Offshore Wind: Future of logistics

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Disclaimer

Introduction: Context of the study

BCG has been commissioned by Airbus Helicopters to run an independent survey on the future of logistics in the offshore wind industry. BCG has assessed and compared the benefits of several logistic solutions in the offshore wind farm construction and operations, based on customer expectations and industry pain points and preferences. Airbus Helicopter has agreed that BCG publishes broadly the main study outcomes considering the results could be beneficial to the fast-growing greener industry.

The study is focused on two geographies: Europe and North America. Still, conclusions of this study are applicable to the Asian situation, all the more so as local climatic conditions (icing in Northern Asia, typhoons) further impact accessibility.

To do so, BCG interviewed 30+ experts from 7 countries: OSW developers, turbine OEMs, construction companies, vessel and helicopter operators, working at different levels of their organization.

In addition, BCG performed a bottom-up analysis based on a model of logistic costs and carbon emissions for an offshore wind farm.

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Executive summary

Offshore wind industry is booming worldwide, increasing the need for new logistic solutions

Offshore wind market has boomed in the 2010s reaching **41GW installed capacity in 2021**. This trend is expected to further accelerate with **200+ GW additional capacity** to be commissioned **by 2030** in Europe (60%), Asia (20%) and North America (15%).

All these projects require strong logistic support for both construction and maintenance. BCG has looked at the logistics models currently at play and investigated potential new solutions.

OSW players face five major challenges for logistics

- **Technical challenge**: larger turbines farther from shore require new logistic solutions
- **Economic challenge**: reducing subsidies increases pressure on costs
- **Safety challenge**: offshore wind industry still suffers from too many incidents and injuries
- **Human resources challenge**: qualified staff is scarce, and will become scarcer with more projects materializing
- **Climate challenge**: players are setting ambitious carbon emissions targets

Excluding installation vessels, there are three main logistic means:

- **CTVs** are small high-speed vessels with limited transportation capacity, operating only in good sea conditions, with safety issues during transfer to turbines
- **SOVs** have emerged to address safety and accessibility issues and provide accommodation and larger transportation capacities
- With higher speed, even better accessibility to wind farms and strong safety track record, **helicopters** are used for crew transfer, troubleshooting and medevac, yet with low utilisation rate

There is **no solution fitting all needs, but rather a set of solutions to be assessed for each farm**.

Multiple mixed solutions will cope with different logistic requirements

During construction phase, decoupling component transportation with vessels and crew transfer with **helicopters would contribute to secure project delivery**, with marginal impact on costs.

There are four competitive combinations for O&M:

- Fleet of CTVs
- CTV & helicopters
- SOV & daughter crafts (small CTVs)
- SOV & helicopters

In essence, and as much as has been witnessed in the offshore O&G industry in the past 50 years, a growing use of helicopters will allow to cope with both scarce qualified resources and longer distances.

Depending on the different hypotheses, as per our modelling, we have regrouped optimized solutions as follows:

For medium farms (<100 turbines) close to shore (<30 NM), fleet of CTVs is a competitive solution. Adding helicopters (not only as back-up) would provide additional benefits as distance to shore and number of turbines increase:

- **Reduce logistic costs** by up to 25% thanks to lower hourly rate (higher utilization rate)
- **Limit power loss** during downtime by up to 45% thanks to higher speed of helicopters

Going even further, using helicopters and barges to decouple crew transfer and part cargo and mutualize resources or farms with other players would drastically improve utilization rate, and further reduce transit time and power loss.

For large farms (>100 turbines) or remote farms (>30 NM), SOV is the preferred solution with either daughter craft or helicopter for troubleshooting:

- **Increase technicians' productivity** thanks to offshore accommodation (limited transit time)
- **Limit power loss** with daughter craft for small farms in calm waters and with helicopters for larger farms in rougher seas
- **Optimize logistic costs** by increasing utilisation rate of SOVs, daughter crafts and helicopters

Looking further ahead, disruptive logistic solutions could enable additional benefits

Substantial benefits can be further achieved through mutualization between players, clustering of farms, decoupling of component and personnel transportation, bundling of scheduled and unscheduled maintenance.

Based on our model, **up to 30% reduction of full cost of logistics could be achieved**.

We believe that OSW industry will strive towards:

- 24/7 operations with limited downtime
- Bigger and bigger turbines
- Farther away offshore

Therefore, and as of the design phase of all current projects, we believe that the logistic scheme shall include those future trends as key parameters.

The challenges of the OSW industry require to question today economics.

Offshore wind operations: the logistic need

An OSW project is broken down into four phases

- Development phase: 1-3 year(s)
- Construction phase: 1-2 year(s)
- Operational phase: 20-30 years
- Decommissioning - *not covered in this study*

The industry is still young, and we observe various models to build or operate OSW farms. Despite ownership consolidation, a number of subcontractors could rise as historically internalized owners are moving towards more outsourcing.

Compared to onshore wind, the main challenge of offshore wind is the necessity to conduct activities with challenging weather conditions and higher HSE requirements, far from any logistic base. The nature of the operations requires specific logistics that we describe hereafter (see illustration 15, appendix 3).

Development: limited logistics, mainly for surveys

Development phase covers seabed surveys, resource assessments, environmental assessments, feasibility studies, permits and approvals, offtake searches or PPA signing, engineering design and procurement as well as financing and tax.

Developers mostly use vessels to perform surveys, but also helicopters or drones for observations. Satellite data is increasingly being used.

Construction: large fleet of vessels

During this phase, project is highly focused on timing to secure power production start.

This phase aims to install large components - foundation, towers, blades -, build substations, install cables, and commission turbines. It involves hundreds of workers from several contractors.

Logistic needs are component and equipment transportation, crew transfer and accommodation.

Depending on the project, the fleet is composed of 10 to 50 vessels: heavy lifting vessels, cable laying vessels, cable pull-in vessels, SOVs, CTVs, etc.

Large vessels can accommodate 40 to 100 workers and typically have helidecks. Large components and equipment are transported with vessels or barges.

Crew transfer is done either with helicopters or CTVs, or at port during vessel's reloading.

