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Review

A Review of Perspectives on Developing Floating Wind Farms

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Abstract: Floating wind is becoming an essential part of renewable energy, and so highlighting perspectives of developing floating wind platforms is very important. In this paper, we focus on floating wind concepts and projects around the world, which will show the reader what is going on with the projects globally, and will also provide insight into the concepts and their corresponding related aspects. The main aim of this work is to classify floating wind concepts in terms of their number and manufacturing material, and to classify the floating wind projects in terms of their power capacity, their number, character (if they are installed or planned) and the corresponding continents and countries where they are based. We will classify the corresponding additional available data that corresponds to some of these projects, with reference to their costs, wind speeds, water depths, and distances to shore. In addition, the floating wind global situation and its corresponding aspects of relevance will be also covered in detail throughout the paper.

Keywords: renewable energy; floating platforms; wind; marine environment; sustainable development

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1. Introduction

Floating wind is currently a leading candidate for renewable energy in many countries around the world, as governments and companies investing large financial resources into developing floating wind projects. The purpose of this paper is to present all the corresponding projects in the world, their implemented wind turbine types, and corresponding concepts, as this will make a very significant contribution to understanding the floating wind situation around the world.

Renewable energy has become essential to respond to the increasing world population, and its corresponding demand for energy. It is also seen as essential to stop the reliance on fuels and eliminate pollution and climate change [1].

Renewable energy is also a way to prevent countries with oil and gas resources from becoming economically and politically dominant over countries that lack these resources [2].

Unlike oil and gas energy, renewable energy is carbon-free and limitless, which makes it the perfect solution to both climate change and population growth [2].

While onshore wind energy is currently the cheapest source of renewable energy, it has weaker and more turbulent wind speeds, compared to its offshore counterpart, which is anticipated to dominate in the years to come. Floating wind projects are therefore expected to be constructed in high water-depth areas [1].

From this perspective, the European Union will need 450 GW of offshore wind by 2050 to achieve its complete decarbonization, a substantial increase on its current corresponding power capacity of 25 GW [3].

The European Union must develop 150 GW of floating wind to be carbon neutral by 2050, which is likely to happen, both due to the available financial resources and the substantial efforts of the specialized floating wind companies [4].

Europe currently has 318 MW of floating wind from 34 corresponding concepts, compared to the rest of the world, which has 32 MW power capacity from 16 concepts. Floating wind cumulative capacity is currently led by the European Union, whose future investments will facilitate its industrialization process and reduce the capital expenditures (CAPEX) of future floating wind projects [4].

In 2030, France plans to have 750 MW of floating wind power capacity, the UK plans to have 1 GW, Norway plans to have 1.5 GW (or 3 GW [5]), and Portugal plans to have 275 MW [6], as compared to current floating wind capacities of 114 MW in France, 80 MW in the UK, 95 MW in Norway, and 30 MW in Portugal. The US currently has 12 MW, and Japan has a 20 MW corresponding power capacity [4].

Floating wind projects will be implemented in areas where their offshore bottom-fixed counterparts are not feasible, due to their corresponding negative assembly impact on the marine environment and limited water-depth capacities. Floating wind projects have exceeding water-depth capacities and have less environmental impact because of their early assembly in the ports. Further, floating wind turbines are on their way toward industrialization, making them cost competitive as compared to their offshore bottom-fixed counterpart [4]. Offshore bottom-fixed turbines are generally limited to water depths of roughly 100 m, while their floating counterparts can be extended to kilometers of water depths.

The conversion of both the existing European infrastructures of oil and gas and bottom-fixed offshore wind will contribute to Europe becoming the world’s floating wind leader. Europe is currently planning to take the lead in the floating wind supply chain areas, which will produce tremendous job creation in field areas that include electrical cabling, mooring, and installation. The outcome will be significant when the floating wind global market obtains 18,000 GW in the future [4].

The floating wind levelized cost of energy (LCOE) will be 250 euros/MWh when the floating wind capacity reaches 0.5 GW and will drop to 50 euros when the floating wind capacity approaches 4 GW in 2030 [7].

Romania has a current installed onshore wind capacity of 3 GW, but it lacks a corresponding electrical infrastructure in sea areas, which is currently the main obstacle to implementing floating wind projects in the country [3], although ongoing efforts are being made in this regard [8]. The solution to the lack of a corresponding offshore electrical infrastructure in Romania is possibly the implementation of Power-to-X technology, which will be used to convert the produced floating wind electrical power (mainly into hydrogen and compressed air) and eliminate the need for a tremendous electrical infrastructure in the sea region.

Figure 1 shows the most widely used bottom-fixed and floating wind turbine concepts, which are bottom-fixed monopile, floating wind spar, semi-submersible, and TLP platforms. More details about these concepts, including their advantages and disadvantages are presented in Section 4 and Table 1.

Table 1. Advantages and disadvantages of the most widely used floating wind concepts. Table data processed by the authors mainly based on the information presented in [9].

Floating Wind Turbine Types	Advantages	Disadvantages
Spar-buoy	Most simple manufacturing, convenient stability	Relatively lower water depth capacity, compared to TLP
Semi-submersible (one turbine)	Most widely used	More complex and difficult manufacturing, less stable, more expensive

Table 1. *Cont.*

Floating Wind Turbine Types	Advantages	Disadvantages
Semi-submersible (multi-turbine)	Reducing the structural materials and corresponding operation and maintenance costs	Relatively more faults, due to the interaction between the loads coming from different turbines on the same support structure, which influences each floater's operation and stability
Barge	Can be made of concrete (feasible for countries with a lack of steel material)	More complex and difficult to manufacture, less stable, more expensive
TLP	Most stable, highest water depth capacity	Most expensive, difficult to install

The following section will present collected data related to global floating wind concepts and installed and planned projects, including further classifications of some of these projects, which is required because not all projects have further available data.

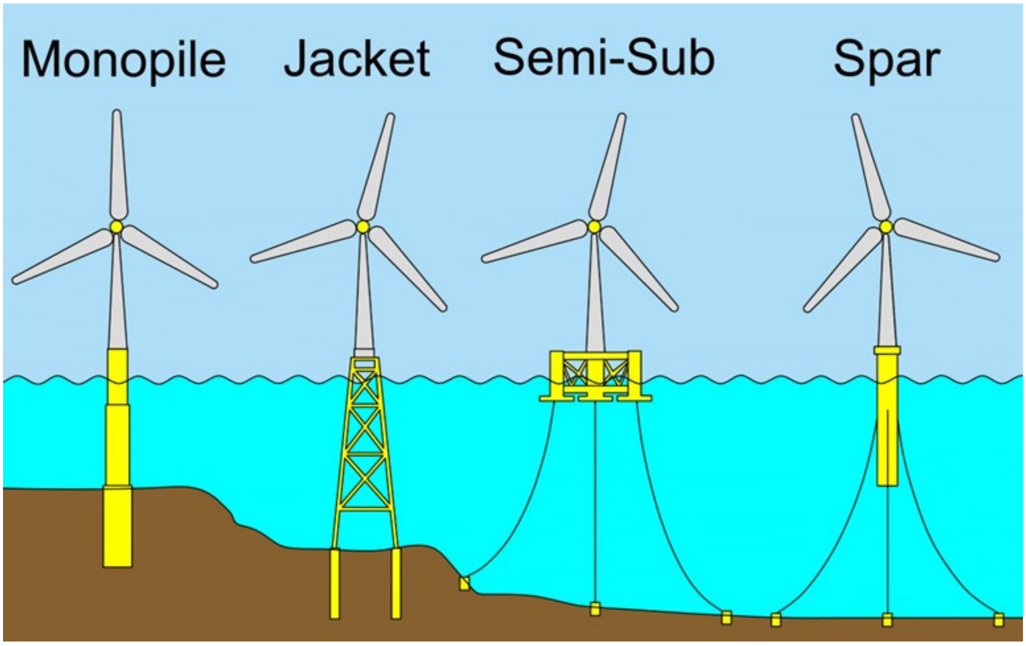

Figure 1. Most widely used bottom-fixed and floating wind support structures in the world, indicated. From left to right: monopile, jacket, semi-submersible, and spar-buoy. The authors processed the figure in accordance with the information presented in [10].

2. Materials and Methods

This section mainly presents floating wind projects and concepts from all around the world, and the data presented in this section is mainly based on the ABSG Consulting report [11] and illustrates the global floating wind situation in 2020.

The following subsection presents the world's floating wind concepts.

2.1. World's Floating Wind Concepts

This subsection presents the world's floating wind concepts.

The following Table 1 presents the main advantages and disadvantages of the world's five most common floating wind types. Refer to Section 4 for further information on each of the presented types.

Table 2 shows the four most frequently used types of floating wind turbines: spar-buoy, semi-submersible, barge, TLP, and multi-turbine type). The table also provides further information that is relevant to the most frequently used corresponding concepts of these wind turbine types, together with their corresponding details.

Table 2. Floating wind concepts applied in the world. Table data processed by the authors on the basis of information presented in [11].

Type	Concept	Designer	Hull Material
Spar-buoy	Hywind	Equinor	Steel or Concrete
	Toda Hybrid Spar	Toda	Steel and Concrete Hybrid
	Fukushima FORWARD Advanced Spar	JMU	Steel
	SeaTwirl	SeaTwirl	Steel
	Stiesdal TetraSpar	Stiesdal	Steel
Semi-submersible	WindFloat	Principle Power	Steel
	Fukushima FORWARD compact semi-submersible	MES	Steel
	Fukushima FORWARD V-shape semi-submersible	MHI	Steel
	VolturnUS	University of Maine	Concrete
	Sea Reed	Naval Energies	Steel, Concrete or Hybrid
	Cobra Semi-Spar	Cobra	Concrete
	OO-Star	Iberdrola	Concrete
	Hexafloat	Saipem	Steel
	Eolink	Eolink	Steel
	SCD nezzy	SCD Technology	Concrete
	Nautilus	NAUTILUS Floating Solutions	Steel
	Tri-Floater	GustoMSC	Steel
	TrussFloat	DOLFINES	Steel
Barge	Ideol Damping Pool Barge	Ideol	Concrete or Steel
	Saitec SATH (Swinging Around Twin Hull)	Saitec	Concrete
Tension leg platform	SBM TLP	SBM Offshore	Steel
	PivotBuoy TLP	X1 Wind	Steel
	Gicon TLP	Gicon	Concrete
	Pelastar TLP	Glosten	Steel
	TLPWind TLP	Iberdrola	Steel
Multi-turbine platform	Hexicon multi-turbine semi-submersible	Hexicon	Steel
	W2Power	EnerOcean	Steel
	Floating Power Plant	Floating Power Plant	Steel

The table shows that there are more concepts of semi-submersible than any of the other wind turbine types, followed by spar-buoy, TLP, barge, and multi-turbine platform. Most of these concepts are made of steel, and a few of concrete. Figure 2 presents an illustrative layout that addresses most of these concepts.

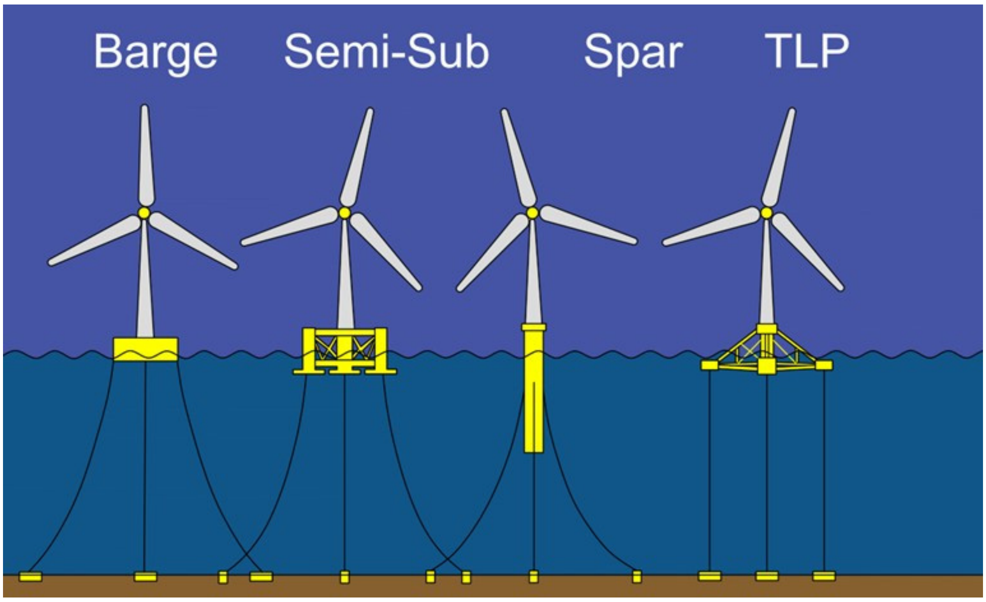

Figure 2. Most popular floating wind support structures in the world. From left to right: barge, semi-submersible, spar-buoy, and TLP. Figure processed by the authors according to the information presented in [10].

