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Research paper

TOPSIS methodology applied to floating offshore wind to rank platform designs for the Scotwind sites

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A B S T R A C T

Floating offshore wind turbines are perceived as a techno-economically attractive solution due to their huge potential, however, their Levelised Cost of Energy (LCoE) has the potential to be further reduced, making it more competitive with current technology. The Multidisciplinary Design, Analysis, and Optimisation (MDAO) method is considered a promising way to reduce LCoE. The substructure is expected to accounts for around 35% of the capital cost hence optimisation frameworks have been applied to this area in numerous studies. A difficulty with this method is creating a flexible and robust framework which can model all platform types (i.e., waterplane, ballast, and mooring stabilised configurations), which, simultaneously, remains computationally affordable. In this work, a concept selection method to rank the platform types based on their suitability for a given site is provided. The approach allows a reduction of the design space for an MDAO approach, creating substantial computational time savings. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a Multi-Criteria Decision Analysis (MCDA) method which is used in this work to rank the platform types in order of relevance for a given site. This technique allows a decision to be made when there are conflicting parameters such as cost and performance. The parameters are prescribed a weighting value by the user, representing the importance based on their specific point of view. In order to determine which platform is appropriate for a specific site, a number of criteria were set related to the site's water depth, tidal range, soil condition, and wave height. This determines which platform is most suitable based on the physical parameters related to the site. The ranking can be found by combining the weighting of each parameter, the criteria related to the site, and the physical characteristics of each site. In order to support our proposed method, a case study considering the recent Scotwind lease is performed, showing that the derived best solutions are largely in agreement with the platform types considered by the developers.

1. Introduction

The global offshore wind market has grown by nearly 30% per year between 2010 and 2018, and has seen a 73-fold increase from 2001 to 2021 in the UK alone (IEA, 2019; Sky News, 2021). This staggering growth highlights the sheer success of fixed offshore wind farms. However, with the rapid deployment of offshore wind farms, the number of available nearshore sites is decreasing. Developers are now being forced into deeper, further offshore waters. It is suggested that fixed platforms become economically and technically impractical beyond a water depth of approximately 70 m (Hannon et al., 2019; Paya and Du, 2020). This trend has been further reinforced with the recent Scotwind auction revealing that 60% of the proposed sites have opted for a floating support structure expectantly due to the water depth. There are a number of difficulties in moving further offshore such as distance to travel, harsher operating conditions, and the risk and cost associated with the new proposed technology. This is, however, expected to be rewarded with a stronger and more consistent resource, hoping to aid overall the cost of energy reduction (OMV Group, 2022).

Focusing research efforts on cost reduction is imperative to reduce floating offshore wind costs, ensuring it is competitive with fixed offshore wind and other energy sources. One area which has been highlighted with the potential to reduce cost is the Capital Expenditure (CapEx), typically accounting for around 70% of the overall cost (Maienza et al., 2020; Laura and Vicente, 2014). A large contributor to the CapEx is the floating support structure. This component can contribute up to 35% of the total CapEx costs (Maienza et al., 2020), more information on the cost breakdown can be found in Sykes et al. (2023b). The platform design and subsequent geometry can also have a heavy influence on the installation cost and operation and maintenance cost. Hence by optimising the geometry the percentage of cost which

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could be affected is greater than 35%. Larger platforms, such as a spar, require more storage space and more complex installation techniques compared to a simple tow-to-site exercise, which can be utilised for a semi-submersible. Smaller platform geometries, such as the Tension Leg Platform (TLP), are also expected to have a more difficult installation process compared to the semi-submersible since the platform has lower stability and the mooring system is more complex. It is expected that with increasing turbine size, the platform size will also increase and potentially create added difficulties for the tow-to-site procedure, with the potential for stricter limiting criteria such as vessel speed, wave height, and wind speed. This is an unknown of floating offshore wind, further research and real-life installations are required to solidify this notion.

Standardising a single suitable floating platform for all sites poses an extremely difficult challenge, especially given the huge variation in platform geometry currently found in the literature (Sykes et al., 2023a). Therefore, since the industry lacks maturity and there is not yet one single solution for all cases, initial platform design exploration is important. Optimisation techniques are used in numerous industries, exploring large design spaces, unlike traditional iterative design methods. Applying an optimisation technique to floating offshore wind will allow new geometries to be explored particularly in the early design stages, highlighting optimal configurations for each typology. A number of optimisations for the platform have already been carried out within the literature (Hegseth et al., 2020; Clauss and Birk, 1996; Sclavounos et al., 2008; Ghigo et al., 2020; Leimeister and Kolios, 2021; Leimeister et al., 2019; Pollini et al., 2021; Gilloteaux and Bozonnet, 2014; Birk and Clauss, 2008; Dou et al., 2020; Leimeister et al., 2021, 2020; Fylling and Berthelsen, 2011; Myhr and Nygaard, 2012; Hegseth et al., 2021; Ferri et al., 2022; Bracco and Oberti, 2022; Benifla and Adam, 2022; Lemmer et al., 2020; Ferri and Marino, 2022; Hall et al., 2013; Karimi et al., 2017; Wayman, 2006). A comprehensive review of these studies is provided in Sykes et al. (2023a). Utilising this technique could be the key to reducing the platform and installation costs, which make up a significant portion of the CapEx (Maienza et al., 2020). A key takeaway from these papers is typically the three main platform typologies are assessed for the same site and compared. One of the main drawbacks of optimisation techniques is the high computational time and, generally, a trade-off between time and design space has to be made. This paper proposes a new initial pre-filtering step to the optimisation process, removing platforms which are not suitable for a specific site, and ranking the remaining platforms in the order of 'best' to 'worst'. By doing so, the design space will be scaled down and the simulation time will be reduced. This allows a more realistic approach to be taken, unlike the majority of existing work which evaluates the three main platform typologies for the same generic site (Sykes et al., 2023a). A commonly used method across a range of industries such as: Human Resource Management, transportation, product design, manufacturing, water management, quality control, and location analysis is the Technique of Order Preference Similarity to the Ideal Solution (TOPSIS) (Kolios et al., 2010). This approach can be used to rank the platforms based on a number of criteria and weighting provided by the user, leaving the user with the most preferable solution for the site.

This work is presented in the following sections: Section 2 provides a review of parameters and criteria to determine the suitability of a specific platform for a given site, Section 3 describes the approach to implementing the TOPSIS methodology, and Section 4 introduces the ScotWind case study with the subsequent most suitable platform for each of the selected regions. Section 5 has a discussion on the results presented in the previous section. Finally, the conclusion and future work is explained in Section 6.

2. Platform typology review

Platforms can easily be separated into three main types, ballast, waterplane and mooring stabilised. Ballast stabilised platforms such as a spar a long slender cylindrical column which utilises ballast in the bottom sections to lower the centre of gravity (cog) and provide the desired restoring force. Waterplane stabilised platforms such as semi-submersibles and barge have a large waterplane area and shallow draft in comparison to the spar, where the stability comes from the large second moment related to the waterplane area. Finally, TLPs are in general the smallest, with a central column and a number of legs from which the taut mooring lines area attached. Unlike the other two, the taut mooring lines provide stability.

