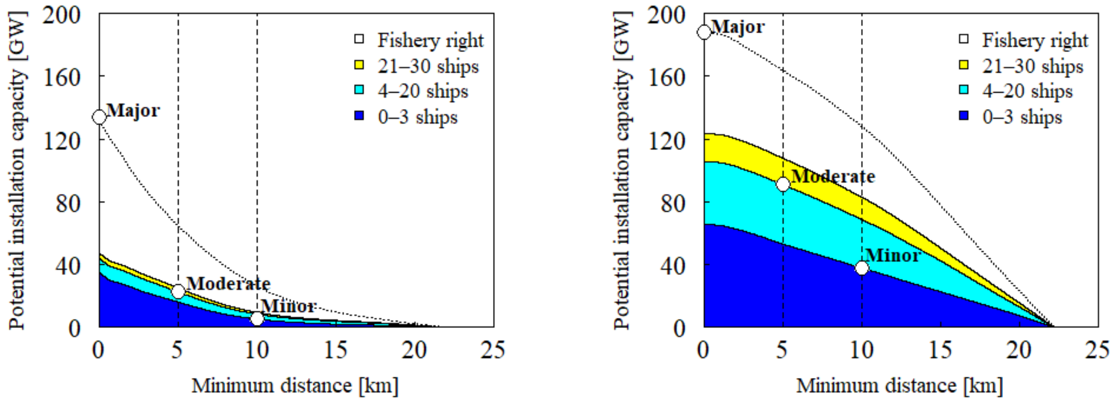
Areas covered by fishery rights were considered to be major conflict areas in this study, and approximately half of all potential promising zones fall into this category. These areas may overlap with nearshore or with high marine traffic areas. Hence, in areas not covered by fishery rights, the total capacities of bottom-fixed and floating wind turbines are 48.0 GW and 123.5 GW, respectively (Fig. 5). Avoiding conflict with fishery cooperatives by not including the area covered under the fishery rights will considerably reduce the potential installation capacity. This issue is of particular concern in Hokkaido as almost all potential promising zones are located in areas covered by fishery rights. If further bottom-fixed or floating wind turbines are to be installed in Japan, it will be necessary to reconcile the interests of fishery groups, particularly in Hokkaido.

With respect to the potential for conflicts with fishery groups, shipping agents, and local residents, potential promising zones for offshore wind capacity in Japanese territorial waters are considerably limited (Fig. 6).



(A) Bottom-fixed wind turbines (B) Floating wind turbines

Fig. 5. Potential installation capacity by transmission network area according to fishery rights [GW].



(A) Bottom-fixed wind turbines (B) Floating wind turbines

Fig. 6. Potential installation capacity according to the minimum distance from the shore, monthly shipping density, and consideration of fishery rights [GW].

4.4. Conflict levels in the potential promising zone

The total area of minor conflict areas is 7,213 km^2, or only 2% of Japanese territorial waters. In these areas, the potential installation capacities for bottom-fixed and floating wind turbines are 5.3 GW and 37.9 GW, respectively (Table 6). If the combined capacities of bottom-fixed and floating wind turbines are converted into annual generated electricity by assuming a capacity factor of 30%, it would result in power generation of 113.7 TWh/year, or 13% of Japan's total annual electricity demand in 2018 (896.5 TWh/year) [25]. Thus, the electricity energy generated in minor conflict areas alone is insufficient to meet current electricity demands. Moreover, the potential installation capacity for bottom-fixed wind turbines in minor conflict areas is considerably low owing to extensive nearshore fishery rights and because the necessary minimum distance from the shore often impedes development. Hence, it is important to develop floating wind turbines based on a low risk of social conflicts.

Fig. 7 shows the conflict levels of potential promising zones spatially. While minor conflict areas for bottom-fixed wind turbines are limited in all areas, there are extensive minor conflict areas for floating wind turbines, particularly in the Tohoku, Hokuriku, and Kyushu areas. However, while the Kyushu area has the largest potential for floating wind turbines in minor conflict areas, the available transfer capacity from Kyushu to Chugoku in 2019 was 2,470 MW [48]. While it is technically possible to transmit electricity to the Chugoku area from offshore wind systems in Kyushu through marine cables, potential promising zones are concentrated on the opposite side of Chugoku across the main Kyushu Island (Fig. 7[B]). Therefore, the issue of transfer capacity needs to be addressed before these areas can be fully utilized.