The following sub-subsection presents the world's Spar floating wind concepts.

2.1.1. World's Spar-Buoy Floating Wind Concepts

This sub-subsection presents the world's Spar floating wind concepts.

One of the most widely used floating wind spar-buoy concepts is Hywind [12], which is designed by Equinor and constructed of either steel or concrete material. Advanced Spar [13] and Sea Twirl [14], which are also well-known, are developed by JMU and Sea Twirl, respectively, and are both made of steel. Stiesdal Tetra Spar [15] and Fukushima Forward [16,17] are other worth mentioning spar concepts. They are developed by Stiesdal and JMU, respectively, and are both made of steel. Toda Hybrid Spar [18] is also a Spar floating wind concept that is developed by Toda and is a hybrid that is made of a combination of steel and concrete.

The following sub-subsection presents semi-submersible floating wind concepts used across the world.

2.1.2. World's Semi-Submersible Floating Wind Concepts

This sub-subsection presents semi-submersible floating wind concepts used across the world.

One of the most widely used floating wind semi-submersible concepts is Wind Float [19], which is designed by PRINCIPLE-POWER and made of steel. VOLTURNUS [20], OO-Star [21], and Tri-Floater [22] are also well-known floating wind semi-submersible concepts developed by the University of Maine, Iberdrola, and Gusto MSC, respectively. The first two are made of concrete, and the third is made of steel. Cobra Semi-Spar and SCD NEZZY [23] are also semi-submersibles made of concrete that have been developed by Cobra and SCD Technology, respectively. Hexa-Float [24], EOLINK, Nautilus [25], Tri-Floater, and Truss Float [11] are also floating wind semi-submersibles made of steel that have been developed by Saipem, EOLINK, Nautilus floating solutions, Gusto MSC, and DOLFINES, respectively. Sea Reed [26] is also a floating wind semi-submersible floating wind concept that is made of either steel or concrete (or both, in a hybrid) that has been developed by Naval Energies.

The following sub-subsection presents the world's barge, TLP, and multi-turbine floating wind concepts.

2.1.3. World's Barge, TLP, and Multi-Turbine Floating Wind Concepts

This sub-subsection presents the world's barge, TLP, and multi-turbine floating wind concepts.

One of the most widely used barge floating wind concepts is the IDEOL Damping Pool Barge, which was designed by IDEOL and is made of either steel or concrete. SAITEC SATH (Swinging Around Twin Hull) is a Barge floating wind concept that was developed by SAITEC and is made of concrete.

One of the most widely used floating wind TLP concepts is TLPWIND [27] which was designed by Iberdrola and is made of steel. SBM [11], Pivot Buoy [28], and PelaStar are also TLP concepts that are made of steel and were designed by SBM Offshore, X1 Wind, and GLOSTEN, respectively. GICON [29] is a TLP floating wind concept that is made of concrete and was designed by GICON.

One of the most widely used multi-turbine floating wind concepts is the HEXICON multi-turbine semi-submersible [30] which was designed by HEXICON and is made of steel. W2Power [31] and Floating Power Plant [32] are multi-turbine concepts that are made of steel and were developed by EnerOcean and Floating Power Plant, respectively.

The following subsection presents floating wind projects installed across the world in the period 2008–2020.

2.2. World's Installed Floating Wind Projects in the Period 2008–2020

This subsection presents floating wind projects installed across the world in the period 2008–2020.

Table 3 presents all the floating wind projects installed across the world in the period 2008–2020. The following will illustrate the data in this table and classify projects by referring to their contributing countries.

The following illustrates the countries that made the largest contribution to the installation of floating wind projects in the period 2008–2020.

Table 3. All the floating wind projects installed across the world in the period 2008–2020. Table data was processed by the authors on the basis of information presented in [11].

Continent	Country, Location	Year, Turbine—Power	Project Name, Designer
North America	U.S., Maine	2013, Renewegy 20 kW	VolturnUS 1:8, University of Maine
	U.S.—Oregon, WindFloat semi-submersible	2013, 5 × 6 MW	WindFloat Pacific (WFP), Principle Power
Asia	Japan, Goto	2013, Hitachi 2 MW downwind	Kabashima, Toda
	Japan, Fukue	2015, Hitachi 2 MW downwind	Sakiyama, Toda
	Japan, Fukushima	2013, 66 kV—25 MVA Floating Substation	Fukushima FORWARD Phase 1, Fukushima Offshore Wind Consortium
	Japan, Fukushima	2013, Hitachi 2 MW downwind	Fukushima FORWARD Phase 1, Fukushima Offshore Wind Consortium
	Japan, Fukushima	2015, MHI 7 MW	Fukushima FORWARD Phase 2, Fukushima Offshore Wind Consortium
	Japan, Fukushima	2016, Hitachi 5 MW downwind	Fukushima FORWARD Phase 2, Fukushima Offshore Wind Consortium
	Japan, Kitakyushu	2019, Aerodyn SCD 3 MW—2 bladed	Hibiki, Ideol

Table 3. *Cont.*

Continent	Country, Location	Year, Turbine—Power	Project Name, Designer
Europe	Denmark, Lolland	2008, 33 kW	Poseidon 37 Demonstrator [33], Floating Power Plant
	Norway, Karmøy	2009, Siemens 2.3 MW	Hywind Demo, Equinor
	Portugal, Aguçadoura	2011, Vestas 2 MW	WindFloat 1 (WF1), Principle Power
	Portugal, Viana do Castelo	2020, MHI Vestas 3 × 8.4 MW	WindFloat Atlantic (WFA), PrinciplePower
	Sweden, Lysekil	2015, 30 kW Vertical Axis Wind Turbine	SeaTwirl S1, SeaTwirl
	UK, Peterhead	2017, Siemens 5 × 6 MW	Hywind Scotland, Equinor
	UK, Dounreay	2017, N/A 2 × 5 MW	Hexicon Dounreay Trì project [34], Hexicon
	UK, Kincardineshire	2020, MHI Vestas 2 MW (former WF1) & MHI Vestas 5 × 9.5 MW	Kincardine, Principle Power
	Spain, Gran Canaria	2019, 2 × 100 kW twin-rotor	W2Power 1:6 Scale, EnerOcean
	Spain, Santander	2020, Aeolos 30 kW	BlueSATH, Saitec
	France, Le Croisic	2018, Vestas 2 MW	Floatgen, Ideol
	Germany, Baltic Sea	2017, Siemens 2.3 MW	Gicon SOF [35], GICON

Table 3 shows that the UK, Portugal, and Japan made the largest contribution to the installed floating wind projects. The table shows that the UK has a total installed power capacity of 79.5 MW, which is contributed by two floating wind projects. The first one is Kincardine [36], which was developed by Principle Power and has a power capacity of 5 × 9.5 MW. This project also contains an additional 2 MW wind turbine, which was first implemented in the WindFloat 1 (WF1) floating wind project. The UK's second floating wind project is Hywind Scotland [37], which was developed by Equinor and has a power capacity of 5 × 6 MW. The first project in the UK implemented a Vestas wind turbine brand, and the other implemented a Siemens brand.

It is seen from the table that Portugal has a total installed floating wind power capacity of 27.2 MW, which is contributed by two projects. The first project is WindFloat Atlantic (WFA) [38,39], which has a total power capacity of 3 × 8.4 MW, and the second is WindFloat 1 (WF1) [40], which has a total power capacity of 2 MW. They were both developed by Principle Power and implement wind turbines with a Vestas brand.

Japan has a total installed power capacity of 21 MW, which is contributed by seven projects. The main contributors are Fukushima FORWARD Phases I and II [41], which have a total of 14 MW power capacity and were developed by the Fukushima Offshore Wind Consortium. They are followed by the Hibiki [42], Kabashima, and Sakiyama projects. The first project was developed by Ideol, and the other two by Toda. The Hibiki project has a 2 MW power capacity and a downwind Hitachi wind turbine. The Sakiyama floating wind project also implements a 2 MW Hitachi downwind wind turbine.

Other floating wind projects in Europe include the Norwegian Hywind Demo, which has a total power capacity of 3.2 MW, implements a Siemens wind turbine brand, and is developed by Equinor.

The Spanish BlueSATH [43] and W2Power 1:6 scale projects which were developed by Saitec and EnerOcean respectively. The first project has a 30 kW power capacity, and the second has a 2 × 100 kW power capacity. The latter is accompanied by two separate wind turbines that are supported on a single multi-turbine support structure.

The Danish Poseidon 37 Demonstrator floating wind project which has a power capacity of 33 kW, and was developed by Floating Power Plant.

The French Floatgen floating wind project, which has a total power capacity of 2 MW, implements a Vestas wind turbine brand and is developed by Ideol.

The Swedish SeaTwirl S1 floating wind project [44] which is developed by SeaTwirl and has a power capacity of 30 kW. It implements a vertical-axis wind turbine (i.e., the blades rotate around the tower and not around the typical horizontal-axis wind turbine's hub, meaning their rotation axis faces the sky).

On the basis of Table 3, we conclude that Europe is currently the largest contributor to the world's installed floating wind projects.

The following subsection presents the world's planned floating wind projects in the period 2020–2027.

2.3. World's Planned Floating Wind Projects in the Period 2020–2027

This subsection presents the world's planned floating wind projects in the period 2020–2027.

Table 4 shows all the European, North American, and Asian floating wind projects in the world. Further discussions of the data presented in the table are provided in Sections 3 and 4.

Table 4. All the planned floating wind projects in the world in the period 2020–2027. Table data processed by the authors, based on the information presented in [11].

Continent	Country—Location, Floating Substructure Design—Type	Year, Turbine—Power	Project Name, Designer
Europe	Norway—Karmøy, Stiesdal TetraSpar—Spar	2020, Siemens Gamesa 3.6 MW	TetraSpar Demo [45], Stiesdal
	Norway—Haugaland, SeaTwirl Spar	2021, 1 MW Vertical Axis Wind Turbine	SeaTwirl S2 [46], SeaTwirl
	Norway—Snorre & Gullfaks offshore fields, Hywind Spar	2022, Siemens Gamesa 11 × 8 MW	Hywind Tampen, Equinor [47]
	Norway—Karmøy, OO-Star semi-submersible	2022, 10 MW	Flagship Demo, Iberdrola [48]
	Offshore Norway	2023, N/A	NOAKA, N/A
	Offshore UK, Ideol damping pool—barge	2021, 100 MW	Atlantis Ideol [49], Ideol
	Offshore UK, TLPWind TLP	N/A, 5 MW	TLPWind UK, Iberdrola
	Ireland—Offshore Irish west coast, Hexafloat -semi-submersible	2022, 6 MW	AFLOWT [50], Saipem
	Ireland—Offshore Kinsale, WindFloat semi-submersible	N/A, 100 MW	Emerald [51], Principle Power
	France—Gruissan, Ideol Damping Pool, barge	2021, Senvion 4 × 6.2 MW	EolMed [52], Ideol
	France—Offshore Napoleon Beach, SBM TLP	2021, Siemens Gamesa 3 × 8.4 MW	Provence Grand Large (PGL) [53], SBM Offshore
	France—Offshore Leucate-Le Barcarès, WindFloat semi-submersible	2022, MHI Vestas 3 × 10 MW	Golfe du Lion (EFGL) [54], Principle Power
	Spain—Offshore Canary Island, PivotBuoy TLP	2020, Vestas 200 kW	PivotBuoy 1:3 Scale [57], X1 Wind