O&M: various models depending on each farm

O&M activities are performed by the OEM during warranty period, then completed by the operator.

We distinguish two types of maintenance activities:

- **Scheduled maintenance**, which is predictable and optimised to limit costs
- **Unscheduled maintenance**, which aims to troubleshoot turbine failures to resume power generation (see Zoom 3, Appendix 5)

Scheduled maintenance is planned during summer to benefit from better weather and sea conditions. A team of 3-10 technicians performs mechanical, electrical and quality activities in each turbine.

Unscheduled maintenance cannot be predicted but requires technicians for troubleshooting. 3-4 highly qualified technicians are deployed onto the turbines to diagnose and fix the problem.

Construction and O&M phases require strong logistic support with several choices of assets from small boats to helicopters. Current logistic scheme needs to be rethought to take into account cost pressure, labour scarcity, greener regulation and stringent safety regulation.

Available logistic solutions

There are mainly three options to transport technicians, tools and equipment to and from an offshore wind farm: CTVs, SOVs and helicopters.

CTVs are 20m vessels used to transport personnel and equipment from shore to wind farm on a daily basis. Large equipment (1-10t) can be transported on the foredeck. Deck cranes are used to lift equipment from CTV to wind turbines.

CTVs are limited by sea conditions below 1.5m significant wave height maximum. Factoring in swell, tide and current, CTVs show lowest accessibility rate compared to other logistic means. Lack of proper accommodation on board limits their utilisation to OSW farms located within 30 NM from port.

CTVs have been the preferred solution over the last decade but are challenged by other transports.

SOVs are 70m all-purpose vessels, which can transport and accommodate up to 60 technicians. They can host a spare parts warehouse on board and have deck cranes to lift equipment. They are usually supported by daughter crafts, which are used to transport technicians in good sea conditions (<1m significant wave height). Otherwise, they use motion compensated gangways to transfer technicians to wind turbines.

Compared to CTVs, SOVs offer accommodation and better accessibility (below 3m wave height). On the other side, SOVs are slow and expensive.

SOVs have been widely used during construction phase in the past and are getting more used for O&M activities farther than 30 NM from shore.

Helicopters transport personnel or parts to OSW farms, but can also by used for medical evacuation.

Helicopters have a clear advantage on speed and accessibility. They can fly at 130-150 knots and reach all existing OSW assets. They are not limited by sea or wind conditions. They are mostly used in the daytime. The stringent safety regulation allows safe operations across the whole spectrum of operation (crew change, maintenance, medical evacuation).

Helicopters can land on helidecks located on substations, accommodation platforms and large vessels. Technicians can also be hoisted directly on wind turbines, e.g., for troubleshooting.

Helicopters are mainly used for critical operations today but are expected to be more used for standard operations to cope with scarce qualified resources and longer distances.

Substations have helidecks, allowing crew transfer. Although technically possible, there is typically neither accommodation nor refuelling equipment on substations for safety and regulatory reasons. Accommodation platforms are not widespread in the industry. They offer offshore accommodation and have helidecks.

Since each logistic means presents benefits and challenges depending on the number of turbines, distance from shore and accessibility to offshore wind farm, the optimum solution is likely a combination of two or three types of transport.

Illustration 1: Comparison of logistic solutions

	CTV	SOV	Helicopter
Speed (knots)	15-25	10-15	130-150
Accessibility (main limits)	Waves Hs<1.5m[1]	Waves Hs<3m[1]	Visibility 95% daytime
Comfort			
Capacity (#technicians)	12-20	40-60	3-16
Capacity (tons)	1-10	2,000-3,000	0.5-1

1. Depending on each sea, see Zoom 1, appendix 5

Multiple solutions to cope with different logistic requirements

The logistic equation depends on numerous parameters

The logistic equation depends on a large set of parameters for each OSW farm:

- **Geography:** distance from shore, accessibility (e.g., sea conditions, wind conditions), etc.
- **Technology:** number of turbines, capacity per turbine, failure rate, foundations, etc.
- **Operations:** availability of technicians, transport speed, shift duration, etc.
- **Economics:** offtake price, costs of logistics, costs of personnel, etc.
- **Regulation:** CO_2, NO_x, wildlife protection, usage of vessels (e.g., Jones act),

In our study, we identified six key parameters for OSW logistics:

- Distance from shore
- Accessibility
- Number of turbines
- Capacity per turbine
- Failure rate per turbine
- Electricity price

The logistic solution can combine various logistic means

It is crucial to take a holistic standpoint on the logistic equation to find the solution, that optimises full cost of ownership (direct logistic costs, related operational costs, power loss during downtime).

Industry players can combine various logistic means and sometimes decouple transportation of workers and components with advantages and limitations.

In order to optimise costs, logistic utilisation rate needs to be increased through mutualization of transport means across contractors and/or farm clustering.

Organisation of activities varies widely across projects due to different farm parameters. Therefore, each farm needs to be analysed independently.

"There is no solution fitting all needs"

- General Manager, OSW Developer

Two logistic solutions for the Installation phase

In our study, we looked at various logistic combinations for component transportation and crew transfer during installation.

We identified two competitive solutions:

- **1 - Fleet of operating vessels**: rotation of personnel during vessel reload at port
- **2 - Fleet of vessels, helicopters and barges**: rotation of personnel with helicopters and component transportation with barges

Illustration 2: Using helicopters for crew transfers to improve resource utilization and de-risk the project

Location: **North Sea**
Distance from shore: **80 NM**
turbines: **200**
Start Year: **2028**

Standard solution

Alternative solution

Benefits[2]

-3[1] €m

-550 tCO2e

Transferring crew with helicopters and transporting components with barges instead of going back to port with construction vessels will:

- **Reduce lead time to production**, thanks to accelerated construction
- **Reduce cost of chartering vessels**, as vessels will be dedicated to construction only
- **Improve productivity of workers**, as they will spend less time in transfer

Additionally, combining helicopters with vessels contributes to **project de-risking**. In case of emergency, e.g., urgent need for expert or parts, helicopter provides a quick and reliable solution.