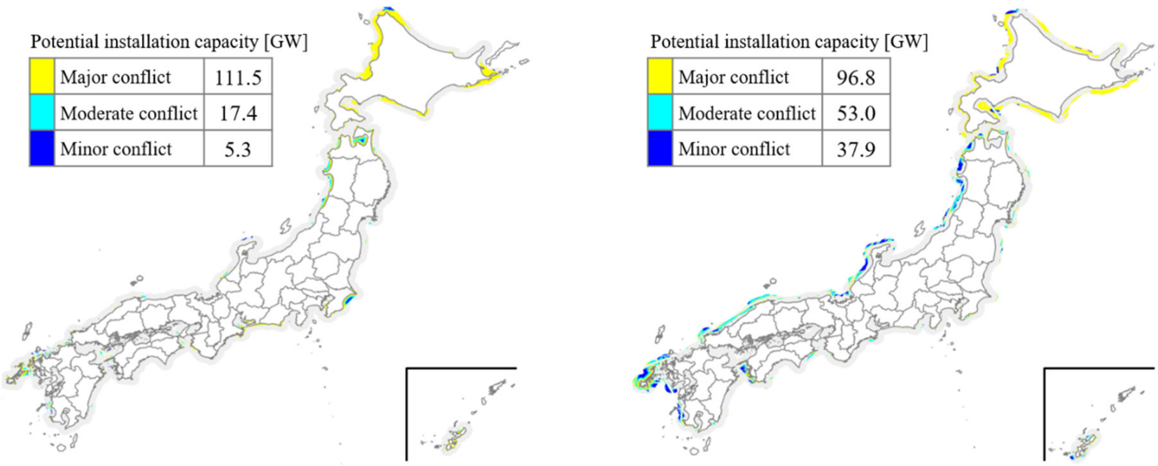
Table 6. Potential installation capacity by transmission network area based on conflict level [GW].

(A) Bottom-fixed wind turbines

	Hokkaido	Tohoku	Tokyo	Chubu	Hokuriku	Kansai	Chugoku	Shikoku	Kyushu	Okinawa	Total
Major	62.7	15.4	5.3	5.5	0.9	1.2	1.9	2.1	11.3	5.2	111.5
Moderate	0.9	7.3	2.2	0.6	0.5	0.2	1.0	0.6	3.9	0.3	17.4
Minor	**1.4**	**0.8**	**1.2**	**0.0**	**0.4**	**0.0**	**0.2**	**0.2**	**1.1**	**0.0**	**5.3**
Total	65.0	23.5	8.7	6.1	1.8	1.4	3.1	2.8	16.3	5.5	134.2

(B) Floating wind turbines

	Hokkaido	Tohoku	Tokyo	Chubu	Hokuriku	Kansai	Chugoku	Shikoku	Kyushu	Okinawa	Total
Major	61.5	8.1	1.3	0.5	3.4	0.9	5.0	2.7	11.6	1.9	96.8
Moderate	1.0	13.1	0.4	0.9	5.8	1.6	12.0	3.1	13.4	1.7	53.0
Minor	**4.6**	**8.2**	**0.0**	**0.1**	**6.0**	**0.8**	**2.6**	**1.7**	**13.0**	**1.0**	**37.9**
Total	67.1	29.5	1.6	1.5	15.1	3.2	19.6	7.4	38.0	4.7	187.8



(A) Bottom-fixed wind turbines (B) Floating wind turbines

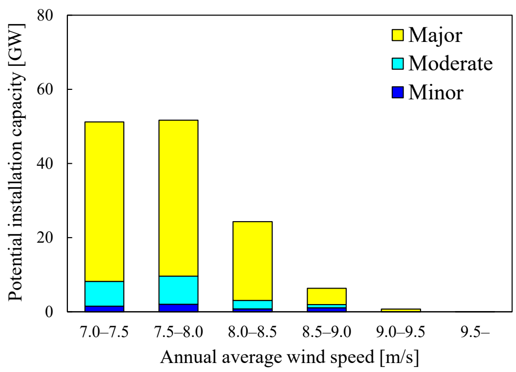
Fig. 7. Spatial distribution of potential promising zones classified according to conflict classification.