Table 4. *Cont.*

Continent	Country—Location, Floating Substructure Design—Type	Year, Turbine—Power	Project Name, Designer
	Spain—Offshore Canary Islands, Cobra semi-spar	2020, 5 × 5 MW	FLOCAN5 [58], Cobra
	France—Offshore Brittany, Sea Reed semi-submersible	2022, MHI Vestas 3 × 9.5 MW	Groix & Belle-Ile [55], Naval Energies
	France—Offshore Le Croisic, Eolink semi-submersible	N/A, 5 MW	Eolink Demonstrator [56], Eolink
	Spain—Offshore Basque, Saitec SATH	2021, 2 MW	DemoSATH [59], Saitec
	Spain—Offshore Gran Canaria, N/A	N/A, 4 × 12.5 MW	Parque Eólico Gofio, Greenalia
	Spain—Basque, N/A	N/A, 26 MW	Balea, N/A
	Spain—Offshore Gran Canaria, N/A	N/A	WunderHexicon, Hexicon
North America	U.S.—Monhegan Island, VolturnUS semi-submersible	2023, 12 MW	New England Aqua Ventus I [11], University of Maine
	U.S.—California, WindFloat semi-submersible	2024, 100–150 MW	Red Wood Coast [60], Principle Power
	U.S.—Hawaii, WindFloat semi-submersible	2025, 400 MW	Progression South [61], Principle Power
	U.S.—California, SBM TLP/Saitec SATH	2025, 4 × 12 MW	CADEMO, SBM Offshore/SAITEC [62]
	U.S.—California, N/A	2026, 1 GW	Castle Wind, N/A
	U.S.—Hawaii, WindFloat semi-submersible	2027, 400 MW	AWH Oahu Northwest, Principle Power
	U.S.—Hawaii, WindFloat semi-submersible	2027, 400 MW	AWH Oahu South [63], Principle Power
	U.S.—California, N/A	N/A	Diablo Canyon [64], N/A
	U.S.—Massachusetts, N/A	N/A, 10 + MW	Mayflower Wind, Atkins
Asia	Japan—Goto, Toda Hybrid spar	2021, 22 MW	Goto City [65], Toda
	Offshore Japan, Ideol Damping Pool, barge	2023, N/A	Acacia [66,67], Ideol
	Offshore Japan, SCD NEZZY Semi-Submersible	N/A, Aerodyn SCD 6 MW—2-bladed	Nezzy Demonstrator [68], SCD Technology
	Korea—Ulsan, Hexicon multi-turbine semi-submersible	2022, 200 MW	Donghae TwinWind, Hexicon
	Korea—Ulsan, Semi-submersible	2020, 750 kW	Ulsan 750kW Floating Demonstrator, University of Ulsan
	Korea—Ulsan, N/A	2020, 5 MW	Ulsan Prototype [69,70], N/A
	Korea—Ulsan, N/A	2023, 500 MW	Gray Whale [71], N/A
	Korea—Ulsan, Hywind Spar	2024, 200 MW	KNOC (Donghae 1) [72,73], Equinor
	Korea—Ulsan, WindFloat semi-submersible	N/A, 500 MW	KFWind, Principle Power
	Korea—Ulsan, N/A	N/A, 200 MW	White Heron, N/A

This following presents the countries that made the largest contribution to planned floating wind projects in the period 2020–2027, and also outlines their corresponding power capacity:

1. The US had a power capacity of 2.45 GW, coming from nine floating wind projects in the period 2023–2027.
2. Korea had a power capacity of 1.6 GW, coming from seven floating wind projects in the period 2020–2024.
3. France had a power capacity of 113.5 MW, coming from five projects in the period 2021–2022.
4. Ireland had a power capacity of 106 MW, coming from two projects in 2022.
5. The UK had a power capacity of 105 MW, coming from two projects in 2021.
6. Spain had a power capacity of 103.2 MW, coming from six projects in the period 2020–2021.
7. Norway had a power capacity of 102.6 MW, coming from five projects in the period 2020–2023.
8. Japan had a power capacity of 28 MW, coming from three floating wind projects in the period 2020–2023.

It is worth mentioning that some other Asian countries, such as Taiwan, [74] have established a preliminary plan for their future floating wind projects. However, due to a lack of corresponding relevant details, we have eliminated them from our study (refer to the ABSG Consulting report [11] for more information about the names of the planned projects in Taiwan, for example). Paper [75] refers to large-scale offshore wind production in the Mediterranean Sea. While it does not directly relate to the present discussion, it can be taken into account in further discussions.

Figures 3 and 4 show the world's largest floating wind project (Hywind Tampen).

Figure 5 shows the world's first floating wind project (Hywind Scotland). Figures 6–8 show the world's most widely used floating multi-turbine concept (HEXICON).

The following subsection presents further details about the world's installed and planned floating wind projects in the period 2009–2026, including project costs, wind speeds, water depths, and distances to shore. The presented data does not cover all the mentioned projects in this paper, as some of them lacked corresponding data.

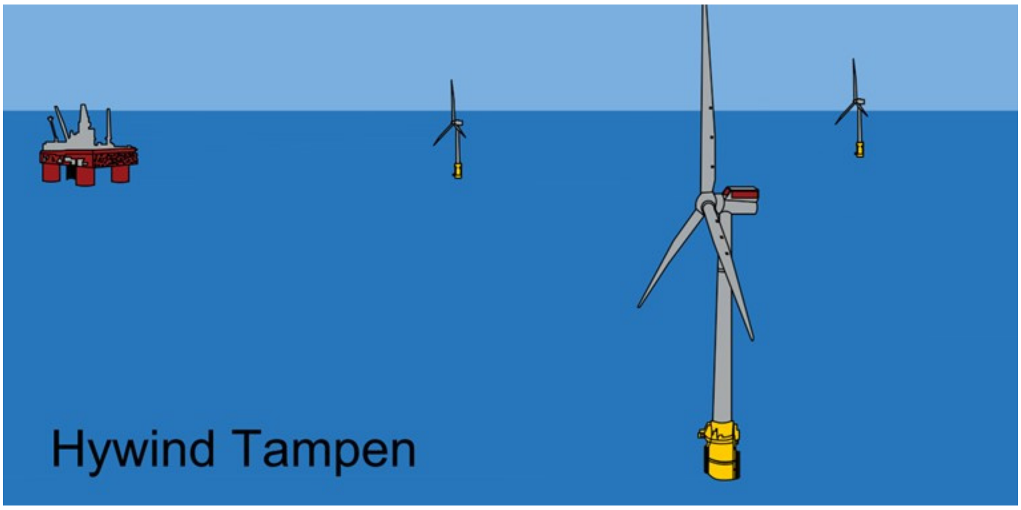

Figure 3. The largest installed floating wind turbine in the world (Hywind Tampen). Figure processed by the authors on the basis of information presented in [76].

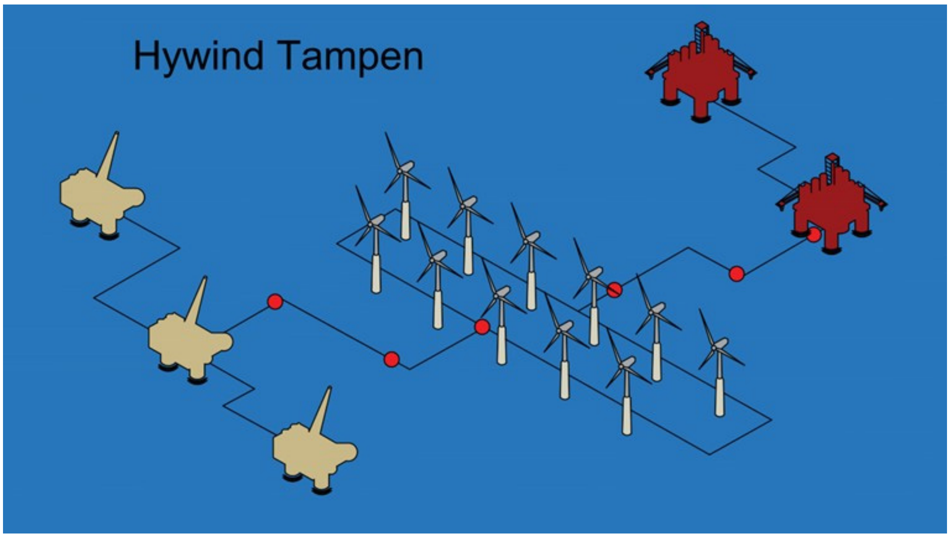

Figure 4. The largest installed floating wind project in the world (Hywind Tampen). Figure processed by the authors on the basis of information presented in [76].

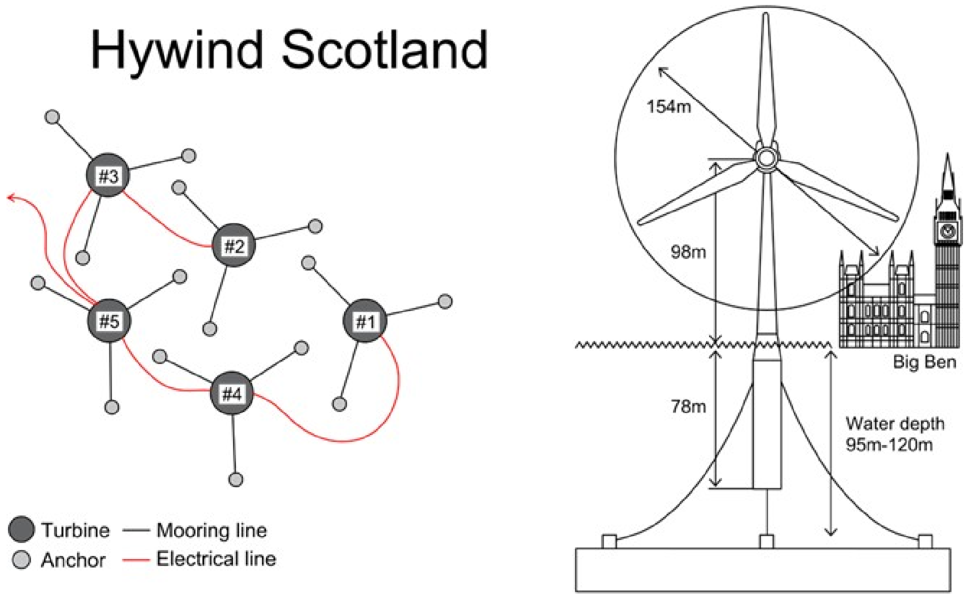

Figure 5. The first installed floating wind project in the world (Hywind Scotland). Figure processed by the authors on the basis of information presented in [77].

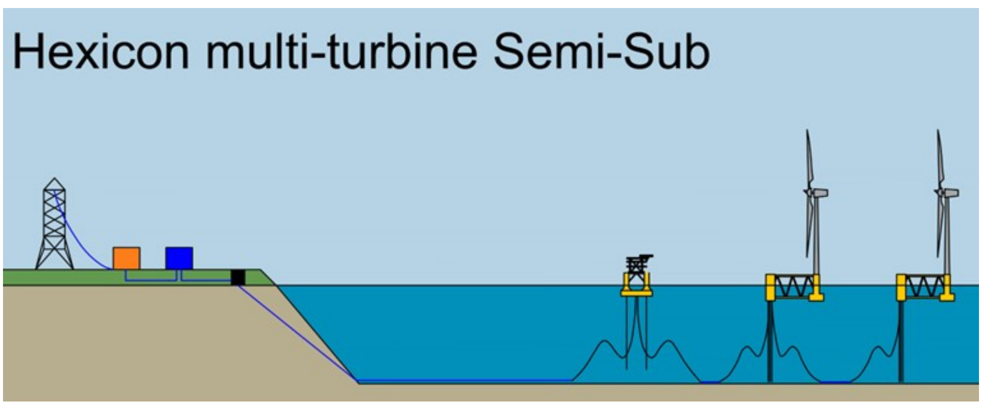

Figure 6. The most widely used multi-turbine floating wind turbine support structure in the world (HEXICON). Figure processed by the authors on the basis of information presented in [78].

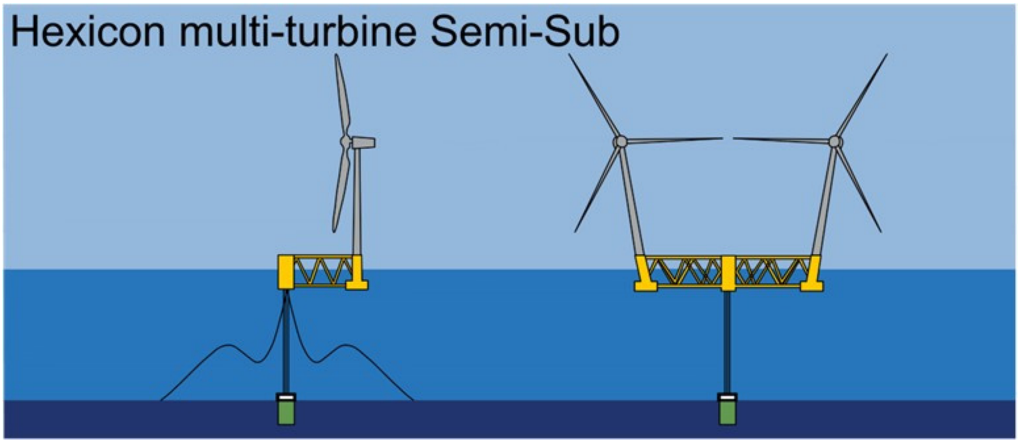

Figure 7. The most widely used multi-turbine floating wind support structure in the world (HEXICON). Figure processed by the authors on the basis of information presented in [78].