1. Only over installation timeline: 2 years 2. Savings achieved by using alternative solution

Four logistic solutions for O&M

Based on existing and future projects, we identified four competitive logistic solutions:

- **1 - Fleet of CTVs**: transportation of personnel and parts using CTVs, when transit time from port and between turbines is limited
- **2 - Helicopter & CTVs**: transportation of people and parts using CTVs and helicopters when transit time from port is limited but the number of turbines requires many trips
- **3 - SOV & daughter craft (small CTV)**: offshore accommodation on SOV saving transit time, scheduled activities supported by SOV and troubleshooting supported by daughter craft
- **4 - SOV & helicopter**: offshore accommodation on SOV saving transit time, scheduled activities supported by SOV and troubleshooting performed with helicopters

Four OSW archetypes requiring different solutions

We have used a bottom-up approach to determine the most economical logistic solution depending on farm parameters. Then, we compared the four logistic solutions on existing and future projects.

Finally, we grouped OSW projects into three archetypes, which combine similar characteristics and require similar logistic solutions.

Europe is the largest market with 22GW commissioned to date and more than 100 GW additional capacity to be installed by 2030. We defined two archetypes for this market:

- **Archetype 1**: farms located less than 30 NM from shore with less than 100 turbines (33% of 2030 installed WTGs)
- **Archetype 2**: farms located less than 30 NM from shore with more than 100 turbines and farms located more than 30 NM from shore (58% of 2030 installed WTGs)

Each archetype covers different sea conditions:

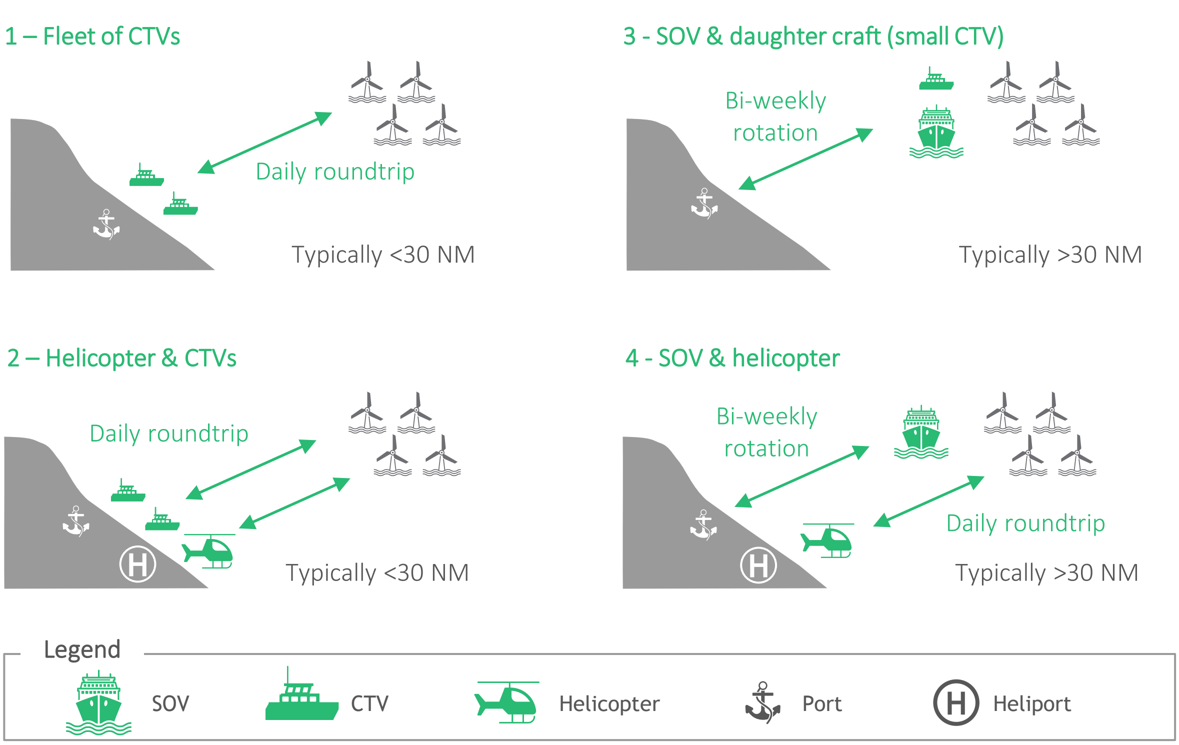
- **North sea**: 28% turbines of Archetype 1 and 72% of Archetype 2
- **Baltic, Celtic and Irish seas**: 42% turbines of Archetype 1 and 58% of Archetype 2

US market is emerging and expected to reach 28 GW by 2030. In this context and given the US regulation (see zoom 2, appendix 5), we defined a specific archetype for the US market:

- **Archetype 3**: all offshore wind farms in the US (9% of 2030 installed WTGs)

In the next section, we describe the main characteristics of each archetype and identify the most economical solution.

Illustration 3: Logistic solutions



Archetype 1: CTVs and helicopters to service farms close to shore in Europe

Illustration 4: Combining CTV with helicopter to reduce logistic costs and power loss

Location: **Baltic Sea** # turbines: **65**
Distance from shore: **15 NM** Capacity: **975 MW**

Standard solution

Alternative solution

Benefits

-34[1] €m

People costs: ***Limited***
Logistic costs: **-26 €m**
Power loss: **-8 €m**

-7%[2] tCO2e

Combining helicopters with CTV enables to

- **Reduce power loss** thanks to lower transit time and better accessibility, especially during winter
- **Reduce logistic costs** by increasing utilization rate of helicopter – hence, reducing hourly cost – and reducing number of CTVs required

Below 50 turbines located less than 15NM from shore, the most beneficial solution is a fleet of CTVs for both scheduled maintenance and troubleshooting. Such logistic setup is usually complemented by a backup helicopter.

Between 50-100 turbines or above 15NM from shore, a combination of CTVs with helicopter is more adequate.

In 2030, we estimate that 60% of the total number of turbines can be served by CTVs only, 40% require a combination of helicopters with CTVs.