4.5. Natural conditions in minor conflict areas

Natural conditions, including average wind speed and water depth, were evaluated in potential promising zones (Fig. 8). Annual average wind speed in the almost all potential promising zones is 7.0–8.0 m/s, which is lower than the areas with offshore wind systems in the UK (approximately > 9.0 m/s [49]). Generally, wind speeds around Japan are lower than those around the UK, even in moderate and major conflict areas.

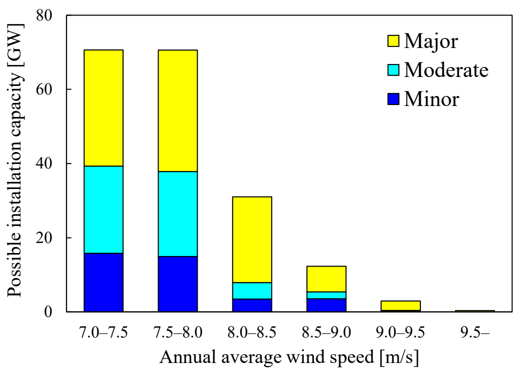
Over 81.5% of offshore wind turbines installed in Europe are mono-pile bottom-fixed wind turbines suitable for water depths of less than 30 m [50]; however, the scope to install such turbines in minor conflict areas is very limited in Japanese waters (Fig. 9). If bottom-fixed wind turbines were to be installed in minor conflict areas around Japan, a more expensive jacket or tripod type mounting system would be necessary.

To accurately determine the feasibility of an offshore wind energy project, detailed cost estimations and collection of wind data are required. However, despite a lack of detailed data for Japanese territorial waters, the results of this study indicate that the business feasibility of offshore wind projects in Japan is lower than in Europe. During deliberations for the Act, a question was raised regarding how to reduce the generation costs of offshore wind projects under the current high Feed in tariffs (FIT) price (36 JPY/kWh) [51]. In response to this question, it was stated that future costs could be reduced by recognizing the importance of suggested subsidy levels when selecting installers. However, the results in this study imply that future costs in Japan will not necessarily converge with international costs even after introducing a FIT auction, owing to the less suited natural conditions. To reduce generation costs in Japan, research and development would be necessary to identify and address key elements required to reduce costs under natural conditions, particularly for water depths of 60–120 m.



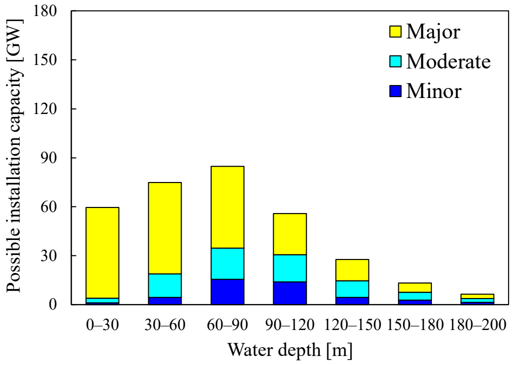
(A) Annual average wind speed

(water depth < 60 m)



(B) Annual average wind speed

(water depth ≥ 60 m)

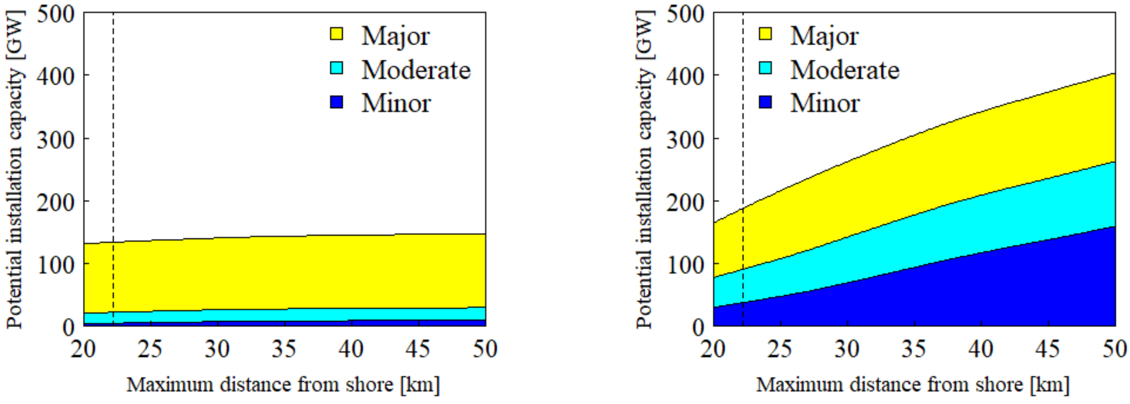


(C) Water depth

Fig. 8. Natural conditions in potential promising zones.