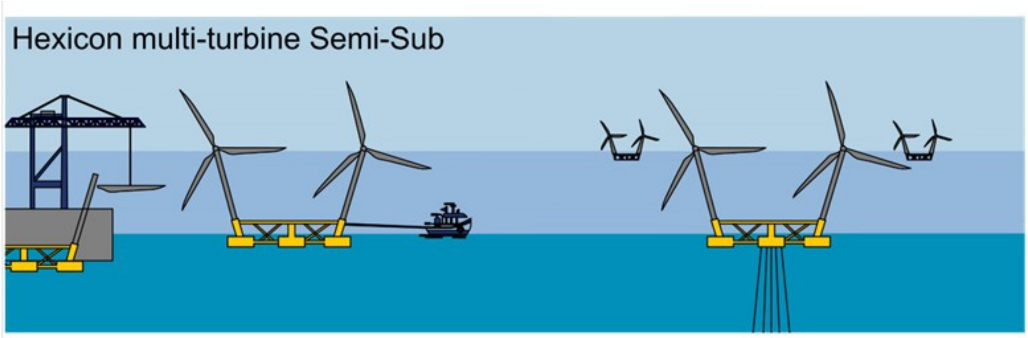

Figure 8. The most widely used multi-turbine floating wind support structure in the world (HEXICON). Figure processed by the authors on the basis of information presented in [78].

2.4. Further Details on Some of the Presented World's Installed and Planned Floating Wind Projects in the Period 2009–2026 (Based on Tables 3 and 4)

This subsection presents further details, including project costs, wind speeds, water depths, and distances to shore, which are classified on the basis of countries and their corresponding projects. This classification could not cover all the projects in this paper, as some of them lacked corresponding data. The data presented here relates to the period 2009–2026.

Table 5 presents further details of installed and planned floating wind projects in the world, which were first mentioned in their corresponding tables (Tables 3 and 4). Their corresponding mentioned data will be discussed and classified in Sections 3 and 4. In this subsection, we only present the table. Note that Table 5 contains 14/16 of the installed floating wind projects mentioned in Table 3 and 12/25 of the planned floating wind projects mentioned in Table 4.

The following section will provide results based on the collected and presented data in this section (Section 2). It will provide tables related to global floating wind concepts and installed and planned projects and will further classify some of the presented projects that have additional available data, including corresponding project costs, wind speeds, water depths, and distances to shore.

Table 5. Further details of some of the presented world's installed and planned floating wind projects in the period 2009–2026. Table data processed by the authors on the basis of information presented in [11].

Year	Project, Location, Distance to Shore	Turbine & Power, Floating Substructure Design & Type, Designer	Water Depth, Site Condition, Estimated Cost
2009	HYWIND DEMO (ZEFYROS), Offshore Karmøy Norway, 10 km	Siemens 2.3 MW, Hywind Spar, Equinor	220 m, wind speed 40 m/s & max wave height 19 m, US $71 million
2011	WINDFLOAT 1 (WF1), Offshore Aguçadoura Portugal, 5 km	Vestas 2 MW, WindFloat semi-submersible, Principle Power	49 m, wind speed 31 m/s & max wave height 17 m, US $25 million
2013	VOLTURNUS 1:8, Offshore Castine Maine US, 330 m	Renewegy 20 kW, VolturnUS, semi-submersible, University of Maine	27.4 m, 50-year wind speed 14.1 m/s & 50-year significant wave height 1.3 m, US $12 million
	SAKIYAMA, Offshore Sakiyama Fukue Island Japan, 5 km	Hitachi 2 MW downwind, Haenkaze -Toda Hybrid spar, Toda	100 m, 50-year wind speed 45.8 m/s & 50-year significant wave height 12.1 m, N/A
	FUKUSHIMA FORWARD PROJECT phase I, Offshore Fukushima Japan, 23 km	66 kV—25 MVA Floating Substation, Fukushima Kizuna—Advanced Spar, Japan Marine United Corporation (JMU)	120 m, 50-year wind speed 48.3 m/s & 50-year significant wave height 11.71 m, US $157 million for all the phases of the project
	FUKUSHIMA FORWARD PROJECT phase I, Offshore Fukushima Japan, 23 km	Hitachi 2 MW downwind, Fukushima Mira—compact semi-submersible, Mitsui Engineering & Shipbuilding Co., Ltd. (MES)	122–123 m, 50-year wind speed 48.3 m/s & 50-year significant wave height 11.71 m, US $157 million for all the phases of the project
2015	FUKUSHIMA FORWARD PROJECT, phase II, Offshore Fukushima Japan, 23 km	MHI 7 MW, Fukushima Shimpuu—V-shape Semi-Submersible, Mitsubishi Heavy Industries, Ltd. (MHI)	125 m, 50-year wind speed 48.3 m/s & 50-year significant wave height 11.71 m, US $157 million for all the phases of the project
	SEATWIRL S1, Offshore Lysekil Sweden, N/A	30 kW Vertical Axis Wind Turbine, SeaTwirl Spar, SeaTwirl	35 m, wind speed 35 m/s, N/A
2016	FUKUSHIMA FORWARD PROJECT, phase II, Offshore Fukushima Japan, 23 km	Hitachi 5 MW downwind, Fukushima Hamakaze—Advanced Spar, Japan Marine United Corporation (JMU)	110–120 m, 50-year wind peed 48.3 m/s & 50-year significant wave height 11.71 m, US $157 million for all the phases of the project
2017	HYWIND SCOTLAND, Offshore Peterhead Scotland UK, 25 km	Siemens 5 × 6 MW, Hywind Spar, Equinor	95–120 m, average wind speed 10 m/s & average wave height 1.8 m, US $210 million
2018	FLOATGEN, Offshore Le Croisic France, 20 km	Vestas 2 MW, Ideol Damping Pool-barge, Ideol	33 m, wind speed 24.2 m/s & significant wave height 5.5 m, US $22.5 million
2019	HIBIKI, Offshore Kitakyushu Japan, 15 km	Aerodyn SCD 3 MW—2 bladed, Ideol Damping Pool-barge, Ideol	55 m, typhoon-prone area, N/A
	W2POWER 1:6 SCALE, Offshore Gran Canaria Spain, N/A	2 × 100 kW twin-rotor, EnerOcean W2Power semi-submersible, EnerOcean	N/A

Table 5. *Cont.*

Year	Project, Location, Distance to Shore	Turbine & Power, Floating Substructure Design & Type, Designer	Water Depth, Site Condition, Estimated Cost
2020	WINDFLOAT ATLANTIC (WFA), Offshore Viana do Castelo Portugal, 20 km	MHI Vestas 3 × 8.4 MW, WindFloat semi-submersible, Principle Power	85–100 m, N/A, US $134 million
	KINCARDINE, Offshore Kincardineshire Scotland UK, 15 km	MHI Vestas 2 MW (former WF1)—MHI Vestas 5 × 9.5 MW, WindFloat semi-submersible, Principle Power	60–80 m, UK North Sea off the coast of Scotland, US $445 million
	BLUESATH, Offshore Santander Spain, 800 m	Aeolos 30 kW, Saitec SATH 1:6, Saitec	N/A, Abra del Sardinero, US $2.2 million
	TETRASPAR DEMO, Offshore Karmøy Norway, 10 km	Siemens Gamesa 3.6 MW, Stiesdal TetraSpar—Spar, Stiesdal	220 m, Near Zefyros (former Hywind Demo), US $20.5 million
2021	DEMOSATH, Offshore Basque Spain, 3.2 km	2 MW, Saitec SATH, Saitec	85 m, wind speed 12 m/s & significant wave height 2.8 m, $17.3 million
	EOLMED, Offshore Gruissan Mediterranean Sea France, 15 km	Senvion 4 × 6.2 MW, Ideol Damping Pool—barge, Ideol	55 m, Mediterranean Sea, US $236.2 million
	PROVENCE GRAND LARGE (PGL), Offshore Napoleon beach Mediterranean Sea France, 17 km	Siemens Gamesa 3 × 8.4 MW, SBM TLP, SBM Offshore	100 m, Mediterranean Sea, US $225 million
2022	HYWIND TAMPEN, Snorre & Gullfaks offshore fields Offshore Norway, 140 km	Siemens Gamesa 11 × 8 MW, Hywind Spar, Equinor	260–300 m, mean significant wave height 2.8 m, US $545 million
	GOLFE DU LION (EFGL), Offshore Leucate-Le Barcarès Mediterranean Sea France, 16 km	MHI Vestas 3 × 10 MW, WindFloat semi-submersible, Principle Power	65–80 m, Mediterranean Sea, US $225 million
	GROIX & BELLE-ILE, Offshore Brittany France, 22 km	MHI Vestas 3 × 9.5 MW, Sea Reed semi-submersible, Naval Energies	60 m, Atlantic Ocean off the coast of France, US $254 million
	DONGHAE TWINWIND, Offshore Ulsan Korea, 62 km	200 MW, Hexicon multi-turbine semi-submersible, Hexicon	N/A
2023	NEW ENGLAND AQUA VENTUS I, Offshore Monhegan Island in the Gulf of Maine US, 4.8 km	12 MW, VolturnUS-semi-submersible, University of Maine	100 m, 50-year wind speed of 40 m/s & 50-year significant wave height 10.2 m, US $100 million
2024	REDWOOD COAST, Offshore Humboldt County California US, 40 km	100–150 MW, WindFloat semi-submersible, Principle Power	600 m–1 km, average annual wind speed 9–10 m/s, N/A
2025	CADEMO, Offshore Vandenberg California US, 4.8 km	4 × 12 MW, SBM TLP/Saitec SATH, SBM Offshore/Saitec	85–96 m, average wind speed 8.5 m/s, N/A
2026	CASTLE WIND, Offshore Morro Bay California US, 48 km	1 GW, N/A, N/A	813 m–1.1 km, average wind speed 8.5 m/s, N/A

3. Results

This section presents the results obtained from Section 2, which are classified on the basis of global floating wind concepts and projects. Further classifications of some projects that have further available data, on corresponding countries, costs, wind speeds, water depths, and distances to shore, are also provided. The following subsections present the results from Tables 2–5 for all floating wind concepts and projects in the world in the period 2008–2027.

The following subsection presents the world's floating wind turbine concepts' results obtained from Table 2.

3.1. Results from Table 2 (World's Floating Wind Turbine Concepts—Part 1)

This subsection presents the results obtained from Table 2 for the world's floating wind turbine concepts.

The results in Table 6 show a total number of 28 floating wind turbine concepts (thirteen semi-submersibles, five spar buoys, five TLPs, three multi-turbines, and two barges).

Table 6. World's floating wind turbine concepts.

Floating Wind Turbine Types	Number of Corresponding Concepts
Spar-buoy	5
Semi-submersible	13
Barge	2
TLP	5
Multi-turbine	3
Total	28

The following subsection also presents the results obtained from Table 2 for the world's floating wind turbine concepts.

3.2. Results from Table 2 (World's Floating Wind Turbine Concepts—Part 2)

This subsection also presents the results obtained from Table 2 for the world's floating wind turbine concepts.

The results in Table 7 show a total number of 28 presented floating wind turbine concepts (eighteen are made of steel, six of concrete, and four of steel and/or concrete.

Table 7. World's floating wind turbine manufacturing materials.

Floating Wind Manufacturing Material	Number of Corresponding Concepts
Steel	18
Concrete	6
Steel and/or concrete	4
Total	28

The following subsection presents the results obtained from Table 2 for the world's floating wind turbine concepts.

3.3. Results from Table 2 (World's Floating Wind-Turbine Concepts—Part 3)

This subsection presents the results obtained from Table 2 for the world's floating wind turbine concepts.

Table 8 shows that there are a total number of 28 presented floating wind turbine concepts, thirteen semi-submersibles, eight of which are made of steel, four of concrete, and one of steel or concrete; five spar-buoys, three of which are made of steel, and two of steel and/or concrete; five TLPs, four of which are made of steel, and one of concrete; three multi-turbines, all are made of steel; two barges, one is made of concrete and one of steel or concrete.