A more in depth review of each platform typology can be found in previous work (Sykes et al., 2023b), it is clear that there are common key parameters which can help identify which platform is appropriate for a given site. The parameters related to the site characteristics which affect platform choice which were identified are: seabed typology, water depth, wave height, and tidal range. It can be noted that the turbine itself will also have an impact on the platform performance however at this early design stage it cannot be considered but can be considered in the optimisation process itself. The following sections review each key parameter related to the site characteristics and are as follows: Section 2.1 details the seabed characteristics, Section 2.2 focuses on water depth, Section 2.3 details information of wave height and Section 2.4 considers the effects of tidal range. The remaining sections are related to the platform: Section 2.5 reviews the cost of each platform, Section 2.6 details Technology Readiness Level (TRL), and finally Section 2.7 compares the size of each platform.

2.1. Seabed characteristics

The type of seabed the platform must anchor into plays a key role in determining which anchors and hence mooring arrangements are applicable. For a taut mooring system, it is required that the anchor can handle both horizontal and vertical loading (Rhodri and Ros, 2015; Salvação and Guedes Soares, 2016). For this reason, specialised anchors such as driven piles, suction piles, or gravity anchors are required. Driven pile anchors are harmful to the environment. Since this process requires piling via a hammer for installation, a large amount of noise is created, affecting surrounding life. The gravity anchor and the driven pile are challenging to remove upon decommissioning due to their weight and embedded characteristics, respectively. Suction piles offer a less intrusive, comparatively straightforward installation and decommissioning process (Monfort, 2017). Catenary mooring systems can use simplistic drag-embedded anchors which are cheap, simple to install, and recoverable in the decommissioning phase (Rhodri and Ros, 2015; Salvação and Guedes Soares, 2016). The four main anchor types can be seen in Fig. 1. Each anchor is compatible only with specific types of soils/seabeds, and categorising soil is a complex problem. Monfort (2017) also state that this is difficult and in general, when selecting an anchor in situ tests will be required, but soil can be categorised as sand or clay. The reason for this is other substrates such as gravel and cobbles have very similar behaviour to sand, and silt and clay can both be considered as clay due to their shared characteristics.

The drag anchor is most suited to cohesive sediment, however, it cannot be too stiff or it will not be able to penetrate the seabed (ABS, 2023; Rhodri and Ros, 2015; Heidari, 2017). For this reason, it is expected a 'soft' to 'medium' sea bed soil such as sand and clay would be most applicable. The driven pile is applicable to all types of seabeds, however in conditions where the seabed is 'hard', like bedrock, installation can become expensive. Due to the nature of suction pile anchors, they have difficulty holding in certain soft seabeds like sand and struggle to penetrate hard seabeds, but can hold in soft soil such as clay. For this reason, clay seabeds are most suitable (ABS, 2023; Rhodri and Ros, 2015; Nordstrom, 2014). Finally, the gravity anchor

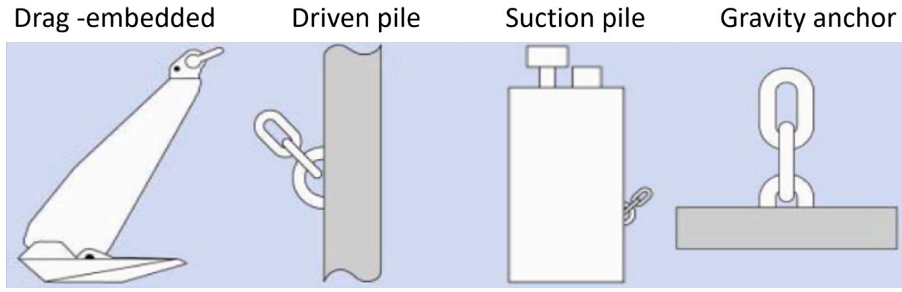

Fig. 1. Anchor types (Rhodri and Ros, 2015).

Table 1
Details on anchor suitability for seabed types (ABS, 2023; Rhodri and Ros, 2015; Heidari, 2017; Nordstrom, 2014).

Anchor type	Loading	Applicable mooring system type	Seabed type
Drag anchor	Horizontal	Catenary	Soft/Medium
Driven Pile	Vertical or Horizontal	Catenary or Taut	Soft/Medium/Hard
Suction pile	Vertical or Horizontal	Catenary or Taut	Soft/Medium
Gravity Anchor	Vertical or Horizontal	Catenary or Taut	Soft/Medium/Hard

can be used in a range of seabeds, and it is expected that the holding capacity can change with time in soft soil since loose soils can be displaced (Rhodri and Ros, 2015; Salvação and Guedes Soares, 2016; Ikhennicheu et al., 2021; ABS, 2023; Cribbs et al., 2023; Heidari, 2017). A summary can be found below in Table 1.

Soil conditions of a site as mentioned previously can be categorised by soft, medium, and hard, using the same description in Li et al. (2016). Soft soil consists of <30% hard material, medium material contains between 30 and 70% hard material, and hard soil consists of >70% hard materials. Anything larger than gravel materials, such as rubble, cobbles, boulders, and bedrock, is classed as a 'hard' material, and mud, sand, and gravel are considered soft material (Tissot et al., 1992). This classification scale was used to determine which would be best for each anchor type shown in Table 1 Since the type of platform dictates the mooring system, the seabed of the sites can help determine the best platform (Salvação and Guedes Soares, 2016).

2.2. Water depth characteristics

Water depth is a relatively simple parameter to help determine which platform is suitable or unsuitable. The spar platform is restricted to deep water locations, due to its large draught (Rhodri and Ros, 2015; Salvação and Guedes Soares, 2016; Leimeister et al., 2018). On the other hand, TLPs are expected to be most appropriate for intermediate water depths due to their expensive station-keeping systems (Leimeister et al., 2018). The semi-submersible is flexible in that it can be used in all water depths (Rhodri and Ros, 2015; Salvação and Guedes Soares, 2016; Leimeister et al., 2018). However, for shallow water deployment, fixed bottom turbines are also suitable. These have the advantage of being cheaper with a higher TRL than semi-submersible designs. It has been expressed that there is a cut-off point for both fixed and floating platforms. Fixed platforms are expected to be appropriate up until 70 m and the floating platform depth range starts from 30 m (Paya and Du, 2020). However, in the range between 30–70 m, the cost and TRL will play a huge role in determining the most appropriate platform (Paya and Du, 2020). Water depth can be categorised as shallow, intermediate, and deep. The cut-off for these categories is determined by the user in this work however, based on the mentioned points, shallow water is considered below 70 m, intermediate water is from 70 m to 150 m, and deep water is greater than 150 m.