Archetype 2: SOVs and daughter crafts or helicopters to serve remote and large farms

Illustration 5: Using SOVs for scheduled maintenance and helicopters for troubleshooting to reduce personnel costs and power loss

Location: **North Sea** # turbines: **115**
Distance from shore: **30 NM** Capacity: **1.7 GW**

Standard solution

Alternative solution

Benefits

-95[1] €m

People costs: **-50 €m**
Logistic costs: **-1 €m**
Power loss: **-44 €m**

-23% tCO2e

Long transit time to access turbines and long timeframe to serve the farm recommend offshore accommodation in SOV. Logistic choice for troubleshooting depends on farms parameters.

Using helicopters for troubleshooting instead of daughter crafts will

- **Reduce cost of personnel** as troubleshooters will be accommodated onshore and transit time will be reduced
- **Reduce power loss** thanks to lower transit time and better accessibility

Between 100 and 250 turbines and below 75NM from shore, helicopter usage will be limited and therefore cheaper than daughter crafts that will be mobilized for the whole year. The most beneficial solution is SOV and helicopter.

Above 250 turbines and farther than 75NM, a daughter craft is more economical than a helicopter. SOV with daughter craft is consequently the optimal solution.

In 2030, we estimate that 69% of OSW turbines can be served by a combination of SOV and Helicopter and 31% by SOV and daughter craft.

1. Cumulated over 30 years 2. Including carbon opportunity cost (using CCGT as back-up during downtime)

Archetype 3: Three solutions for offshore wind farms in the US

Illustration 6: Combining helicopters with CTVs to reduce logistic costs and power loss

Location: **Atlantic Ocean**
Distance from shore: **15 NM**
turbines: **45**
Start Year: **675 MW**

Standard solution (CTV, CTV)

Alternative solution (CTV, CTV, helicopter)

Benefits

-50[1] **€m**

People costs: *Limited*
Logistic costs: **-36 €m**
Power loss: **-14 €m**

-10%[2] **tCO_2e**

The Northern part of the Atlantic Ocean coast of the US includes a large **protected area for critical sea habitat,** in which vessels are restricted on speed. Helicopters are needed in order to decrease power loss.

Combining CTVs with helicopters enables to:

- **Reduce power loss** thanks to lower transit time and better accessibility, especially close to protected areas
- **Reduce logistic costs** by reducing the number of CTVs required

In 2030, 2% of WTG could be served by CTVs, 16% by a combination of CTV with helicopters and 82% by a combination of SOV with helicopters.

In this section, four logistic solutions have been compared for three offshore wind farm archetypes. Illustration 7 provides the share of total number of turbines in 2030. In 2030, the historical solution (Solution 1 - Fleet of CTV) is expected to account for only 20% of the total number of turbines, only for small OSW farms close to shore.

Illustration 7: Share of total number of turbines by archetype and logistic solution

Archetypes and solutions in % of number of installed turbines in 1990-2030 in Europe and North America (13.6k turbines)		Solution 1 Fleet of CTVs 20%	Solution 2 Helicopter & CTVs 15%	Solution 3 SOV & Daughter crafts 18%	Solution 4 SOV & helicopter 47%
Archetype 1 < 30 NM & < 100 turbines	33%	✓	✓	✗	✗
Archetype 2 > 30 NM or >100 turbines or clusters	58%	✗	✗	✓	✓
Archetype 3 All farms	9%	✓	✓	✗	✓

1. Cumulated over 30 years 2. Including carbon opportunity cost (using CCGT as back-up during downtime)

Future challenges and new trends in OSW logistics

OSW players face five major challenges for logistics

- **Technical challenge**: larger turbines farther from shore require new logistic solutions
- **Economic challenge**: reducing subsidies increases pressure on costs
- **Safety challenge**: despite improvements, the industry still suffers from too many incidents and injuries
- **Human resources challenge**: qualified staff is scarce, and will become scarcer with increasing cumulated installed capacity
- **Climate challenge**: players are setting ambitious carbon emissions targets requiring reduction of carbon footprint for logistics

Technical challenge: bigger projects, farther away

OSW farms are expected to get farther from shore. In parallel, emergence of floating turbine technology will enable to install turbines in very deep and remote areas. To limit transit, developers are expected to increase usage of fast transportation and offshore accommodation.

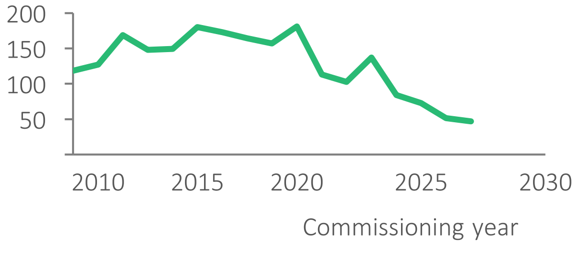
Turbines are also becoming larger with increasing capacity, requiring larger installation vessels. This will make a higher business case for quick intervention, e.g., by helicopter.

Economic challenge: increasing pressure on costs

The sector has been benefitting from strong public support over the past decade. Auction prices have dropped by 40% in the last five years (see illustration 8). In recent tenders, several developers won projects with a bid price of 0 €/MWh, renouncing the guaranteed price.

Reducing subsidies is increasing pressure on costs, including cost of logistics.

Illustration 8: Average negotiated price of OSW projects in Europe and America (€/MWh)

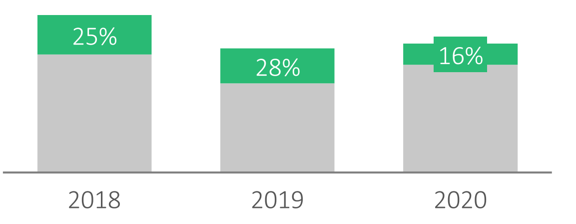


Safety challenge: reduce number of incidents and injuries and secure reliable solution for medevac

The OSW industry has experienced significant improvements on safety with TRIR[1] decreasing from 5.9 to 3.7 in 2015-2020.

Nevertheless, incidents and injuries are still too frequent, especially in marine operations[2]. In 2020, CTVs were the main incident area with 79 incidents, as among the top three areas of high potential incidents.