Table 8. World's floating wind turbine concepts and their corresponding manufacturing materials.

Floating Wind Types	Number of Corresponding Concepts	Steel	Concrete	Steel and/or Concrete
Spar-buoy	5	3	-	2
Semi-submersible	13	8	4	1
Barge	2	-	1	1
TLP	5	4	1	-
Multi-turbine	3	3	-	-
Total	28	18	6	4

The following subsection presents results obtained from Table 3 for the world's installed floating wind turbine projects in the period 2008–2020.

3.4. Results from Table 3 (World's Installed Floating Wind Turbine Projects in the Period 2008–2020)

This subsection presents the results obtained from Table 3 for the world's installed floating wind turbine projects in the period 2008–2020.

The total installed floating wind capacity in Europe is 123.5 MW, which is provided by 12 projects in 8 contributing countries (the UK, Portugal, Norway, France, Spain, Denmark, Sweden, and Germany—see Table 9). Refer to Section 4 for further discussion of the contribution that each country makes to the global installed floating wind power capacity.

Table 9. World's installed floating wind turbine projects.

Continents	Total Installed Floating Wind Capacity	Corresponding Number of Projects	Corresponding Number of Countries	Corresponding Countries
Europe	123.5 MW	12	8	UK, Portugal, Norway, Germany, France, Spain, Denmark, Sweden
North America	30.2 MW	2	1	US
Asia	21 MW	4	1	Japan
Total	174.7 MW	18	10	The UK, Portugal, Norway, Germany, France, Spain Denmark, Sweden, The US and Japan

The total installed floating wind capacity in the US is 30.2 MW, which is provided by two projects.

The total installed floating wind capacity in Asia is 21 MW, which is provided by four projects in Japan.

The following subsection presents the results obtained from Table 4 for the world's planned floating wind turbine projects in the period 2020–2027.

3.5. Results from Table 4 (World's Planned Floating Wind-Turbine Projects in the Period 2020–2027)

This subsection presents results obtained from Table 4 for the world's planned floating wind turbine projects in the period 2020–2027.

Table 10 briefly classifies the power capacity of the world's planned floating wind projects on the basis of corresponding continents and countries. Further power capacity classifications regarding each of the presented countries are given in the following.

Table 10. World's planned floating wind turbine projects.

Continents	Total Planned Floating Wind Power Capacity	Corresponding Number of Projects	Corresponding Number of Countries	Corresponding Countries
Europe	525.1 MW	17	5	France, Ireland, UK, Spain, Norway
North America	2.42 GW	8	1	US
Asia	1.634 GW	9	2	Korea, Japan
Total	4.5791 GW	34	8	France, Ireland, the UK, Spain, Norway, the US, Korea and Japan

France has a planned floating wind power capacity of 113.5 MW, provided by four projects (Golfe du Lion—EFGL, GROIX & Belle-Ile, Provence Grand Large—PGL, and EOLMED).

Ireland has 106 MW, provided by two projects (Emerald and AFLOWT).

The UK has 105 MW, provided by two projects (Atlantis IDEOL and TLP Wind).

Spain has 103 MW, provided by five projects (Parque EOLICO Gofio, Balea, FLOCAN 5, Demo SATH, and Pivot Buoy 1:3 Scale).

Norway has 102.6 MW, provided by four projects (Hywind Tampen, Flagship Demo, Tetra Spar Demo, and Sea Twirl S2).

The US has 2.42 GW, provided by eight projects (Castle Wind, Progression South, AWH Oahu Northwest, AWH Oahu South, Red Wood Coast, CADEMO, New England Aqua Ventus I, and Mayflower Wind).

Korea has 1.606 GW, provided by seven projects (Gray Whale, KF Wind, DONGHAE Twin Wind, KNOC (DONGHAE 1), White Heron, Ulsan Prototype, and Ulsan 750 kW Floating Demonstrator).

Japan has 28 MW, provided by two projects (Goto City and NEZZY Demonstrator).

The following subsection presents results obtained from Table 5 for further details on the costs of some of the presented world's installed and planned floating wind projects in the period 2009–2026.

3.6. Results from Table 5 (Further Details on Costs of Some of the Presented World's Installed and Planned Floating Wind Projects in the Period 2009–2026)

This subsection presents the results obtained from Table 5 for further details on the costs of some of the presented world's installed and planned floating wind projects in the period 2009–2026.

Table 11 briefly classifies the world's planned floating wind projects' costs on the basis of corresponding continents and countries. Further cost classifications for each of the presented projects and their corresponding countries follow.

France's 962.7 million dollars of floating wind project cost is accounted for by one installed project (FLOATGEN) and four planned projects (GROIX & Belle-Ile, EOLMED, Provence Grand Large, and Golfe du Lion).

The UK's 655 million dollars is accounted for by two installed projects (Kincardine and Hywind Scotland).

Norway's 316.5 million dollars is accounted for by one installed project (Hywind Demo—ZEFYROS) and two planned projects (Hywind Tampen and Tetra Spar Demo).

Portugal's 159 million dollars is accounted for by two installed projects (Wind Float Atlantic and Wind Float 1).

Spain's 19.5 million dollars is accounted for by one installed project (Blue SATH) and one planned project (Demo SATH).

The US's 112 million dollars is accounted for by one installed project (VOLTURNUS 1:8) and one planned project (New England Aqua Ventus I).

Japan's 157 million dollars is accounted for by one installed project (Fukushima Forward Phases I & II).

Table 11. Further cost details for some of the presented world's installed and planned floating wind projects.

Continents	Corresponding Project Costs	Corresponding Number of Installed Projects	Corresponding Number of Planned Projects	Corresponding Number of Countries	Corresponding Countries
Europe	2.1127 billion dollars	7	7	5	France, UK, Norway, Portugal, Spain
North America	112 million dollars	1	1	1	US
Asia	-	-	-	-	-
Total	2.2247 billion dollars	8	8	6	France, the UK, Norway, Portugal, Spain and the US

The following subsection presents the results obtained from Table 5 for further details on wind speeds in some of the presented world's installed and planned floating wind projects in the period 2009–2026.

3.7. Results from Table 5 (Further Details about the Wind Speeds of Some of the Presented World's Installed and Planned Floating Wind Projects in the Period 2009–2026)

This subsection presents results obtained from Table 5 for further details about the wind speeds of some of the presented world's installed and planned floating wind projects in the period 2009–2026.

Table 12 briefly classifies the world's planned floating wind projects' wind speeds on the basis of corresponding continents and countries. Further wind speed classifications for each presented country follow.

Table 12. Further wind speed details for some of the presented world's installed and planned floating wind projects.

Continents	Corresponding Project Wind Speed	Corresponding Number of Installed Projects	Corresponding Number of Planned Projects	Corresponding Number of Countries	Corresponding Countries
Europe	10–40 m/s	5	1	6	Norway, Sweden, Portugal, France, Spain, UK
North America	8.5–40 m/s	1	4	1	US
Asia	45–48 m/s	2	-	1	Japan
Total	8.5–48 m/s	8	5	8	Norway, Sweden, Portugal, France, Spain, the UK, the US and Japan

Norway's 40 m/s wind speed is provided by one installed floating wind project (Hywind Demo—ZEFYROS).

Sweden's 35 m/s is provided by one installed floating wind project (Sea Twirl S1).

Portugal's 31 m/s is provided by one installed floating wind project (Wind Float 1).

France's 24.2 m/s is provided by one installed floating wind project (FLOATGEN).

Spain's 12 m/s is provided by one planned floating wind project (Demo SATH).

The UK's 10 m/s is provided by one installed floating wind project (Hywind Scotland).

The US's 8.5–40 m/s is provided by one installed floating wind project (VOLTURNUS 1:8) and four planned projects (CADEMO, Castle Wind, Red Wood Coast, and New England Aqua Ventis I).

Japan's 45–48 m/s is provided by two installed floating wind projects (Sakiyama and Fukushima Forward Phases I & II).

The following subsection presents the results obtained from Table 5 for further details about the water depths of some of the presented world's installed and planned floating wind projects in the period 2009–2026.

3.8. Results from Table 5 (Further Details about the Water Depths of Some of the Presented World's Installed and Planned Floating Wind Projects in the Period 2009–2026)

This subsection presents the results obtained from Table 5 for further details about the water depths of some of the presented world's installed and planned floating wind projects in the period 2009–2026.

Table 13 briefly classifies the world's planned floating wind projects' water depths on the basis of continents and corresponding countries. Further water depth classifications for each presented country follow.

Table 13. Further water depth details of some of the presented world's installed and planned floating wind projects.

Continents	Corresponding Projects' Water Depth	Corresponding Number of Installed Projects	Corresponding Number of Planned Projects	Corresponding Number of Countries	Corresponding Countries
Europe	33–300 m	8	6	6	Norway, UK, France, Portugal, Spain, Sweden
North America	27.4 m–1 km	1	3	1	US
Asia	55–125 m	3	-	1	Japan
Total	27.4 m–1 km	12	9	8	Norway, the UK, France, Portugal, Spain, Sweden, the US and Japan

Norway's 220–300 m water depth came from one installed floating wind project (Hywind Demo—ZEFYROS) and two planned projects (Tetra Spar Demo and Hywind Tampen.

The UK's 90–120 m came from two installed floating wind projects (Kincardine and Hywind Scotland).

France's 33–100 m came from one installed floating wind project (FLOATGEN) and four planned projects (EOLMED, GROIX & Belle-Ile, Golfe du Lion—EFGL, and Provence Grand Large—PGL).

Portugal's 49–100 m came from two installed floating wind projects (Wind Float Atlantic—WFA and Wind Float 1—WF1).

Spain's 85 m came from one installed floating wind project (Demo SATH).

Sweden's 35 m came from one installed floating wind project (Sea Twirl S1).

The US's 27.4 m–1 km came from one installed floating wind project (VOLTURNUS 1:8) and three planned projects (CADEMO, New England Aqua Ventus I, and Red Wood Coast).

Japan's 55–125 m came from three installed floating wind projects (Hibiki, Sakiyama, and Fukushima Forward Phases I & II).

The following subsection presents the results obtained from Table 5 for further details about the distance to shore of some of the presented world's installed and planned floating wind projects in the period 2009–2026.

3.9. Results from Table 5 (Further Details about the Distance to Shore of Some of the Presented World's Installed and Planned Floating Wind Projects in the Period 2009–2026)

This subsection presents the results obtained from Table 5 for further details about the distance to shore of some of the presented world's installed and planned floating wind projects in the period 2009–2026.

Table 14 briefly classifies the world's planned floating wind projects' distance to shore on the basis of corresponding continents and countries. Further distance-to-shore classifications for each presented country follow.

Table 14. Further distance-to-shore details for some of the presented world's installed and planned floating wind projects.

Continents	Corresponding Projects' Distance to Shore	Corresponding Number of Installed Projects	Corresponding Number of Planned Projects	Corresponding Number of Countries	Corresponding Countries
Europe	800 m–140 km	7	7	5	Norway, UK, France, Portugal, Spain
North America	330 m–48 km	1	4	1	US
Asia	5–62 km	3	1	2	Korea, Japan
Total	300 m–140 km	11	12	8	Norway, the UK, France, Portugal, Spain, the US, Korea and Japan

Norway's 10–140 km distance to shore came from one installed floating wind project (Hywind Demo—ZEFYROS) and two planned projects (Tetra Spar Demo and Hywind Tampen).

The UK's 15–25 km came from two installed floating wind projects (Kincardine and Hywind Scotland).

France's 15–22 km came from one installed floating wind project (FLOATGEN) and four planned projects (EOLMED, Golfe du Lion—EFGL, Provence Grand Large—PGL, and GROIX & Belle-Ile).

Portugal's 5–20 km came from two installed floating wind projects (Wind Float 1—WF1 and Wind Float Atlantic).

Spain's 800 m–3.2 km came from one installed floating wind project (Blue SATH) and one planned project (Demo SATH).

The US's 330 m–48 km came from one installed floating wind project (VOLTURNUS 1:8) and four planned projects (New England Aqua Ventus I, CADEMO, Red Wood Coast, and Castle Wind).

Korea's 62 km came from one planned floating wind project (DONGHAE Twin Wind).

Japan's 5–15 km came from three installed floating wind projects (Sakiyama, Hibiki, and Fukushima Forward Phases I & II).