2.3. Wave height characteristics

The wave height of the given site is not a particular issue for the spar as these can operate in high-sea states due to their small waterplane area. Similar to the spar, a TLP can also operate in high sea states because of its high stability provided by the taut mooring lines (Leimeister et al., 2018). Since the semi-submersible has a large waterplane area, it is more susceptible to higher motions in larger sea states. The semi-submersible is, therefore, more suited to lower sea states compared to other typologies (Leimeister et al., 2018). This is however a very difficult way to categorise which platform is most suitable given the huge variety in shape and size of each platform typology. It is expected the only way to determine which platform has the best dynamic response accurately in a given sea state is to carry out hydrodynamic analysis, which should be done later in the optimisation stage instead. However, in this work, it is considered that TLP operates best followed by the TSpar and semi-submersible, sticking to the generic shapes and respective dynamic response in different sea states. As a rule of thumb for this work the sea states can be classed as follows, a low sea state would have a significant wave height of 3 m and less, and a high sea state would be 8 m and greater, since there is no literature on this classification the assumption is purely based on the authors knowledge and the Beaufort scale. Similar to the water depth categorisation this categorisation of water depth is a user input which can be changed based on opinion.

2.4. Tidal range characteristics

The tidal range is an important parameter for the TLP as it has a taut mooring system (Leimeister et al., 2018). The platform is designed in order to avoid a situation whereby one or more tendons are slack since this would induce snap loads. For these reasons, the TLP needs to be positioned in an area which is exposed to little changes in mean water level due to tide. Rather than using an allowable fixed tidal range, the ratio of water depth to tidal range can be taken for a site and a suitable ratio could be determined to make it more universally applicable since generally tidal range changes with water depth and distance to shore. A reasonable assumption for the tidal range to water depth ratio is 5%.

2.5. Cost breakdown

The wind turbine and its support structure are often shown in a cost breakdown, as roughly 35% of the CapEx. The CapEx itself is the majority of the overall cost ranging from 53% to 77% (Laura and Vicente, 2014; Maienza et al., 2020), Operational Expenditure (OpEx) is between 18% and 30% and Decommissioning Cost (DecEx) cost found in the literature range from creating revenue to costing 5% of the overall cost. It can be highlighted that work should be done to reduce the CapEx since it is the largest percentage of the cost, however, there could

Table 2
Cost breakdown for each geometry, highlighting minimum, means and maximum values found across the literature (Alsubal et al., 2021; Catapult, 2023; Westwood, 2010; Gonzalez-Rodriguez, 2017; Slengesol et al., 2010; Kaiser and Snyder, 2013; Jacquemin et al., 2009; ODE, 2007; Ghigo et al., 2020; Castro-Santos et al., 2016; Laura and Vicente, 2014; Maienza et al., 2020; Stehly et al., 2020; Martinez and Iglesias, 2022, 2021; Myhr et al., 2014; Heidari, 2017; Bjerkseter and Ågotnes, 2013; Lerch et al., 2018).

	Spar			Semi-submersible			Barge			TLP			Monopile		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Structure (£M/MW)	1.49	0.545	0.957	1.64	0.664	0.891	0.984	0.398	0.534	1.2	0.326	0.796	0.5	0.225	0.367
Mooring and Anchor (£M/m)	0.335	0.017	0.192	3.2	0.107	0.710	3.2	0.107	0.710	1.053	0.017	0.481	N/A	N/A	N/A
Installation (£M/MW/km)	0.038	0.001	0.022	0.036	0.001	0.01	0.036	0.001	0.01	0.138	0.012	0.053	0.028	0.012	0.019
OpEx (£M/MW/km)	0.209	0.0007	0.046	0.208	0.0007	0.036	0.208	0.0007	0.036	0.21	0.0007	0.046	0.056	0.002	0.015
DecEx (£M/MW/km)	0.039	−0.001	0.012	0.039	−0.001	0.009	0.039	−0.001	0.009	0.042	0.001	0.025	0.015	0.005	0.011

potentially be a trade-off where increasing the CapEx slightly might reduce the OpEx a considerable amount by decreasing the probability of failure, or introducing more sensors allowing maintenance requirements to be better predicted. Given the different platform typologies, it is clear that there is a cost variation depending on the platform. In order to compare platforms in terms of cost, information was collected from the existing literature and is presented in Table 2 (Alsubal et al., 2021; Catapult, 2023; Westwood, 2010; Gonzalez-Rodriguez, 2017; Slengesol et al., 2010; Kaiser and Snyder, 2013; Jacquemin et al., 2009; ODE, 2007; Ghigo et al., 2020; Castro-Santos et al., 2016; Laura and Vicente, 2014; Maienza et al., 2020; Stehly et al., 2020; Martinez and Iglesias, 2022, 2021; Myhr et al., 2014; Heidari, 2017; Bjerkseter and Ågotnes, 2013; Lerch et al., 2018). Since the preliminary costs, turbine, and transmission costs are considered constant for all platform types, they were not considered in the CapEx cost. Information on the cost of a barge was difficult to quantify due to a lack of relevant sources. For this reason, the mooring and installation costs were assumed to be the same as a semi-submersible, given their similar size and the use of a similar mooring arrangement. This is a limitation of this paper since no other information was available. It can also be noted that the costs have been considered separately within this work. The reason for this is there is often a bias towards CapEx since it holds the largest share of overall cost. Considering each separately will allow the impact of each to be considered when selecting a design.

Cost is an important part of any project. Hence CapEx, OpEx, and DecEx have been considered separately in this work, allowing the user to input which is most important or which is equally important to their work. The mean cost for the support structure for the spar is the greatest, which makes sense given its large size and quantity of steel required. This is followed by the semi-submersible, TLP, and monopile, which makes sense given the reducing mass of material used. The monopile is roughly half the cost of the TLP and semi-submersible this is expected to be due to the standardisation and lower complexity in geometry and therefore lower manufacturing costs for the monopile. It can however be noted that the barge is cheaper than all other floating platforms, the reason for this is expected to be due to the very little amount of research related to its cost and the research which has been carried out is very basic. The variation in cost is lowest for the monopile this is likely to be related to the maturity of the technology. The spar, semi-submersible, and TLP have a similar range in cost but the variation in barge cost is much lower, potentially related to the lack of research on it.

The cost of the station keeping is the same for the barge and the semi-submersible since they were assumed to be the same due to the lack of literature surrounding the barge. It would be expected that the spar would also be the same since the same mooring system is deployed, however, it is expected to be cheaper. A possible reason for this is the semi-submersible and barge have a larger waterplane area and hence experience greater effects due to wave load, requiring a station-keeping system to handle higher loads, which would be more expensive. Three of the pieces of research consider the spar M&A cost to be less (Heidari, 2017; Bjerkseter and Ågotnes, 2013; Myhr et al., 2014).

The average installation cost (£/MW/km) is the lowest for the semi-submersible and the barge due to their simplistic installation technique and lack of vessel requirements. The monopile is cheaper than the other floating options potentially due to the lack of floating cranes and specialised anchor handling vessels, along with better weather to carry out the installation. The semi-submersible is expected to be cheaper than the monopile since a jack-up vessel would be required to install the turbine, whereas the semi-submersible only requires tugs and AHVs. The spar is expected to be the second most expensive, and the TLP is the most expensive. The reasons for this are related to the more complex installation procedure. The TLP has the largest range in cost but this could be related to there being no commercially installed TLPs to compare to.