Illustration 9: Share of marine operations[2] in high potential incidents and injuries[3] (%)



On the other side, helicopters have better safety track records, but are perceived as more dangerous than vessels. Between 2010 and 2019, there were only 2.6 helicopter accidents or serious incidents per year on average in offshore operations (OSW and O&G). Helicopters are not in the top 10 causes of potential incidents and injuries.

> *"If it was my choice, I would definitely transfer by helicopters"*
>
> \- HSE expert, OSW developer

In addition to limiting the number of incidents, it is crucial to set up a reliable and fast solution in case of emergency. With the increasing number of technicians offshore, farm owners are expected to take more responsibility in emergency response, possibly due to regulation like in Germany.

Thanks to its superior performance in terms of speed, accessibility and comfort, helicopter is the recommended solution for medical evacuation. Combination of hoisting with landing capabilities provides superior flexibility.

1. Number of recordable injuries per million hours 2. Transfer from/to vessels, vessel operation (including jack-ups and barges), transit by vessel

Human resources challenge: scarce qualified staff

With qualified staff becoming increasingly scarce and expensive, decoupling transportation of personnel and equipment and optimizing effective work time becomes more important. Additionally, rough working conditions - marine environment, work-at-height, rotations – impose constraints on the recruitment of qualified technicians For example, using helicopters rather than CTVs could save 40-50% time of technicians on average. Using SOVs also drastically reduces transit time but requires two teams for rotations.

"It is not difficult to find people, it is difficult to find qualified people"

- Senior Executive, OSW developer

Climate challenge: carbon footprint reduction

European developers and OEMs have set ambitious GHG reduction targets. For example, Orsted targets carbon neutrality for scope 1-2 and is committed to reducing scope 3 emissions by 90% by 2040.

Focusing on logistics, carbon emissions are not yet a key differentiator. However, it is expected to become a decisive criterion for tenders, starting with European markets.

"Carbon emissions are not critical yet, but will be very soon"

- Operational manager, OSW developer

With different usages, it is difficult to compare transportation means in terms of carbon emissions. However, for a similar usage, helicopters emit five times less carbon than vessels for the same distance.

Additionally, quick access to a failed turbine for troubleshooting will limit the carbon emitted by conventional resources to compensate for power generation loss during downtime.

Looking forward, vessel and helicopter OEMs are developing new solutions to improve carbon footprint. Green fuels will drive the main reduction in the short term. More disrupting solutions such as clean vessels (e.g., H2) are not expected until 2030 due to high infrastructure needs.

Future trends for OSW logistics

To cope with those challenges, the OSW industry is developing new logistic solutions.

Clustering of OSW farms and **mutualization of logistic solutions** across stakeholders will result in economies of scale and higher utilization rate of transportation. This requires better cooperation between industry stakeholders, which would all benefit from cost reduction. In parallel, practices need to be further standardized at all levels resulting eventually in higher operating efficiency and higher level of safety.

Decoupling transportation of personnel and equipment to optimize transportation costs, speed and capacity by usage. For example, equipment and tools can be transported to the turbines with barges equipped, whereas personnel can be either transported by helicopters or accommodated offshore to limit transit time.

Digitalization of operations is expected to result in more preventive and predictive maintenance, with a higher number of failures being solved preventively thanks to Machine Learning and big data. Failure rate of turbines is expected to further decrease, making production losses less important. Troubleshooting will therefore be more and more bundled with planned activities.

Combination of scheduled with unscheduled maintenance by advancing scheduled work packages in case of an unscheduled event. This allows to reduce logistic costs and make more efficient use of the time in the wind turbine. It also requires a larger team that covers the different skills needed.

OSW industry is facing tremendous challenges: technical challenge, cost pressure, safety improvements, scarcity of resources and climate challenge. On the other side, the industry is developing new solutions to address challenges.

Looking further ahead, disruptive solutions for OSW logistics

Two disruptive logistic solutions

In this section, we investigate two disruptive solutions:

- Solution 5 - Helicopter & barges
- Solution 6 - SOV & helicopters & CTVs

Decoupling crew transfer by helicopter and cargo transport by barges

In solution 5, people transfer and equipment transport are fully decoupled:

- Transport of parts performed by barge once every two weeks on turbines that will be maintained over the next two weeks
- Transfer of personnel done by helicopter every day, using the substation as offshore base from which teams are transferred and hoisted to wind turbines

Illustration 10: Decoupling crew transfer and cargo transport to reduce logistic costs, costs of personnel and power loss

Location: **Baltic Sea**
Distance to shore: **15 NM**
turbines: **80**
Capacity: **1.5 GW**

Standard solution

Alternative solution

Benefits

-217[1] €m

People costs: **-38 €m**
Logistic costs: **-34 €m**
Power loss: **-145 €m**

-57%[2] tCO2e

This solution presents several advantages

- **Lower costs of personnel** thanks to shorter transit time and lower number of technicians
- **Lower power loss** using helicopters, thanks to better accessibility and higher speed
- **Lower costs of logistics** by using barges only a few days per month.

Solution 5 is the preferred solution below 50 turbines and 40 NM from shore.

Combining and mutualizing all logistic means to increase utilization rate

Solution 6 combines SOV with daughter crafts and helicopters

- SOV used for scheduled maintenance, technicians are accommodated offshore
- Helicopter and daughter craft used for troubleshooting

All transportation means are mutualized with other OSW farms to improve utilization rate

- SOV operating nine months per year
- Utilization of helicopter is optimized to reach lowest average cost per hour

Illustration 11: Combining all means to minimize costs of logistics and personnel, and power loss

Location: **North Sea**
Distance to shore: **80 NM**
turbines: **100**
Capacity: **1.5 GW**