The following section will primarily discuss the results presented in this section (Section 3) for global floating wind concepts and projects, and also for further classifications;

however, only some of the presented projects will be discussed with reference to their costs, wind speeds, water depths, and distances to shore, as data unavailability prevented us from engaging all of the projects presented in this paper.

4. Discussion

In this section, we will further discuss the results obtained from Section 3. This section also includes external references that are relevant to the world's floating wind situation, with particular emphasis on Europe and some related aspects. Figure 9 shows the floating wind Power-to-X technology that is used to transform the produced floating wind electrical energy (mainly into hydrogen and compressed air), eliminating the need for the construction of corresponding tremendous electrical infrastructures in countries that do not have such infrastructures in their sea region/s. Romania's floating wind feasibility will also be considered at the end of this section.

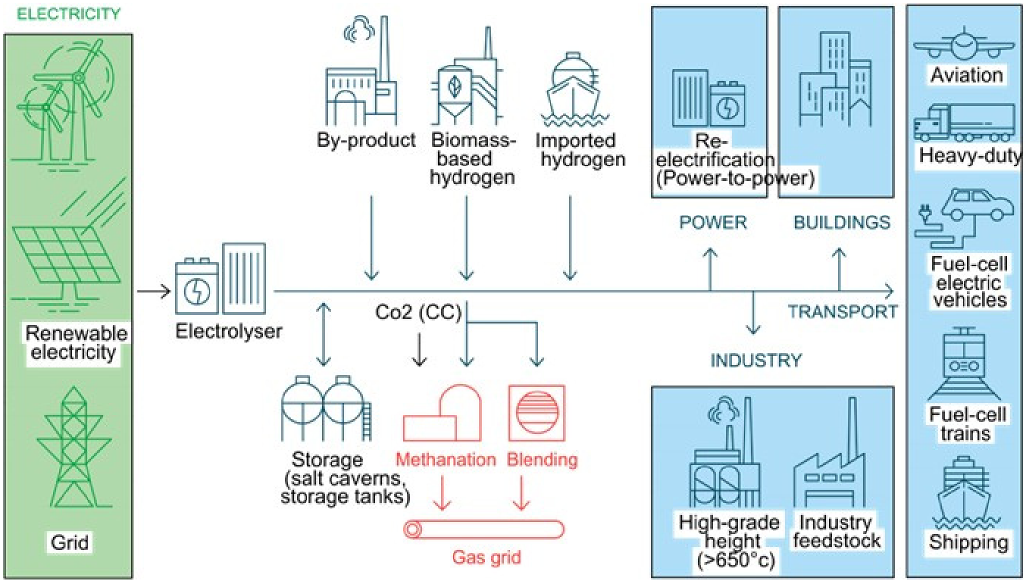

Figure 9. The floating wind Power-to-X technology, that transforms the produced floating wind electrical power (mainly into hydrogen and compressed air). Figure processed by the authors on the basis of information presented in [79].

The following subsection discusses the data presented throughout the paper, and particularly focuses on data presented in Section 3 that concerns the reliability of some of this paper's data references.

4.1. Discussions of the Data Presented in This Paper, with a Particular Focus on the Data Presented in Section 3, Which Addresses the Reliability of Some of the Paper's Data References

This subsection discusses data presented throughout the paper, with a particular focus on the data presented in Section 3 and addresses the reliability of some data references in this paper. It is worth mentioning that the reference this data is taken from is found to be the most complete and covers global floating wind concepts and projects up to 2020. The installed floating wind projects that are considered are from the period 2008–2020, and the considered planned floating wind projects are from the period 2020–2027. Our analysis is limited to these time intervals.

In the Introduction part of this paper, it was observed that Europe's floating wind plan is to achieve 150 GW by 2050 [4]. The planned power capacity is, on the basis of the results presented in Section 3, 525.1 MW, which will come from 17 projects [11]. An installed power capacity of 123.5 MW (see the results in Section 3) is also anticipated for the period 2008–2027 [11]. It is therefore obvious that there is a shortage in the presented data when compared to the overall European plan, as noted by [4]. It should also be noted that most of the projects that are planned to increase Europe's overall floating wind power capacity in Europe to 150 MW by 2050 have, according to [4], not been announced yet. It could therefore be said that our analysis is not complete because, due to the lack of corresponding published data for the planned floating wind projects (both their names and their corresponding power capacities) for the period 2020–2050, it is only able to consider floating wind projects for the period 2008–2027.

According to [4], the installed floating wind power capacity in Europe is 318 MW, which is provided by 34 floating wind concepts. However, Section 3 suggested that the installed floating wind power capacity is 123.5 MW, provided by 28 concepts (see [11]). This confirms discrepancies between the different references.

According to [4], the installed floating wind capacity is 114 MW in France, 80 MW in the UK, 95 MW in Norway, 30 MW in Portugal, 12 MW in the US, and 20 MW in Japan. According to Section 3, the installed floating wind power capacity in France is 2 MW, set against a planned capacity of 113.5 MW (the reference may be referring to this capacity, instead of the actual capacity installed in 2020). The installed capacity, according to Section 2, is 89.5 MW in the UK and 2.3 MW in Norway; however, the planned capacity is 105 MW in the UK and 102.6 MW in Norway (the reference may be referring to this capacity instead of the actual installed capacity in 2020). The installed capacity, according to Section 2, is 25.23 MW in Portugal, 30.2 MW in the US, and 21 MW in Japan. It can therefore be noted that different references have different power capacity values for the same countries (i.e., [4,11]).

According to [4], the planned floating wind capacity for 2030 is 750 MW in France, 1 GW in the UK, 1.5 MW (or 3 GW [5]) in Norway, and 275 MW in Portugal. Section 3 shows a planned power capacity of 113.5 MW in France, 105 MW in the UK, and 102.6 MW in Norway, but gives no data for Portugal, according to [11]. This corresponds to the period 2020–2027. This confirms there are discrepancies between the different references and probably a lack of detailed corresponding plans about the name of the projects and their corresponding power capacities, and this probably explains why the mentioned references did not include these details.

It can be generally concluded that the reference that the Section 2 data was taken from [11] is not 100% accurate. However, it is, to the best of our knowledge, the most complete reference existing up to 2020 that provides insight into global floating wind concepts and projects in the period 2020–2027.

The following subsection will discuss the data presented in Section 3.

4.2. Further Discussion of the Data Presented in Section 3

This subsection will discuss the data presented in Section 3. As has been reiterated throughout the paper, the plans in different countries of the world for floating wind projects do not necessarily include the projects that will cover the planned power capacities in each country. This paper's main aim was to list the announced global installed and planned floating wind projects, along with their corresponding power capacities and their details for the period 2008–2027. We can therefore assert that, according to reference [11], this paper collects all the announced installed and planned floating wind projects in the world (as of 2020) for the period 2008–2027. Their sum has a different value from the total floating wind power capacity planned by each country. Refer to Section 4.1 to see some of the discrepancies that arise between the floating wind power capacity in different references (e.g., [4,11], and possibly other references not covered in this paper).

The following seven sub-subsections will discuss the data presented in Section 3 on the global floating wind turbine concepts, installed and planned projects, and also further details, including costs, wind speeds, water depths, and distances to shore of some of these projects which contain further data.

The following sub-subsection discusses the results for global floating wind turbine concepts produced by the Section 3 data.

4.2.1. Discussion of the Results for Global Floating Wind Turbine Concepts Produced by the Section 3 Data

This sub-subsection discusses results for global floating wind turbine concepts, and specifically refers to the data presented in Section 3.

In accordance with the presented concepts in Section 3, we will discuss the following results.

The total number of the floating wind concepts is 28, coming from 5 wind-turbine types. The type that has the highest number of corresponding concepts is semi-submersible with 13 concepts (8 of which are made of steel and 5 are made of concrete or a combination of both materials). The second highest number of five concepts comes from both Spar (three of which are made of steel and two of steel and/or concrete) and TLP (four made of steel and one of concrete). The third highest number of concepts comes from the multi-turbine platform with three concepts (all made of steel). The lowest number of concepts is barge, with 2 concepts (one made of steel and one of concrete).

Semi-submersible is the most frequently used floating wind turbine type with the highest concept number; it is then followed by Spar and TLP, which have approximately half the number of concepts. The paper's data also establishes that steel is the most frequently used manufacturing material in all floating wind turbine types.

The total number of floating wind concepts is 28, 18 of which are made of steel, 6 of concrete, and 4 of steel and/or concrete.

The most frequently used manufacturing material in floating wind concepts is steel, followed by concrete or a combination of both materials.

In referring to the projects presented in Section 3, we will discuss their corresponding results in the following sub-subsections (Sections 4.2.2–4.2.7). The following sub-subsection discusses results for the global installed floating wind turbine projects in the period 2008–2020.

4.2.2. Discussion of the Results for the Global Installed Floating Wind Turbine Projects in the Period 2008–2020

This sub-subsection discusses the results obtained for the global installed floating wind turbine projects in the period 2008–2020.

With regard to installed floating wind power capacity per continent, Europe comes first, with 123.5 MW coming from the highest number of (8) corresponding countries and 12 projects. It is followed by North America, with a quarter of the power capacity (30.2 MW) coming from one country (the US) and two projects (Please note that the US project which corresponds to 30 MW power capacity had some uncertainty regarding its actual installation in the references it was taken from. The same also applies to the installed German project in this paper). Asia follows, with a sixth of Europe' power capacity, with 21 MW and four projects coming from one country (Japan). This data corresponds to the period 2008–2020, according to [11].

The overall installed floating wind power capacity in the world is 174.7 MW, which mostly comes from Europe, which is accounted for 123.5 MW (coming from 10 countries and 18 projects) in the period 2008–2020, according to [11].

With regard to Europe's installed floating wind power capacity of 123.5 MW, two countries mostly account for this value, namely the UK, with a power capacity of 89.5 MW, and Portugal, with 27.5 MW. The following six European countries make a more minor contribution to the installed European floating wind capacity: Norway with a power capacity of 2.3 MW, Germany with 2.3 MW, France with 2 MW, Spain with 230 kW, Denmark with 33 kW, and Sweden with 30 kW.

The UK is Europe's largest contributor to the installed floating wind capacity, with 89.5/123.5 MW. The second largest contributor is Portugal with 27.5/123.5 MW, followed by countries with an overall minor capacity of 6.5 MW: Norway, Germany, France, Spain, Denmark, and Sweden. According to [11], this covers the period 2008–2020, although the situation in 2023 may be different (e.g., Hywind Tampen, with 88 MW capacity, was installed in Norway in 2023, in a way that diverged from its original plan in 2022; this example corresponds to a planned project and was given merely for the sake of illustration).

The following sub-subsection discusses the results concerning the global planned floating wind turbine projects in the period 2020–2027.

4.2.3. Discussion of the Global Planned Floating Wind Turbine Projects' Results for the Period 2020–2027

This sub-subsection discusses the global planned floating wind turbine projects' results for the period 2020–2027 according to [11].

With regard to the planned floating wind power capacity per continent, North America takes the first place, with 2.42 GW power capacity coming from one corresponding country (the US) and 8 projects. Then comes Asia, with 1.634 GW coming from two countries (Korea and Japan) and nine projects. Korea (1.606 GW), contributes by far the most, followed by Japan (28 MW). Then comes Europe, with 525.1 MW produced by 5 countries and 17 projects. According to [11], this applies for the period 2020–2027.

This data corresponds to announced projects, as of 2020, for the period 2020–2027 and does not necessarily correspond to the current planned floating wind power capacities of each country.

The largest contributor to Asia's planned floating wind power capacity is Korea, followed by the much smaller contribution from Japan in the period 2020–2027, according to [11].

With regard to Europe's planned floating wind power capacity, which was 525.1 MW in the period 2020–2027, the following countries contributed: France with 113.5 MW power capacity, Ireland with 106 MW, the UK with 105 MW, Spain with 103.2 MW, and Norway with 102.6 MW.

The overall planned floating wind power capacity in the world for the period 2020–2027 is 4.5791 GW, which mostly comes from North America (the US-2.42 GW), Asia (mainly from Korea, with 1.606 GW, and Japan, with 28 MW), and Europe (525.1 MW), and specifically the following contributing countries: France (113.5 MW), Ireland (106 MW), the UK (105 MW), Spain (103.2 MW), and Norway (102.6 MW). This is for the period 2020–2027, according to [11].