As expected the OpEx (£/MW/km) for the monopile on average is cheaper, this is expected to be due to the environment a monopile operates in being less harsh and closer to shore, leading to lower failure rates. Moving further offshore the distance to travel becomes greater and the weather becomes much harsher, making it harder to access weather windows to carry out maintenance and a greater potential for higher failure rates since the environmental load is greater. The cost for the barge and semi-submersible is expected to be the same since they are similar, however, there are typically more components and bracings related to a semi-submersible which have the potential to increase failure rates, which presumably is not captured in the literature. Both the spar and TLP OpEx are greater than the semi-submersible and the barge, the TLP is potentially more expensive since it has a complex mooring system.

The DecEx cost for the monopile and floating wind considers the complete removal of the wind farm. It can be noted reviewing the mean values the semi-submersible is the cheapest this is potentially due to the ease of removal, compared to the spar, TLP, and monopile. The reasons for each are large size making it more difficult to handle, lack of stability and complex mooring system, and more complicated removal process respectively. It can be seen that the monopile is more expensive on average than all of the floaters except the TLP, this is potentially due to the complex mooring related to the TLP and the fact that a decommissioning of a TLP for floating offshore wind has never happened. This reason is also expected to affect the cost estimates of the other floating platforms. This is expected to be the reason for the larger range in all costs for the floating wind compared to the monopile. Negative pricing can be seen in this for the decommissioning because (Bjerkseter and Ågotnes, 2013; Myhr et al., 2014) consider the cost-benefit from the scrap material is greater than the cost of the decommissioning process, creating a profit.

For a more detailed analysis of all costs found across the literature see Sykes et al. (2023b).

2.6. Technology readiness level

TRL is a method to evaluate how mature a technology is. The higher the TRL of the technology, the easier it is to implement immediately. Thus proving its feasibility and the existence of a supporting manufacturing supply chain. Table 3 details platform typologies and their TRL in 2015 and 2022 based on installation status, capacity, commercial status, and the number of operational years. The TRL rating is based on the Department of Energy scale (Department of Energy, 2011).

This TRL information was then averaged to give Table 4.

Table 3
TRL for different floating platforms from 2015 updated for 2023.

Platform type	Classification	From 2015			Data as of 2023				
		TRL	Full scale pro-type status	Pre-commercial array status	Full scale pro-type status	Pre-commercial array status	Commercial Array status	Reference	New TRL
WindFloat	Semi-submersible	4	2011	2018	2 MW operational from 2011	25 MW operational from 2020	50 MW operational 2021, with 4 more projects with operational dates through the next 5 years	ABS (2021), Principle Power (2023), Carbon Trust (2022)	8.5
IDEOL	Casisson/ Barge	3	2015	Undisclosed	2 and 3 MW prototype operational since 2018	30 MW operational by 2024	Multiple, multi-MW projects all over the world with no operational dates	ABS (2021), BW-Ideol (2022c,a), Carbon Trust (2022)	7
Saitec SATH	Barge				30 kW operational since 2020 and 2 MW operational since 2022	Underdevelop-ment multi-MW operational dates starting from 2025	Initial stages	ABS (2021), RWE Renewables (2022), Saitec (2023a,b)	7
SeaReed	Semi-submersible	3	2018	2020	N/A	28.5 MW project cancelled	N/A	ABS (2021), BW-Ideol (2022b), Durakovic (2022)	6
Trifloater	Semi-submersible	4	TBC	TBC	Model Proven, via model testing	N/A	N/A	ABS (2021), OER (2021), NOV (2022)	6
Spinfloat	Semi-submersible	3	TBC	TBC	6 MW demonstrator, cancelled	N/A	N/A	4coffshore (2021)	4
Nautilis semi-sub	Semi-submersible	3	TBC	TBC	No model however was used for the LIFE50+ project funded by EU Horizon (2020 program)	N/A	N/A	ABS (2021), Life50+ (2015)	N/A
Nezzy SCD	Semi-submersible	2	TBC	TBC	Scale model operational 2020, and 16.6 MW full scale operational from 2022	N/A	N/A	ABS (2021), Wind Power Monthly (2022), EnBW company (2020)	4
Eolink	Semi-submersible				Scaled prototype operational from 2018	5 MW by 2024	Operational by 2026	ABS (2021), Eolink (2023), Carbon Trust (2022)	4
Tetrafloat	Semi-submersible	3	TBC	TBC	Tank testing carried out 2021	N/A	N/A	Rhodri and Ros (2015), Serrano González et al. (2021)	3
Cobra semi-spar	Semi-submersible				Tank testing carried out	Was proposed for Kincardine offshore farm however was replaced by WindFloat	N/A	ABS (2021), KOWL (2016)	7
OO-star	Semi-submersible				Tank testing 2018, Pre-construction phase 2022	N/A	N/A	ABS (2021), 4coffshore (2023b), Flagship (2022)	4
Hexafloat	Semi-submersible				Full scale testing predicted 2023	N/A	N/A	ABS (2021)	4
vVolturnUS	Semi-submersible	3	2018	TBC	Scaled prototype 2013, 11 MW under consent application	N/A	N/A	ABS (2021), 4coffshore (2023e)	7
V-Shaped Semi-sub	Semi-submersible	3	2015	TBC	Installed 2015	2 and 5 MW turbines decommissioned 2021	N/A	ABS (2021), 4coffshore (2023c)	5

(continued on next page)

Table 3 (*continued*).

Platform type	Classification	From 2015			Data as of 2023				
		TRL	Full scale pro-type status	Pre-commercial array status	Full scale pro-type status	Pre-commercial array status	Commercial Array status	Reference	New TRL
Hywind	Spar	4	2009	2017	Installed 2009	Installed	30 MW operational since 2017	ABS (2021), Equinor (2020)	9
Sway	Spar	3	TBC	TBC	0.01 MW prototype installed 2014 now decommissioned	N/A	N/A	Inocean (2021), New Atlas (2010)	5
WindCrete	Spar	3	TBC	TBC	scale model testing 2022 and prototype development	N/A	N/A	Windcrete (2020, 2023b,a)	4
Hybrid spar	Spar	4	2013	TBC	Installed 2013	Installed 2016	N/A	ABS (2021), Harada (2016)	5
Advanced spar	Spar	4	2013	TBC	Installed 2013	N/A	N/A	ABS (2021), Freeman et al. (2016)	5
SeaTwirl	Spar	3	TBC	TBC	First prototype test 2007 and installation 2015	N/A	2023 first commercial order	ABS (2021), Memija (2023)	4
DeepWind spar	Spar	2	TBC	TBC	1 kW prototype			EU (2014)	4
PelaStar	TLP	3	TBC	TBC	N/A			ABS (2021)	N/A
Blue H TLP	TLP	3	2018	2020	Installed	N/A	N/A	Blue h engineering (2014)	6
GICON-SOF	TLP	3	2015	2017	Tank testing 2013	Pre-construction 2.3 MW, 10 MW consented	N/A	ABS (2021), Carbon Trust (2022)	4
Eco TLP	TLP	3	2018	TBC	2 MW demonstrator cancelled 2016	N/A	N/A	4coffshore (2016, 2023a)	N/A
TLP Wind	TLP	3	TBC	TBC	Tank testing 2018	5 MW 2019 project cancelled	N/A	ABS (2021), ORE Catapult (2022), 4coffshore (2023f)	4
Advanced Floating Turbine	TLP	2	TBC	TBC	Scale model created 2013	N/A	N/A	4coffshore (2023d)	2
SBM TLP	TLP				8 MW underdevelopment, subject to finance	N/A	N/A	ABS (2021), SBM offshore (2020)	7
PivotBouy TLP	TLP				scale model and 6 MW project completed	2022–2025 6 MW development	15 Mw+ under-development expected earliest 2026	ABS (2021), Carbon Trust (2022), X1wind (2023)	4