Standard solution

Alternative solution

Benefits

-186[1] €m

People costs: **-23 €m**
Logistic costs: **-131 €m**
Power loss: **-33 €m**

-22%[2] tCO2e

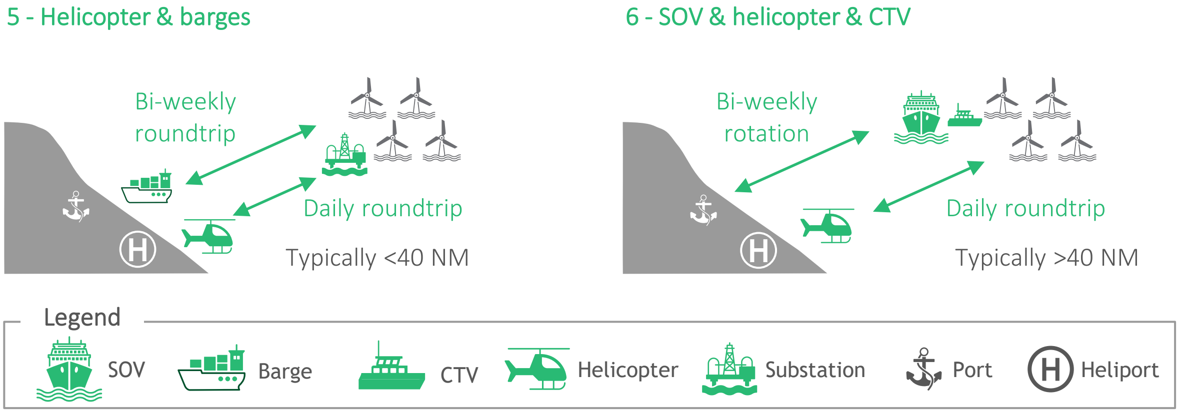
This solution also has several advantages

- **Lower costs of personnel** thanks to offshore accommodation on SOV and usage of helicopters
- **Lower power loss** due to permanent offshore presence with daughter craft combined with quick response with helicopter
- **Lower costs of logistics** thanks to optimized utilization rate of SOV and helicopter
- **Higher flexibility** thanks to combination of all different solutions

Solution 6 - SOV & CTV & helicopter - is most beneficial above 50 turbines and 40NM.

1. Cumulated over 30 years 2. Including carbon opportunity cost (using CCGT as back-up during downtime)

Illustration 12: Disruptive solutions



Substantial benefits can be achieved by transforming logistic operating model

Compared to standard solution, those two disruptive solutions can lead to significant benefits

- Up to 30% financial benefits
- Up to 50% reduction in carbon emissions

However, materializing those benefits requires end-to-end transformation of current business model, including:

- Revamping planning approach to optimize full cost of ownership based on the holistic logistic equation starting from blank page (not optimizing current solutions)
- Setting up full cooperation between stakeholders to achieve mutualization of logistic means and clustering of wind farms
- Revising daily schedule, rotation and working seasons for both personnel and transportation means
- Investing in additional tools and equipment for offshore storage in order to transport them on turbine prior to maintenance

Industry players need to start this transformation quickly to enable benefit realization in the coming years.

Substantial benefits can be further achieved by unlocking the full potential of all new trends under development in the industry. However, this will require drastic changes in the logistic paradigm and will take several years for the offshore wind industry.

Appendix 1: Abbreviations

CCGT	Combined Cycle Gas Turbine
CTV	Crew Transfer Vessel
H_S	Significant Wave Height
KNT	Knots
NM	Nautical Mile
O&M	Operations & Maintenance
OEM	Original Equipment Manufacturer
OSW	Offshore Wind
PPA	Power Purchase Agreement
SOV	Service Operation Vessel
SPV	Special Purpose Vehicle
TRIR	Total Recordable Injury Rate
WTG	Wind Turbine Generator

Appendix 2: Offshore wind, a leading Transition Energy segment

Offshore wind market has boomed in the 2010s

Increasing GHG reduction targets and related public policies have supported the development of offshore wind sector over the last decade. By end of 2021, worldwide installed capacity has reached 41 GW.

Europe is leading the way with the UK (10.4 GW), Germany (7.6 GW), Netherlands (5.3GW) and Denmark (2.3 GW). Asia is following, driven by China (13.4 GW). In contrast, no significant project have been commissioned to date in America.

Growth is expected to accelerate in coming decade

Offshore wind industry is expected to further accelerate with 200+ GW additional capacity to be commissioned by 2030, including 130+ GW (five times more than 2021 baseline) in Europe and US, catching up with onshore wind.

60+% of installed capacity: established markets will continue to grow - United Kingdom (+28 GW), Netherlands (+18 GW), Germany (+13 GW), Denmark (+6 GW) - and other markets will take off - mainly France (+9 GW) and Poland (+8 GW).

Asia will continue its strong development, especially in China (+38 GW). US market will experience strong growth to reach 28 GW by 2030.

The rest of the report focuses on European and North American markets.

OSW farms are becoming larger and getting farther from shore

This strong increase in OSW capacity requires to look for wind potential farther and farther from shore and to build larger OSW farms.

However, the situation varies across countries depending on geography and market maturity: some very large projects in Europe, often far from shore, especially in the UK, and smaller projects closer to shore. US market is nascent, but projects are relatively large and close to shore.

Pressure on costs drives significant technology improvements and increasing turbine size

Historical players from Northern Europe are being challenged by new entrants. Auction prices have dropped by 40% in five years and the market is becoming merchant.

Turbine OEMs have been able to reduce cost per MW by increasing turbine capacity from 3-5 MW in 2015 to 8 MW in 2020 and 15+ MW in 2025. Floating technologies are emerging and will open the door to 9,000 GW of untapped potential (60+m depth), most of the time farther from shore.

To achieve such growth, industry players have been able to build and operate very large projects. Increasing size and distance from shore will bring new challenges for construction and O&M activities, impacting logistics metrics.