The overall planned floating wind power capacity in the world is 4.5791 GW, which mostly comes from North America (the US-2.42 GW), Asia (Korea-1.606 GW and Japan-28 MW), and Europe (Total of 525.1 MW coming from France-113.5 MW, Ireland-106 MW, the UK-105 MW, Spain-103.2 MW, and Norway-102.6 MW) for the period 2020–2027, according to [11]. Note that these values correspond to the announced projects as of 2020 for the period 2020–2027 and do not necessarily correspond to the actual planned floating wind power capacity OF each country.

The following sub-subsection discusses the presented installed and planned floating wind turbine projects' results, with specific reference to countries and contributing costs in the period 2009–2026, according to [11]. Not all the presented projects throughout this paper have available corresponding data that can be classified on the basis of project cost, wind speed, water depth, and distance to shore.

4.2.4. Discussions of the Presented Installed and Planned Floating Wind Turbine Projects' Results in Terms of Their Corresponding Countries and Their Contributing Costs in the Period 2009–2026

This sub-subsection discusses some of the presented installed and planned floating wind turbine projects' results in terms of their countries and their contributing costs in the period 2009–2026, according to [11]. This is because not all the presented projects throughout the paper have available corresponding data that can be classified on the basis of project costs.

With regard to the available data of some of the presented projects throughout this paper in terms of their corresponding continents and countries, Europe is the largest contributor to floating wind projects' cost, with 2.1127 billion dollars coming from 14 projects (7 installed and 7 planned) in 5 countries (France, the UK, Norway, Portugal, and Spain). It is followed by North America, with a project cost contribution of 112 million dollars coming from two projects (one installed and one planned) in one country (the US). The reference [11], which this data was taken from, did not provide information about the contributing cost of floating wind projects in Asia.

With regard to Europe, the highest contributing countries to the floating wind project cost were, according to the available data of some of the presented projects, France (962.7 million dollars), the UK (655 million dollars), Norway (316.5 million dollars), Portugal (159 million dollars), and Spain (19.5 million dollars). This corresponds to the period 2009–2026 according to [11].

The global floating wind projects' cost contribution is, according to the available data, 2.2247 billion dollars, which mainly comes from Europe (2.1127 billion dollars, from seven installed and seven planned projects) and North America (the US, with 112 million dollars from one installed and one planned projects). This corresponds to the period 2009–2026, according to [11].

It can also be said that, according to the available data, France is the largest contributor to the floating wind projects' cost, with 962.7 million dollars (coming from 1 installed and 4 planned projects). It is followed by the UK, with 655 million dollars (coming from 2 installed projects). And then Norway, with 316.5 million dollars (coming from one installed and two planned projects). Portugal follows, with 159 million dollars (coming from two installed projects), and then Spain, with 19.5 million dollars (coming from one installed and one planned project). This corresponds to the period 2009–2026, according to [11].

It can therefore be concluded that the global contributing costs are 2.2247 billion dollars, coming from 16 projects (eight installed and eight planned) in six countries (France, the UK, Norway, Portugal, Spain, and the US). This corresponds to the period 2009–2026 according to [11]. Note that it is not claimed that this data covers all the contributing costs of floating wind projects by continents and countries, both because of a shortage of data in these classifications, and the fact that they correspond to 2020, and not necessarily to 2023, when planned projects have been installed, with further updates.

The following sub-subsection discusses the results for some of the presented installed and planned floating wind turbine projects, with specific reference to their countries and contributing wind speeds in the period 2009–2026, according to [11]. This period is selected because not all the presented projects throughout this paper have available corresponding data that can be classified on the basis of project wind speed.

4.2.5. Discussion of the Presented Installed and Planned Floating Wind Turbine Project Results in Terms of Their Corresponding Countries and Their Contributing Wind Speeds in the Period 2009–2026

This sub-subsection discusses presented installed and planned floating wind turbine projects' results in terms of their corresponding countries and their contributing wind speeds in the period 2009–2026, according to [11]. This period is selected because not all of the presented projects have available corresponding data that can be classified on the basis of project wind speed.

With regard to the available data for some of the presented projects in each of the presented continents and countries, Asia has the highest wind speed of 45–48 m/s, coming from two installed projects and one country (Japan), followed by Europe, with 10–40 m/s coming from six projects (five installed and one planned) and six countries (Norway, Sweden, Portugal, France, Spain, and the UK). And North America, with 8.5–40 m/s coming from one country (the US). This corresponds to the period 2009–2026 according to [11].

In Europe, according to the projects' available data, Norway has the highest wind speed of 40 m/s (coming from one installed project), followed by Sweden with a wind speed of 35 m/s (coming from one installed project). Portugal comes after, with a wind speed of 31 m/s (coming from one installed project), and then France, with a wind speed of

24.2 m/s (coming from one installed project). Spain, with a wind speed of 12 m/s (coming from one planned project) and the UK, with a wind speed of 10 m/s (coming from one installed project) are the last two countries. This corresponds to the period 2009–2026, according to [11].

It can therefore be concluded that the global floating wind projects' wind speed is, according to the available data, 8.5–48 m/s, with the highest wind speed coming from the following continents and countries. Asia with a wind speed of 45–48 m/s, coming from one country (Japan). Then comes Europe with a wind speed of 10–40 m/s, coming from six countries (Norway with 40 m/s, Sweden with 35 m/s, Portugal with 31 m/s, France with 24.2 m/s, Spain with 12 m/s, and the UK with 10 m/s). And North America, with a wind speed of 8.5–40 m/s coming from one country (the US). This corresponds to the period 2009–2026, according to [11].

It can be concluded that the global contributing wind speeds to the floating wind projects are 8.5–48 m/s, coming from 13 projects (8 installed and 5 planned) and 8 countries (Norway, Sweden, Portugal, France, Spain, the UK, the US, and Japan). This corresponds to the period 2009–2026, according to [11]. Note that this data is not claimed to cover all the contributing wind speeds of floating wind projects for continents and countries, as there is a shortage of data in these classifications and it corresponds to 2020, and not necessarily to 2023, where some of the planned projects have been installed and further updates have occurred.

The following sub-subsection discusses the presented installed and planned floating wind turbine projects results, with specific reference to their corresponding countries and their contributing water depths for the period 2009–2026, according to [11]. This is because not all of the presented projects throughout this paper have available corresponding data that can be classified on the basis of projects' water depths.

4.2.6. Discussion of the Presented Installed and Planned Floating Wind Turbine Project Results in Terms of Their Corresponding Countries and Their Contributing Water Depths in the Period 2009–2026

This sub-subsection discusses the presented installed and planned floating wind turbine projects' results, with specific reference to their corresponding countries and their contributing water depths in the period 2009–2026, according to [11]. This period is selected because not all of the presented projects throughout this paper have available corresponding data that can be classified on the basis of projects' water depths.

With regard to the available data for some of the presented projects in each of the presented continents and countries, North America has the highest water depth capacity, with 27.4 m–1 km coming from four projects (one installed and three planned) in one country (the US). Europe is next, with a water depth capacity of 33–330 m coming from 14 projects (eight installed and six planned) in six countries (Norway, the UK, France, Portugal, Spain, and Sweden). And then Asia, with a water depth capacity of 55–125 m coming from three installed projects and one country (Japan). This corresponds to the period 2009–2026, according to [11].

With regard to Europe, the projects' available data shows that Norway has the highest water depth capacity of 200–300 m, from one installed and two planned projects. It is followed by the UK, with a water depth capacity of 90–120 m (coming from two installed projects), and then France, with a water depth capacity of 33–100 m (coming from one installed and four planned projects). Portugal, with a water depth capacity of 49–100 m (coming from two installed projects) is then followed by Spain, with a water depth capacity of 85 m (coming from one installed project) and Sweden, with a water depth capacity of 35 m (coming from one installed project). This corresponds to the period 2009–2026 according to [11].

It can therefore be concluded that the global floating wind projects' water depth capacity is, according to the available data, 27.4 m–1 km with the highest water depth capacity in the following continents and countries. North America, with a water depth capacity of 27.4 m–1 km coming from 4 projects (1 installed and 3 planned) and one country (the US). Followed by Europe, with a water depth capacity of 33–300 m coming from 14 projects (8 installed and 6 planned) in 6 countries (Norway with 220–300 m, the UK with 90–120 m, France with 33–100 m, Portugal with 49–100 m, Spain with 85 m, and Sweden with 35 m). And, finally, Asia, with a water depth capacity of 55–125 coming from three installed projects in one country (Japan). This corresponds to the period 2009–2026, according to [11].

It can therefore be concluded that the global contributing water depths to the floating wind projects are 27.4 m–1 km, coming from 21 projects (12 installed and 9 planned) in 8 countries (Norway, the UK, France, Portugal, Spain, Sweden, the US, and Japan). This corresponds to the period 2009–2026 according to [11]. Note that this data is not claimed to cover all the contributing water depths of floating wind projects for continents and countries, both because of a shortage in data in these classifications, and because this data corresponds to 2020 and not necessarily to 2023, where some of the planned projects have been installed and further updates have occurred.

The following sub-subsection discusses the presented installed and planned floating wind turbine projects results, with specific reference to their corresponding countries and their contributing distances to shore in the period 2009–2026, according to [11]. This period is selected because not all of the presented projects throughout this paper have available corresponding data that can be classified on the basis of projects' distances to shore.

4.2.7. Discussion of the Presented Installed and Planned Floating Wind Turbine Project Results in Terms of Their Corresponding Countries and Their Contributing Distances to Shore in the Period 2009–2026

This sub-subsection discusses some of the presented installed and planned floating wind turbine projects' results, with specific reference to their corresponding countries and their contributing distances to shore in the period 2009–2026, according to [11]. This period is selected because not all the presented projects have available corresponding data that can be classified on the basis of projects' distances to shore.

With regard to the available data for some of the presented projects in each of the presented continents and countries, Europe has the highest distances to shore (of 800 m–140 km) coming from 14 projects (7 installed and 7 planned) in 5 countries (Norway, the UK, France, Portugal, and Spain). Then comes Asia, with distances to shore of 5–62 km coming from 4 projects (3 installed and 1 planned) in 2 countries (Korea and Japan). It is followed by North America, with distances to shore of 330 m–48 km coming from 5 projects (1 installed and 4 planned) in 1 country (the US). This corresponds to the period 2009–2026.

It can therefore be concluded that the global floating wind projects' distances to shore are, according to the available data, 300 m–140 km with the highest distances to shore coming in the following continents and countries. Europe, with distances to shore of 800 m–140 km coming from 14 projects (seven installed and seven planned) in 5 countries (Norway with 10–140 km, the UK with 15–25 km, France with 15–22 km, Portugal with 5–20 km, and Spain with 800 m–3.2 km). Then comes Asia, with distances to shore of 5–62 km coming from four projects (three installed and one planned) in two countries (Korea and Japan). And finally, North America, with distances to shore of 330 m–48 km coming from five projects (one installed and four planned) in one country (the US). This corresponds to the period 2009–2026.

It can therefore be concluded that the global distances to shore are 300 m–140 km, coming from 23 projects (11 installed and 12 planned) in 8 countries (Norway, the UK, France, Portugal, Spain, the US, Korea, and Japan). This data is not claimed to cover all the contributing distances to shore of floating wind projects in continents and countries, both because of a shortage in data in these classifications, and because this data corresponds to 2020, and not necessarily to 2023, where some of the planned projects have been installed and further updates have occurred.

The following three subsections will provide references for the global floating wind situation, with a specific focus on Europe, the Power-to-X technology that is relevant to floating wind farms, and the feasibility of implementing floating wind projects in Romania.

The following subsection presents references for the global floating wind situation, with a specific focus on Europe.

4.3. References Regarding the Global Floating Wind Situation with a Focus on Europe

This subsection presents references for the global floating wind situation, with a focus on Europe.

A European floating wind research project was established to support the European floating wind development, with a total cost of 50 million euros and an expected revenue of 5000 (5 billion) million euros [80]. Europe is working towards both keeping its position as the world's floating wind leader and becoming the largest floating wind manufacturer by focusing on the following aspects. It will first focus on the European pre-commercialized floating wind projects and their corresponding incentives and grants, and then turn its attention towards the European-patent floating wind concepts and collect them in a corresponding design portfolio, which it will rapidly push toward serial production. Third, it will focus on European large-scale floating wind projects and make corresponding large governmental investments before finally developing the European coastal infrastructure and making it suitable for the implementation of large-scale floating wind projects. It will also focus on financing the private sector and making European inter-governmental floating wind collaborations [4].

A typical 2 MW Spar floating wind support structure weighs 140 tons and has a draft of 100 m, a water depth of 700 m, a tower height of 70 m, and a total height of 100 m. The demonstration of a typical floating wind project takes seven years, and an additional eight years is required for its construction, as was the case with the Hywind Scotland project [81].