Table 4
TRL Average and maximum values.

Platform type	TRL Average	Maximum TRL
Spar	5.14	9
Semi-submersible	5.5	7
TLP	5	7
Barge	7	7
Monopile	9	9

2.7. Platform size

The final consideration is the size of the platform, since the geometry of each platform varies, as will the ease of transport and port handling. This is a significant challenge, as it is unknown whether existing ports can handle some of these large platforms (Crown Estate, 2020). This could potentially lead to certain platforms such as the spar being taken out of consideration. Considering generic platform geometries, the size from largest to smallest is expected to be as follows: Spar, semi-submersible and barge, monopile, and TLP. To categorise each platform the waterplane area is considered along with the draft.

3. Methodology

In order to determine the most suitable platform for a specific site the TOPSIS methodology has been implemented, utilising marking criteria and user ranking using the same approach as presented in Kolios et al. (2010). This method is advantageous because it creates a flexible framework with qualitative and quantitative criteria. The TOPSIS method is presented in Section 3.1 and the inputs used for the attributes and marking criteria are given in Section 3.2.

3.1. TOPSIS methodology

The fundamental concept of TOPSIS is that the best solution should have the farthest distance from the Negative Ideal Solution (NIS) and be the closest to the Positive Ideal Solution (PIS), providing a ranking of the solutions. Overall this process is computationally inexpensive and allows human judgement to be considered. Fig. 2 shows the process followed for this work.

For complex decisions, such as platform selection, multi-criteria decision-making (MCDM) is required. This can be presented in matrix

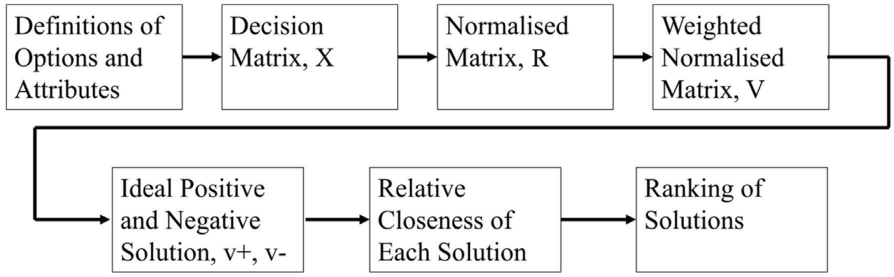

Fig. 2. TOPSIS Methodology.

form, known as the decision matrix, as shown in Eq. (1). X, is constructed of m number alternatives and n criteria where each element in the matrix expressed the mark for the jth option.

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array} \tag{1}$$

The vector C in Eq. (1) represents the alternative support structure options with respect to the A_{i-th} marking criterion. Vector A will be described in Section 3.2. From the initial matrix, X, a normalised matrix, R will be derived to scale the results appropriately making them comparable. This can be done by using the formula presented in Eq. (2) for each element of the decision matrix.

$$r_{i,j} = \frac{x_{i,j}}{\sqrt{\sum_{i=1}^{m} x_{i,j}^2}} \tag{2}$$

Once matrix R is constructed using $r_{i,j}$, the weighted normalised matrix V can be defined. This matrix encompasses all potential ith solutions, characterised by the n marks for each criterion. This utilises a weight vector (w_j) as reported in Eq. (3). This vector is a user input and provides a level of importance for each attribute. The scale of importance can be, for example, 1–5 or 1–10 depending on the granularity required.

$$v_{i,j} = w_j \cdot R \tag{3}$$

This method considers Euclidean space, giving each solution in the V matrix a point in the n-dimensional Euclidean space. The J+ set presented in Eq. (4) describes the maximum mark for every positive marking criterion for example the TRL is a positive criterion, where a higher value is better. The J- set for the PIS presents the lowest mark for every negative criteria i.e. cost criteria. Combining this information together then gives the PIS. The NIS is the opposite, utilising the minimum for the J+ set and maximum values for the J- set. PIS, A+ formula is given in Eq. (4) and NIS, A- is given in Eq. (5)

$$A^+ = (v_1^+, \dots, v_n^+), \quad v_j^+ = \begin{cases} \max(v_{i,j}) & \text{if } j \in J^+ \\ \min(v_{i,j}) & \text{if } j \in J^- \end{cases} \tag{4}$$

$$A^- = (v_1^-, \dots, v_n^-), \quad v_j^- = \begin{cases} \max(v_{i,j}) & \text{if } j \in J^+ \\ \min(v_{i,j}) & \text{if } j \in J^- \end{cases} \tag{5}$$

To determine the ranking of candidates (platforms), the relative distance of each solution to the ideal solution must be found. In order to do so Eqs. (6) and (7) are used where S_i^+ is the distance of the ith solution to the PIS and S_i^- for the NIS respectively.

$$S_i^+ = \sum_{j=1}^{n} (v_j^+ - v_{i,j})^2 \tag{6}$$

$$S_i^- = \sum_{j=1}^{n} (v_j^- - v_{i,j})^2 \tag{7}$$

The relative closeness of each potential solution to the PIS will be indicated through the closeness index, C_i, shown in Eq. (8), where the solution closest to 1 is the most favourable.

$$C_i = \frac{s_i^-}{s_i^+ + s_i^-} \tag{8}$$

3.2. Marking criteria and attributes

For this work, there are a total of nine key attributes to consider in identifying the most appropriate platform. The first five are related solely to the platform and are easily quantifiable parameters: CapEx, OpEx, DecEx, TRL, and size. The remaining four are linked to the platform's compatibility with the site. These considerations involve assessing the platform and station-keeping system with the water depth and wave height, and the tidal range and soil conditions, respectively. These attributes are more difficult to quantify numerically. Therefore, compatibility of zero and one was applied for each platform type, where zero represents incompatibility and one represents compatibility between the platform or mooring system and the site.