4.6. Possibility of offshore wind energy developments in the contiguous zone and EEZ

The Act currently allows the establishment of promotion zones within Japanese territorial waters. However, this study has shown that suitable minor conflict areas are limited within the areas of the Act. Toward the ambitious target of reducing greenhouse gas emissions, potential installation capacities of offshore wind turbines in minor conflict areas are insufficient to meet the target. This study identified the area that satisfies the requirements of the Act and classified the levels of conflict in areas > 22.2 km (12.2 nautical miles) from the shore (Fig. 9). In areas > 22.2 km from the shore, very few conflicts can be expected as these areas are far from local residents and are not subjected to fishery rights. However, suitable areas for bottom-fixed wind turbines with minor conflicts will not increase considerably because of excessive water depths (Fig. 10[A]). Even if potential promising zones were permitted in the contiguous zone and EEZ to avoid conflict with stakeholders such as fishery groups and local residents, suitable areas will be increased only for floating wind turbines.



(A) Bottom-fixed wind turbines (B) Floating wind turbines

Fig. 9. Potential installation capacity according to the maximum distance from the shore [GW].

5. Conclusions

According to the requirements of the Act, this study identified potential promising zones for offshore wind energy development in Japanese territorial waters and classified these zones based on the potential for conflict with fishery group, shipping agents, and local residents.

Among all Japanese territorial waters (430,000 km^2), potential promising zones occupied 53,665 km^2 (12% of total waters), which is equivalent to 134.2 GW for bottom-fixed wind turbines and 187.8 GW for floating wind turbines at an installation density of 6.0 MW/km^2. However, it is unrealistic to assume the complete installation of offshore wind turbines in promotion zones, particularly when fishery rights, distance from the shore, and shipping density are comprehensively considered. Fishers have a strong legal basis to refuse a project or claim compensation, and approximately half of the potential promising zones are subjected to fishery rights. Furthermore, the potential for conflict with local residents may impede potential promising zones for bottom-fixed wind turbines in nearshore areas. Based on a low risk of social conflicts, the potential installation capacities for bottom-fixed and floating wind turbines in minor conflict areas were estimated at 5.3 GW and 37.9 GW, respectively. Consequently, the development of floating wind turbines will be important for establishing offshore wind energy in Japan.

Minor conflict areas for floating wind turbines exist in the Tohoku, Hokuriku, and Kyushu areas, which are expected to become future potential promising zones based on a low risk of social conflicts. This study highlights issues with the electricity transmission grid, which may need to be addressed before these areas can be fully utilized as the capacity of the interconnection from the Kyushu to Chugoku areas is limited.

Notably, this study did not consider all conflict and focused on fishery rights, shipping density, and distance from shore as especially important factors to determine minor conflict areas in Japan. Future processes to determine promoting zones from promising zones may cause conflicts with other stakeholders. For example, potential promising zones in Hokkaido include areas that may affect marine organisms such as seabirds [52]. Therefore, future work should consider various conflict factors according to future discussions.

To date, a massive potential for offshore wind turbines in Japanese territorial waters has been assessed [23]-[26]. However, by considering the requirements of the Act, this study revealed that the total area of potential promising zones (53,665 km^2) is one-third of the potential offshore wind area assessed by the Japanese MOE. Furthermore, this study showed that minor conflict areas are considerably limited by considering the seascape, conflicts with fishery rights, and shipping routes. Thus, it is important to consider the requirements of the Act and conflicts with these stakeholders when determining offshore wind energy potential.

The Japanese Wind Power Association has set bottom-fixed and floating offshore wind energy targets of 19 GW and 18 GW, respectively, by 2050 [53]. To achieve this target, projects with bottom-fixed wind turbines are likely to face conflict with stakeholders such as local residents or fishery groups. While the Japanese government set a target of reducing greenhouse gas emissions by 80% by 2050, a target for offshore wind capacity to be met by 2050 has not yet been established. Offshore wind energies are expected to play vital roles in reducing greenhouse gas emissions; when the Japanese government is to set a target for offshore wind capacity in the future, it is important to recognize how much area is available with a likelihood of facing several conflicts in developing offshore wind energies.

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