Illustration 13: Typical offshore wind project, by commissioning year

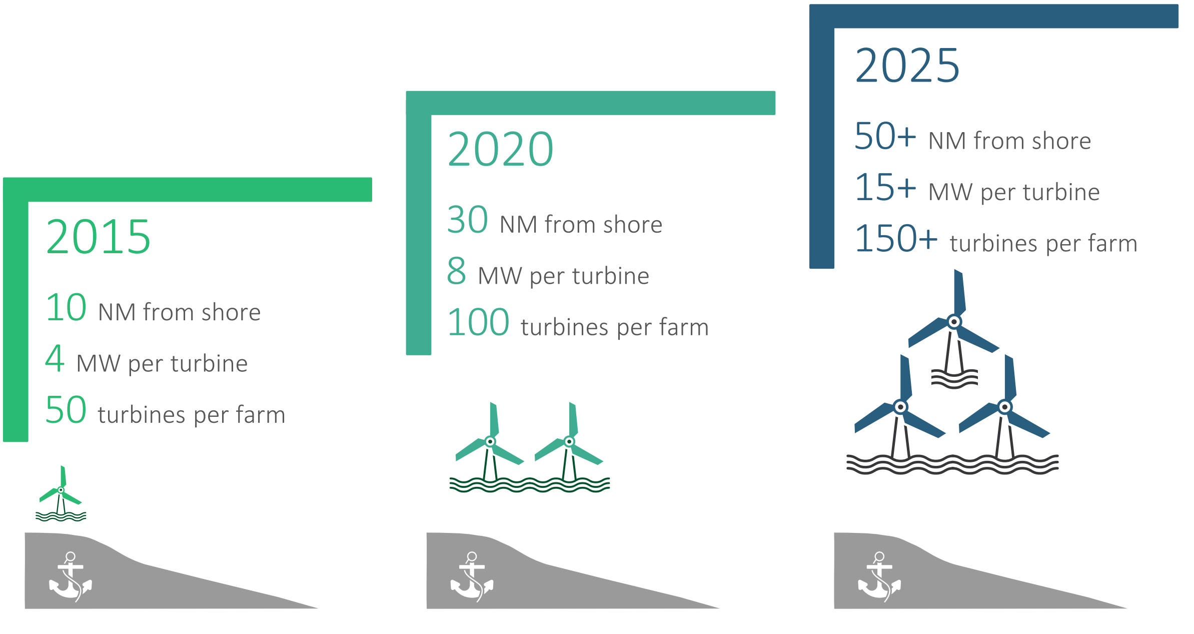
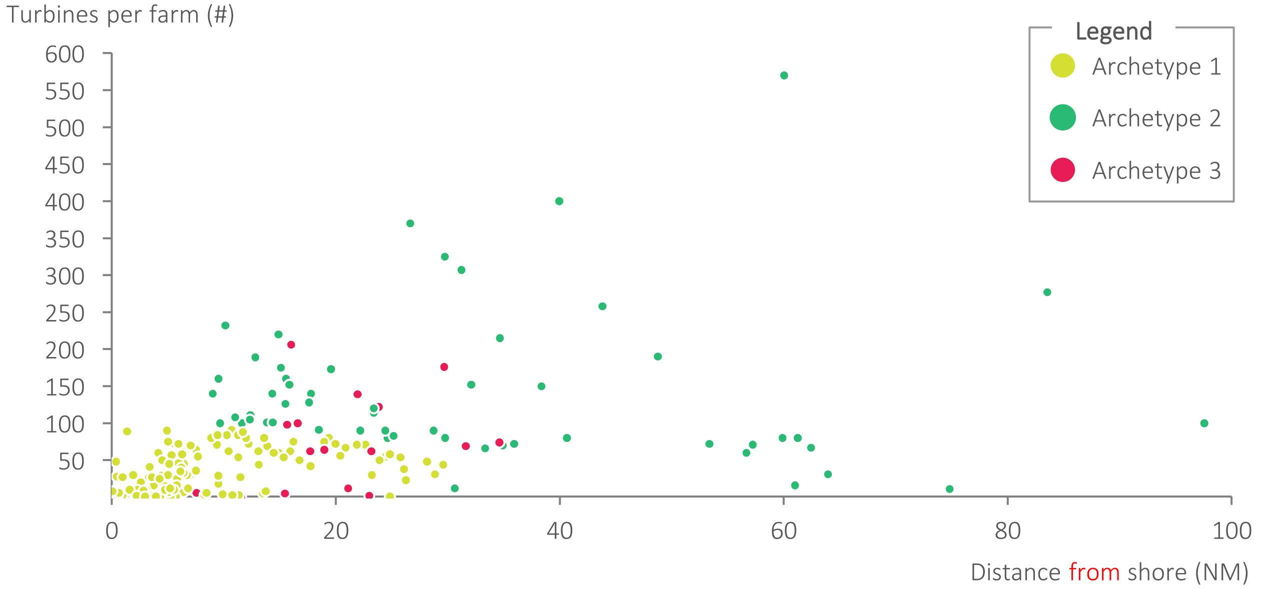


Illustration 14: Overview of OSW farms commissioned in 1990-2030, by distance from shore and number of turbines



Archetype 1

< 30 NM &
< 150 turbines

33%

Archetype 2

> 30 NM or
150-300 turbines

58%

Archetype 3

All farms

9%

Source: 4C offshore   Note: Percentage of existing and future installed turbines in 2030

Appendix 3: Typical logistic setup of an OSW project

Illustration 15: Logistic setup for 1 GW project 30 NM from shore

	1-2 year(s) **Installation**	20-30 years **O&M**
Main activities	• Installing large components • Installing export and array cables • Building substation • Commissioning	• Operating wind farm • Performing scheduled maintenance • Troubleshooting turbines in case of failure
Materials[1] *Illustration: 100 turbines (10 MW) on monopile, 30 NM from shore*	Wind turbine • Foundations : 150 kt (steel) • Transition pieces: 75 kt (steel) • Tower: 100 kt (steel) • Blades: 23 kt (fibre glass) Substation: 4 kt (steel, concrete) Cables • Export cables (50km): 5,000 t (copper) • Array cables (100km): 4,000t (copper)	• Blade: 75 t fibre glass / unit • Large equipment: gearbox (~30t), power converter (~8t), generator (~10t), etc. • Parts: <500 kg
Workers	• 200-400 construction workers • 40-80 OSW technicians for commissioning	• 30-50 OSW technicians
Logistics	10-50 vessels and helicopters, e.g., • Heavy lifting vessels • Cable installation vessels • SOVs • Helicopters	1-5 vessel(s), helicopter(s) and drone(s) • CTVs • SOVs • Helicopters • Drones