Using the information in Section 2.2 the water depth which is suitable for each platform can be defined. For example, a spar would be compatible above the minimum allowable water depth of 120 m, where this is the case for a specific site the water depth compatibility will be prescribed a value of one and for sites where water depth is below 120 m it will be zero. Similarly, a monopile would only be compatible below the maximum allowable water depth (60 m). Both the soil condition and tidal range can be assessed using the information in Sections 2.1 and 2.4, respectively. In the case where the tidal range to depth ratio is greater than the allowable ratio (5%) the site is not compatible with the TLP but is compatible with the other platform types. The soil condition can be easily categorised in terms of compatibility using the anchor type and the suitable mooring lines. The wave height for each platform is slightly more difficult to define since as the wave height increases the performance, in general, will worsen for all platforms. However, as mentioned in Section 2.3, it is expected that a spar and TLP would be able to operate in higher sea states compared to a semi-submersible, based on the maximum significant wave height of the site, it can be determined using the low and high significant wave height if the site and platform are compatible or not. Combining attributes creates the A vector introduced in Section 3.1.

To account for personal or project preference, the user defines a weighted vector by prescribing an importance value to each attribute, this information is then used to create the weighted matrix. The importance ranking can be organised in many different ways however, for this specific work, the criteria are ranked from one to five, five being very important and one being very unimportant. The different options highlighted with vector C are the possible support structures. Both vectors A and C are highlighted in Table 5:

A pre-filtering criteria was set to remove unfeasible platforms for the sites from the TOPSIS ranking process. This was applied to water depth

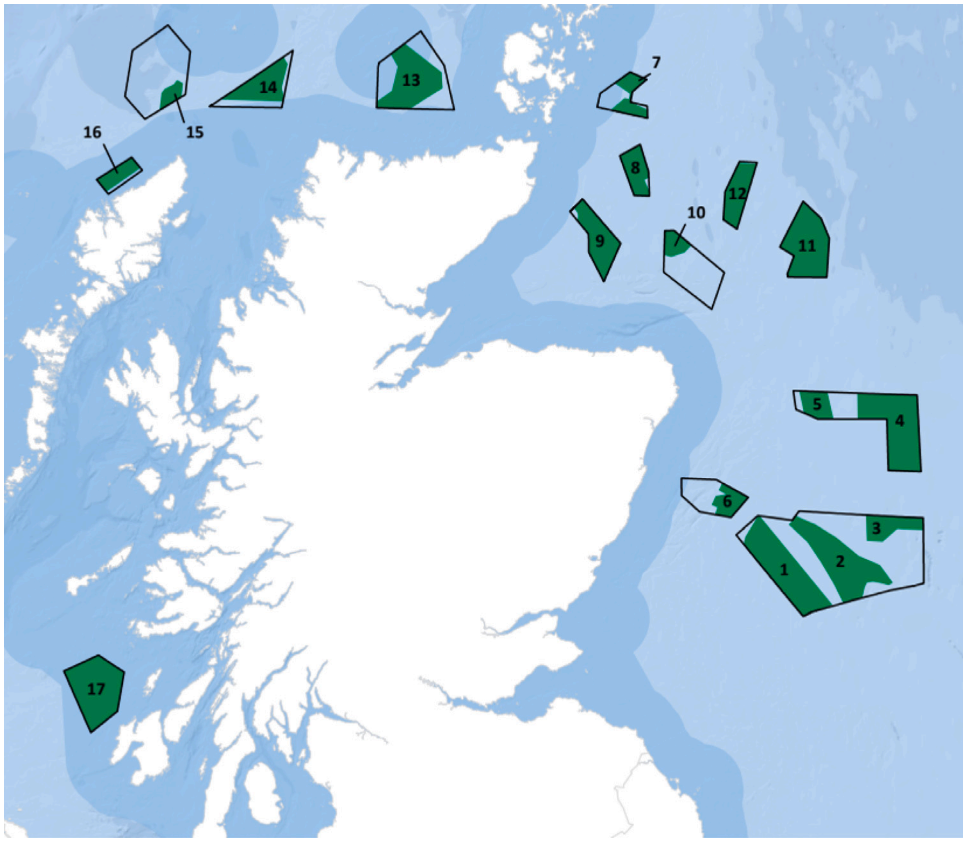

Fig. 3. Recent Scotwind sites up for leasing (Offshore Wind Scotland, 2021).

Table 5
Attributed and potential support structure options.

Attributes (vector A)	Support structures (vector C)
Soil condition compatibility	Spar
Tidal range compatibility	Semi-submersible
Water depth compatibility	Barge
Wave height compatibility	TLP
CapEx	Monopile
OpEx	
DecEx	
TRL	
Size	

compatibility since it is a physical constraint. The same was applied to the tidal range compatibility, removing the TLP platform where the tidal range to depth ratio was greater than 5%.

4. Case study: Scotwind sites

An area of recent interest has been the Scotwind sites awarded in 2022.

Table 6 and Fig. 3 highlight the details of each site, along with the four site parameters related to determining the most appropriate platform. The project developer and proposed installed capacity were easily found on Offshore Wind Scotland (2021). The water depth and maximum significant wave height were found using bathymetry charts and downloadable data from Esox (2022). The tidal range and soil type were identified from maps on Marine Scotland (2022). Based on the sea bed configuration the author could determine which category the soil came under.

For this case study the following inputs found in Table 7 were determined by a panel of four experts filling out a survey independently to avoid bias and these were then averaged. Water depth is important since certain platforms are limited by depth hence it was given a weighting of three. Similarly, the soil condition was also given a weighting of three the reason being the importance of ensuring the anchoring system stays in place. Certain mooring systems require different anchorage but most platforms and catenary systems can be made suitable for the environment but it will come at a cost, hence the rating. The tidal range can heavily affect the mooring system, adding extra loading, particularly when a taut system is used. Since a large tidal range can have serious consequences such as a snapped mooring line, leading to the risk of drifting, shutting down the turbine or potentially asset loss a rating of 4 was considered. The wave height can affect the performance of the turbine, with higher wave height and motions leading to a reduction in power and hence a knock on effect on LCoE, therefore this was given a weighting of four. The cost is an important factor. For this reason, the CapEx was given a weighting of five since it accounts for the majority of the overall cost. The OpEx has been weighted at three since this contributes to 25%–30% of the overall cost. Finally, the DecEx was weighted at two since it makes up a very small portion of the cost and, in the experts' opinion, is less important than CapEx. A higher TRL was attractive because the industry would have already learnt useful lessons for manufacturing, installation, and operation. The size of the platform is of relatively high importance since ports around Scotland have a limited capacity, therefore, it was given an importance ranking of four.

Using the platform-selecting code and input data from the user the results can be found and presented in Table 8. It comes as no surprise that there is no support structure which fits all sites. The results highlighted in red are not applicable.

5. Discussion

The results yielded from this work are generally mixed in comparison to the proposed platform by the developers, with only two of the

Table 6
Details Scotwind sites.