The overall cost of floating wind projects breaks down into the implementation of floating support structures (24%), implementation of wind turbines (33%), operation and maintenance (23%), grid connection (15%), and decommissioning (5%) [82].

Spar-buoy is the simplest floating wind support structure, and it has convenient stability. Semi-submersible is less stable because of its comparably larger water-plane area and is also relatively difficult to manufacture. TLP is the most stable floating wind support structure, but it has both the most difficult installation and an inconvenient mooring system price (See Table 1). The typical cost of a generic floating wind turbine is 8 million euros/MW [9].

Spar-buoy has both ballast and drag-embedded catenary-mooring, as well as anchor stability systems. Semi-submersible and Barge have both buoyancy and mooring stability systems. TLP has both mooring lines and suction pile anchors [82].

Romania is a feasible candidate for floating wind implementation [83,84]. However, it lacks electrical infrastructures in the sea areas, which will make it necessary to implement floating wind Power-to-X technology that will do the job of transforming the produced electrical power mainly into hydrogen or compressed air, before accordingly transporting it through ships or other means to offshore or onshore customers. This technology could also be considered to be a candidate for replacing the European gas import from other countries, by converting renewable energy's produced electricity into other chemicals, such as methanol and synthetic natural gas [85].

The following subsection presents Power-to-X technology references of relevance to the floating wind projects.

4.4. Power-to-X Technology References of Relevance to Floating Wind Projects

This subsection presents Power-to-X technology references of relevance to the floating wind projects.

Paper [86] recommends the integration of Power-to-X technology with floating wind electrical power cables. This paper states that while further Power-to-X technologies will soon come, they are currently costly, and will require some time to reduce feasible implementation and maintenance costs. It also states that there is a Power-to-X project that, through the scope of its integration with the North Sea floating wind farms, will reduce costs of billions of euros in the future. This Power-to-X project is currently proposed to be put into operation in 2029. Paper [87] presents an offshore wind weather conditions modeling, with a specific focus on maintenance aspects. Paper [88] presents a floating wind turbines' reliability approach, which is of direct relevance to their power production conditions. While the latter two references are not necessarily directly relevant to our discussion, they can be taken as a point of reference by relevant discussions in the future.

Paper [89] presents a Power-to-X project that is relevant to the discussion of floating wind projects. This project transforms the produced electrical power into hydrogen by using its integrated Power-to-X technology, which is incorporated in each of the project's corresponding floating wind turbines. The transformed produced hydrogen will then be transported to a nearby hydrogen storage subsea unit before the hydrogen power is transported to an offshore customer. This project is planned to begin operation in 2025. The Power-to-X technology in each of the corresponding wind turbines consists of fuel cells, electrolysis, HV power, and seawater treatment.

Paper [90] presents economic considerations in the use electrolysis and methanol that are relevant to the Norwegian Power-to-X technology. Both the electrolysis and methanol are cost-efficient, which makes this technology implementable. This technology has great potential to produce synthetic natural gas (SNG), which could potentially eliminate the European dependence on gas transport from other continents. The cost of this synthetic natural gas is 110–140 euros/MWh. This technology has been stated to be clean, cheap, and very feasible, especially in northern Europe.

Paper [91] presents floating wind operation and power production aspects, along with important aspects that are relevant to the floating wind Power-to-X technology.

Paper [92] presents the implementation of the Power-to-X technology as being relevant to transforming renewable electricity into green products and services. It also mentions some floating wind aspects that are relevant and shows how the use of this technology can realize the floating wind future potential of 90 GW in New Zealand by converting the produced electrical energy into green hydrogen or green ammonia. This paper also states that the offshore bottom-fixed wind future energy potential of 14.4 GW in New Zealand can be realized if this technology is implemented.

Paper [93] states that the Power-to-X technology will play a great role in achieving zero emissions by 2050 in Europe, and also suggests that this technology should be efficiently integrated into the energy system. It also presents the following detailed layout of the process through which electrical energy is converted into some chemicals, which follows. First, the electrical energy is produced from renewable energy systems, and then electrolysis, such as oxygen and heat, is used to convert the electrical energy into hydrogen, ammonia, or hydrocarbons (gas or liquid forms). This paper also states that the European hydrogen Power-to-X capacity plan is 40 GW as of 2030, with a potential increase of an additional 40 GW coming from electrolysis capacity that will potentially be shipped from Ukraine and some North African countries. The European Power-to-X capacity plan states that, after 2030, 180 GW will be generated in the North Sea.

Paper [89] states that the investment and maintenance costs of the Power-to-X technology should be reduced to enable the technology to become feasible. The implementation of such technologies will connect the future North Sea floating wind projects with each other and cut their costs by 20 billion euros (this is the "Hub-and-Spoke Project in the North Sea").

Paper [94] proposes three Power-to-X typologies for hydrogen energy production in floating wind farms. The first typology uses centralized onshore electrolysis; the second typology uses decentralized offshore electrolysis; and the third uses centralized offshore electrolysis. The first has the advantage of easier installation and lower costs; the second has the advantage of using the existing electrolysis technology that comes from offshore bottom-fixed and onshore wind industries; and the third has the advantage of reducing the maintenance of individual turbines. See the reference for further details on this.

The following subsection refers to research that provides further insight into the feasibility of building floating wind projects in Romania and also addresses relevant considerations.

4.5. Research Related to the Feasibility of Floating Wind Projects in Romania and Relevant Considerations

This subsection addresses previous research contributions that relate to the feasibility of floating wind projects in Romania and also addresses some relevant considerations.

Girleanu et al. [95] state in their paper that the north-western region of the Black Sea has a high wind power density of 500 W/m^2, which makes it feasible to implement floating wind projects with a water depth capacity of 25–125 m.

Raileanu et al. [96] state in their paper that the most feasible Romanian city for floating wind implementation is Constanta, in an offshore region that is 20 km from the shore. In referring to wind turbines available on the market, they also state there are some limitations in the Romanian wind speeds. For example, the 10 MW Vestas wind turbine has a rated wind speed of 10 m/s. However, average Romanian regions have a maximum wind speed of 8 m/s, meaning that, as a consequence, the maximum power cannot be extracted from the respective wind turbine and the levelized cost of energy (LCOE) will be higher for the corresponding case. A further remedy has been suggested, which is to only consider wind turbines with a rated wind speed that is close to the wind speed in project implementation regions.

Onea and Rusu. [97,98] state in their papers that the Black Sea has the potential to implement wind turbines with a height of 80 m and a Betz limit of 50% (i.e., wind turbines that absorb 50% of the wind they are subjected to and convert it into electricity).

In a separate paper, Raileanu et al. [99] conclude that the Romanian Black Sea is a wind energy resource, especially in the winter, between January and April. They also note that Romania has an onshore wind farm ("Fantanele & Cogealac"), which is one of the largest European onshore wind projects. This project is in an onshore area that is 20 km from the Black Sea shore. This project has a power capacity of 600 MW and an installation cost of one billion euros.

Onea et al. [100] observe that the windiest part of the Black Sea is its north-eastern region, in Ukraine. However, they add that, due to its corresponding geopolitical climate issues, the Romanian region of the Black Sea is currently the best offshore wind candidate. They also observe that this area, which has the highest wind speed in the region, has satisfactory wind and wave dynamics that will make it feasible to implement hybrid offshore wind and wave power projects.

The following section concludes the data developed throughout this paper that are directly relevant to global floating wind concepts and projects.

5. Conclusions

This section presents conclusions about the presented and developed data throughout this paper that are directly relevant to global floating wind concepts and projects.

The data presented in this paper mainly relates to floating wind projects in the period 2008–2020 and planned floating wind projects installed in the period 2020–2027.

It was found that the global installed floating wind power capacity is 174.7 MW, mainly coming from Europe (123.5 MW), North America (30.2 MW), and Asia (21 MW). Refer to Section 4 for further details about the involved countries and corresponding projects, as well as comments on the reliability of this data.

It was found that the global planned floating wind power capacity is 4.5791 GW, mainly coming from the US (2.42 GW), Asia (1.634 GW), and Europe (525.1 MW). Refer to Section 4 for further details about the involved countries and corresponding projects, as well as comments on the reliability of this data.

With regard to the installed floating wind projects in Europe, the results of this paper suggest that in the period 2008–2020, the biggest contributor was the UK, with a power capacity of 89.5/123.5 MW, followed by Portugal, with 27.5/123.5 MW, and then a range of countries with an overall minor capacity of 6.5 MW (Norway, Germany, France, Spain, Denmark, and Sweden).

With regard to the planned floating wind projects in Europe, the results of this paper suggest that in the period 2020–2027, the biggest contributor was France, with a power capacity of 113.5 MW, followed by Ireland (106 MW), the UK (105 MW), Spain (103.2), and Norway (102.6 MW). Note that these values correspond to the projects announced up to 2020, and do not necessarily correspond to the current global floating wind power capacity.

Further classifications of some of the presented installed and planned projects were made. The analysis could not cover all the presented projects throughout this paper, due to a shortage of data regarding the costs, wind speeds, water depths, and distances to shore of some of the presented projects in the paper. This data corresponds to the period 2009–2026.

According to the available data of some of the presented projects throughout this paper, the global cost contribution from floating wind projects was 2.2247 billion dollars, mainly coming from Europe (2.1127 million dollars) and North America (112 billion dollars). There was no available cost data for Asian floating wind projects.

According to the available presented data of some of the presented projects throughout this paper, the global wind speed interval from floating wind projects was 8.5–48 m/s, mainly coming from Asia (45–48 m/s), Europe (10–40 m/s), and North America (8.5–40 m/s).

According to the available presented data of some of the presented projects throughout this paper, the global water depth interval from floating wind projects was 27.4 m–1 km, mainly coming from North America (27.4 m–1 km), Europe (33–300 m), and Asia (55–125 m).

According to the available presented data of some of the presented projects throughout this paper, the global distance to shore interval from floating wind projects was 300 m–140 km, mainly coming from Europe (800 m–140 km), Asia (5–62 km), and North America (330 m–48 km). Refer to Section 4 for further details about the countries and projects involved in these classifications.

The number of global floating wind turbine concepts throughout this paper is found to be 28, coming from 5 wind turbine types as follows: semi-submersible (13), spar (5), TLP (5), multi-turbine (3), and barge (2). Eight of these wind turbine concepts are made from steel, six from concrete, and four from steel and/or concrete. Refer to Section 4, where the details and reliability of these results are discussed in further detail.

It was also mentioned in Section 4 that different researchers offer different values when considering the total number of global floating wind concepts. Refer to Section 4, where more details about the corresponding countries and references are provided.

It was also illustrated throughout the paper that different research contributions refer to different data when considering global installed and planned floating wind power capacities. The data was therefore presented as it is in the different contributions, and an effort was made to illustrate some of the differences and possibilities that arose from discrepancies and issues with reliability in the presented data. This is discussed in more detail in Section 4.

It was also hinted throughout the paper that the floating wind levelized cost of energy (LCOE) is becoming comparable with its offshore bottom-fixed and onshore counterparts and it will ultimately depend on the extent and speed of its evolution. For example, according to one finding, the floating wind LCOE will be 50 euros/MWh in 2030, when its power capacity will be 4 GW, compared to its current value of 250 euros/MWh. Other research contributions referenced throughout the paper state that there will be a floating wind power capacity of 3 GW only coming from Norway by 2030. This suggests that such sources of data on the future of floating wind capacities and corresponding LCOE costs have discrepancies and are not necessarily reliable.

This paper also considered the Power-to-X technology of relevance to floating wind projects, and it was stated that this technology eliminates the need for corresponding enormous electrical infrastructures by converting the produced electrical energy, mainly into compressed air and hydrogen, or other chemical substances (such as hydrocarbons, ammonia, methanol, and synthetic natural gas) by using electrolysis such as oxygen and heat for the countries which lack such infrastructures in their offshore regions.

This paper also considered the feasibility of floating wind projects in Romania, and concluded, on the basis of the findings and research contributions referenced throughout the paper, that the lack of corresponding electrical infrastructures in Romanian Sea regions means that it is not currently feasible to implement floating wind projects in Romania. However, the integration of the Power-to-X technology into future floating wind projects in Romania could potentially make it possible to implement such projects. It was stated throughout the paper that the European hydrogen Power-to-X technology plan is 40 GW, with a potential additional plan of an extra 40 GW, making a total of 80 GW by 2030. After 2030, there is a plan to add a further 180 GW in the North Sea region.

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