Number on figure	Developers	Capacity (MW)	Water depth (m)	Water depth category	Maximum significant wave height (m)	Tidal range (m)	Soil type	Soil category
2	SSE Renewables, CIP and Marubeni	2610	100	Intermediate	9.29	3	Sand and muddy sand	Soft
3	Falck Renewables and BlueFloat Energy	1200	100	Intermediate	9.29	2	Sand and muddy sand	Soft
4	Shell and ScottishPower Renewables	2000	100	Intermediate	10.24	2	Sand (major), rock and sediment, gravelly sand	Soft
5	Vattenfall and Fred Olsen Renewables	798	100	Intermediate	10.24	1	Rock and sediment, gravelly sand	Medium
7	DEME, Aspiravi and Qair	1008	100	Intermediate	8.87	3	Sandy gravel, rock and sediment, gravelly sand	Medium
8	Falck Renewables, Orsted and BlueFloat Energy	1000	100	Intermediate	8.5	3	Sandy gravel, rock and sediment, gravelly sand and sand	Medium
10	Falck Renewables and BlueFloat Energy	500	100	Intermediate	8.83	3	Sand	Soft
11	Shell and ScottishPower Renewables	3000	100–250	Deep	9.82	2	Muddy sand, sandy mud	Medium
12	Floating wind Allyance (Baywa r.e., Elicio and BW Ideol)	960	100–250	Deep	9.07	2	Muddy sand, sandy mud	Medium
14	Northland Power	1500	100–250	Deep	11.91	4	Sand, gravel, rock and sediment, sandy gravel, gravely sand	Medium
15	Magnora ASA and Technip UK	495	100–250	Deep	12.08	3	Sand, gravel, rock and sediment, sandy gravel, gravely sand	Medium

Table 7
Inputs for the criteria limits and the weighting vector.

Criteria limits	Value
Maximum allowable water depth for a monopile	60 m
Minimum allowable water depth for a spar	120 m
Allowable ratio of tidal range to water depth	5%
Low significant wave height cut off	3 m
High significant wave height cut off	8 m
Weighting vector inputs	**Value**
Soil condition compatibility	3
Tidal range compatibility	4
Water depth compatibility	3
Wave height compatibility	4
CapEx	5
OpEx	3
DecEx	2
TRL	3
Size	4

sites being correctly predicted. There are however some inconsistencies with the developer's choice. It can be noted that the developers' choice for site 2 is unknown and therefore cannot be compared. A main contributing factor to the differences in the proposed platform is expected to be the user inputs, which can vary heavily from person to person and in this case developer to developer. The reasons for these variations are expressed in the following paragraphs. It can be seen that sites 3, 4, 10, 11, and 12 present the developers' choice as the second best platform, with the barge marginally outranking the semi-submersible. This is expected to be the case since the most important parameter in the weighting vector was CapEx, therefore this is the main consideration in the ranking. This is one of the reasons the barge out-ranks the semi-submersible for all sites. This comes back to a highlighted issue in Section 2.5 which states there is little cost research carried out on the barge platform. Literature suggests a barge would be cheaper because of expensive manufacturing related to the more complex semi-submersible, however, it is possible the barges higher material mass could contribute to it being more expensive, but there is a lack of literature surrounding this. When considering the closeness value it can be seen that these two platforms are very similar only separated by a hundredth. Another key factor in the barge ranking higher is the lack of dynamic response considered in this work, comparing a semi-submersible and a barge, the barge tends to have a larger response which is unfavourable. It was noted by the author that by reducing the weighting of the CapEx importance the semi-submersible was higher ranked than the barge meaning seven of the ten sites which have proposed developer platforms are predicted correctly, see Table 9. Overall, it can be seen that this code is relatively effective in comparison to the developers' choice of platforms and can allow the user to make a better-informed decision based on the users' preference as well as rule out platforms which are not appropriate for the characteristics of the site. It can be noted that the three sites which are not correctly predicted it is likely that the developers had different opinions on what was important for their work.

Firstly site 5 developers propose a semi-submersible, whereas the TOPSIS ranking suggests a TLP would be a more effective platform. The reason for the TLP ranking highest is potentially due to the low tidal changes, larger wave heights and medium hardness soil at the site. The TLP is suited for a small variation in tidal range but can cope with larger wave heights when the platform is submerged. Similar to the tidal range the taut mooring system of a TLP requires relatively firm soil to place the anchor system. Since the site characteristics match a suitable environment for a TLP it was proposed best for the specific weighting. The semi-submersible is considered second best due to the larger waterplane area, since the wave height is larger on this site the platform response will be larger.

Site 8 similarly, to site 5, the developer has proposed a semi-submersible but the TOPSIS suggested a TLP. This is expected to be due to the soil condition being medium and the water depth being intermediate. The developer in both cases may have been more interested in the ease of installation which would affect the platform choice since a TLP is expected to be more difficult to install due to its more complex

Table 8
The most platforms ranked in order of best to worst for each site.

Rank	Site 2	Site 3	Site 4	Site 5	Site 7	Site 8	Site 10	Site 11	Site 12	Site 14	Site 15
1	Barge (0.5925)	Barge (0.5925)	Barge (0.5925)	TLP (0.5744)	TLP (0.5744)	TLP (0.5744)	Barge (0.5925)	Barge (0.5680)	Barge (0.5680)	Spar (0.5863)	Spar (0.5863)
2	Semi-submersible (0.5799)	Semi-submersible (0.5799)	Semi-submersible (0.5799)	Barge (0.5680)	Barge (0.5680)	Barge (0.5680)	Semi-submersible (0.5799)	Semi-submersible (0.5568)	Semi-submersible (0.5568)	Semi-submersible (0.4609)	Semi-submersible (0.4609)
3	TLP (0.5324)	TLP (0.5324)	TLP (0.5324)	Semi-submersible (0.5568)	Semi-submersible (0.5568)	Semi-submersible (0.5568)	TLP (0.5324)	Spar (0.5027)	Spar (0.5027)	Barge (0.4608)	Barge (0.4608)
4	Monopile	Monopile	Monopile	Monopile	Monopile	Monopile	Monopile	TLP (0.4772)	TLP (0.4772)	TLP	TLP
5	Spar	Spar	Spar	Spar	Spar	Spar	Spar	Monopile	Monopile	Monopile	Monopile
Proposed platform	N/A	Concrete Semi-submersible	Steel and concrete Semi-submersible	Semi-submersible	TLP	Concrete Semi-submersibles	Concrete Semi-submersible	Steel and concrete Semi-submersible	Ideol damping pool foundation	N/A But states Deeper water capabilities, potentially a Spar	N/A but possibly a Concrete Semi-submersible

Table 9
The platforms ranked in order of best to worst for each site, with a CapEx importance ranking of three rather than five.

Rank	Site 2	Site 3	Site 4	Site 5	Site 7	Site 8	Site 10	Site 11	Site 12	Site 14	Site 15
1	Semi-submersible (0.6607)	Semi-submersible (0.6607)	Semi-submersible (0.6607)	TLP (0.6407)	TLP (0.6407)	TLP (0.6407)	Semi-submersible (0.6607)	Semi-submersible (0.6407)	Semi-submersible (0.6407)	Spar (0.6194)	Spar (0.6194)
2	Barge (0.6449)	Barge (0.6449)	Barge (0.6449)	Semi-submersible (0.6407)	Semi-submersible (0.6407)	Semi-submersible (0.6407)	Barge (0.6449)	Barge (0.6245)	Barge (0.6245)	Semi-submersible (0.5001)	Semi-submersible (0.5001)
3	TLP (0.5837)	TLP (0.5837)	TLP (0.5837)	Barge (0.6245)	Barge (0.6245)	Barge (0.6245)	TLP (0.5837)	Spar (0.5480)	Spar (0.5480)	Barge (0.4945)	Barge (0.4945)
4	Monopile	Monopile	Monopile	Monopile	Monopile	Monopile	Monopile	Monopile	Monopile	TLP	TLP
5	Spar	Spar	Spar	Spar	Spar	Spar	Spar	TLP	TLP	Monopile	Monopile
Proposed platform	N/A	Concrete semi-submersible	Steel and concrete semi-submersible	Semi-submersible	TLP	Concrete semi-submersibles	Concrete semi-submersible	Steel and concrete semi-submersible	Ideol damping pool foundation	N/A But states deeper water capabilities, potentially a spar	N/A but possibly a concrete semi-submersible

Table 10
The percentage of each platform which ranked best for the weighting matrices with each attribute doubled.

Site Number	2	3	4	5	7	8	10	11	12	14	15
Spar	0%	0%	0%	0%	0%	0%	0%	0%	0%	22%	0%
Semi-submersible	78%	78%	78%	33%	33%	33%	78%	89%	89%	78%	100%
TLP	11%	11%	11%	67%	67%	67%	11%	0%	0%	0%	0%
Barge	11%	11%	11%	0%	0%	0%	11%	11%	11%	0%	0%
Monopile	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 11
The percentage of each platform which ranked best for the weighting matrices with each attribute halved.

Site Number	2	3	4	5	7	8	10	11	12	14	15
Spar	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Semi-submersible	89%	89%	89%	22%	22%	22%	89%	89%	89%	100%	100%
TLP	0%	0%	0%	67%	67%	67%	0%	0%	0%	0%	0%
Barge	11%	11%	11%	11%	11%	11%	11%	11%	11%	0%	0%
Monopile	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

mooring system. Another factor which could have led to site 5 and 8 developers choosing a semi-submersible over a TLP is low TRL since there are no operational TLPs at a commercial scale.

The developers of site 15 are going to use a semi-submersible for their site, rather than a spar, this could be related to the much easier installation and handling. The size of the spar would be practically impossible to handle given the current infrastructure in Scotland. For site 15 the developers suggest they will use a concrete semi-submersible, however, this site has the largest maximum significant wave height which could make it difficult to operate it. For this reason, a spar is proposed as the best solution.

Site 2 did not have a proposed platform but based on this work a barge or a semi-submersible would be best and a TLP would also be possible but would potentially be more expensive.

Site 2, 3, 4, 10, 11, and 12 have similar characteristics causing them to have the same ranked order for platforms. The most suitable platform for these sites is a semi-submersible followed closely by a barge. Both the monopile and spar are not applicable for these sites due to the water depth. In general, the semi-submersible and barge are the most generic platforms, due to being able to be deployed under a wide range of conditions. However, it is recommended that further inspection of hydrodynamic performance would be required. The semi-submersible and barge rank higher than the TLP due to the weighting placed on the TRL and CapEx.

Similarly, sites 5, 7, and 8 have similar characteristics where spar and Monopile platforms are not applicable due to water depth. TLP is expected to be the best choice for these sites due to the sea bed and the importance of the inputs used for the TOPSIS. It can however be noted for sites 5 and 8 the semi-submersible has the same closeness value, making it equally as good an option as the TLP.

Finally, sites 14 and 15 have the same ranking. The spar is considered the best here due to the deep water since water depth importance is high. It can however be noted that the semi-submersible and barge are potential options, but since the spar has a higher TRL, and is better in higher sea states it ranks first based on the weighting parameters. Semi-submersibles have been proven to operate in high wave heights like these sites experience, however, analysis of the specific geometry would be required to draw proper conclusions (Wind Power Monthly, 2020; Statoil, 2017; Onstad et al., 2016; Equinor, 2020; Principle Power, 2020). However, in general terms, it is intuitive to assume that a spar would perform better than a semi-submersible or a barge since it has a smaller waterplane area. It can be noted that further hydrodynamic analysis would need to be carried out for a complete assessment. The Monopile and TLP are both not applicable here due to the water depth and wave height.

Since one of the key benefits of a TOPSIS is the ability to consider different weighting vectors, a number of weighting matrices were generated from the benchmark presented in the previous section. Each weighting attribute was altered individually by doubling and halving it to create 18 new weighting matrices. The percentage of each platform ranking highest for each site was found and is presented in the two Tables 10 and 11.

Tables 10 and 11 confirm the findings in Section 5 that for sites 2 through 12 the platform choice is well predicted with each platform for the site being found as the best solution for 67% and greater for the different weighting matrices. It can be noted however that sites 14 and 15 find that a semi-submersible would in general be the best solution when varying the weighted matrix, which is in agreement with the developer's choice. Overall this work highlights the semi-submersible as being a very good solution which confirms why the majority of developers have opted for this platform.

6. Conclusion

The aim of this work was to create a tool which would help rule out and rank support structures for floating offshore wind turbines in a systematic manner, considering a number of constraints and user inputs, to help reduce computational times related to the optimisation of floating offshore wind platforms. This process will reduce computational time and allow a more realistic optimisation to be carried out considering a specific site and its characteristics. The TOPSIS methodology proposed was used to carry out a case-study on the recent Scotwind sites, confirming the validity of the work, and showing that 70% of sites were accurately predicted compared to the developers' choice of platform. This work does however highlight some disagreements with the developers' choice of floating platform, for site 5, 8, and 14. The main reason for disagreement is likely to be linked to the weighting provided by the group of experts. This technique could be useful not only to help developers make quick and informed decisions but primarily to help reduce computational time for optimisations by ruling out platforms which are not appropriate for a site.

Future work for this area would be to implement it as a pre-filter to an optimisation process and determine how much time can be saved. Carrying out more detailed analyses for the soil suitability for each anchor type is expected to improve on the current work. As more data becomes available regarding the price of installed sites, it would be key to include this in the work presented to improve the accuracy. Finally, including more information regarding the barge would help to differentiate it from the semi-submersible in the ranking.

CRediT authorship contribution statement

Victoria Sykes: Writing – original draft, Methodology, Investigation, Conceptualization. **Maurizio Collu:** Writing – review & editing, Supervision. **Andrea Coraddu:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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