Appendix 4: Fact base and key assumptions

We built a bottom-up model to estimate the most economical logistic solution depending on farm parameters:

- We calculated full costs associated with each solution (direct logistic costs, people costs, cost of opportunity, e.g., power loss during turbine failure or scheduled maintenance)
- We identified the most economical solution for each existing and future project by 2030
- We grouped offshore wind farms with similar parameters (e.g., distance from shore, number of turbines) to build farm archetypes (see details in page 19)
- We computed the share of each logistic solution for each archetype

Table 1 – Offshore Wind farm

Input	Value
Distance from shore (NM)	*Archetype parameter*
Number of turbines (#)	*Archetype parameter*
Farm commissioning year	*Archetype parameter*
Turbine capacity factor (%)	54%

Table 2 – Maintenance input

Input	Value
Man-days for 1 turbine maintenance with SOV (#)	22
Number of SOV pit stop per day (#)	3
Number of technicians per SOV pit stop (#)	8
Number of technicians per troubleshooting team (#)	3
Number of other technicians (#)	3
Number of SOV rotation per month (#)	2
Technician offshore premium, incl. taxes (€/hour)	90
Share of failures resolved within 2h (%)	30
Share of failures resolved within 2-3h (%)	60
Share of failures resolved the next day (%)	10

Table 3 - Transportation input

Input	CTV	SOV	Helicopter
Transit speed (km/h)	29	15	248
Transit speed within wind farm (km/h)	11	11	150
Capacity (#technicians)	12	60	8
Charter costs (€)	4,000/day	20,000/day	3,400/hour
Fuel costs (€/t)	540	540	
Non availability in North Sea (winter/summer) (%)	56%/17%	33%/2%	5%/5%
Non availability in Baltic Sea (winter/summer) (%)	14%/14%	0%/0%	5%/5%
Time to exit harbour (min)	30	0	0
Time for safety briefing (min)	0	0	20
Time for boarding (min)	0	0	10
Time to land turbine (min)	10	10	0
Time to climb turbine (min)	10	10	5
Productivity loss due to sea sickness (min)	30	0	0

Figure 1 – Capacity per commissioning year

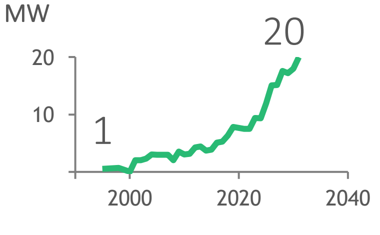


Figure 2 – Failure rate per commissioning year

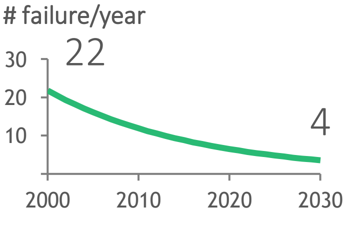
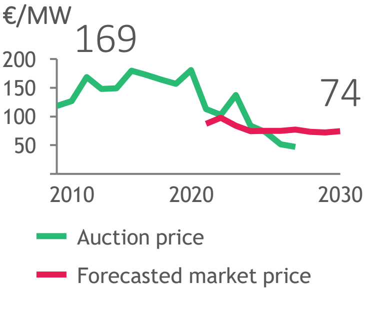


Figure 3 – Electricity price per commissioning year



Sources

a. 4C Offshore Global Market Overview Q4 2021 b. 4C Offshore Wind Database c. https://doggerbank.com d. G+ Global Offshore Wind Health and Safety Organization e. Science Based Targets: Companies Taking action f. "Advanced Logistics Planning for Offshore Wind Farm Operation and Maintenance Activities", Yalcin Dalgic, Iraklis Lazakis, Iain Dinwoodie, David McMillan, Matthew Revie g. BCG Power Market Model

Appendix 5: Zoom on selected topics

Zoom 1: Accessibility varies significantly across seas and oceans

In Baltic sea, current is relatively slow, and waves are limited most of the time, but icing limits the utilization of vessels in winter. CTVs cannot access offshore wind parks 10% of the time, mainly in winter, whereas SOVs can access almost all over the year.

North sea is rougher with higher waves and strong current, which limits operations of CTVs 30-40% of the time, mainly during winter. SOVs are also impacted 20% of the time.

Atlantic ocean is characterized by high waves and swell with high tidal range limiting utilization of SOVs 30% of the time. Combining all constraints, CTVs can only be used in the summer and are often not the best solution.

On the other side, utilization of helicopters is limited by lack of visibility in only 5% of daytime. High humidity combined with low temperatures in North sea can lead to blade icing, which can be overcome with heating systems. Wind speed is not affecting utilization of helicopters, but anyway, no work is allowed when wind speed goes over 22 kts.

Zoom 2: Specific regulation in the US limits utilization of vessels

Two main US specificities need to be considered when designing the adequate logistic solution.

Firstly, the Northern part of the Atlantic Ocean coast of the US includes a large protected area for critical sea habitat. During Spring and Fall, vessels are forced to transit with speed restrictions, making it longer to access farms with vessels.

Secondly, the Jones Act of 1920 requires that goods shipped between US ports are transported on ships that are built, owned and operated by US citizens. This will have an impact on project CAPEX and OPEX, reflected in significantly higher charter rates for US vessels (+25-50%), making helicopter relatively more competitive.

For construction, an alternative option for jack-up vessels would be to sail to a Canadian port or use barges to ship cargo (foundation/turbines) directly to the wind farm.

Zoom 3: A typical workday for OSW technicians

Scheduled maintenance is scheduled over 3-4 months in the summer. Workers typically work 12 hours per day.

The day starts with the morning briefing, including safety. Then, technicians transfer to wind turbines (15mn to 2h depending on logistic solution). Teams of 3-8 technicians are deployed at each turbine (15-30mn depending on logistic solution) with toolboxes and equipment using either walk-to-work systems, cranes or helihoist. Different technicians perform mechanical, electrical and quality maintenance on the turbine over the day. They use elevators to go up and down the turbine. At the end of the day, technicians transfer back to their accommodation, either on-shore or offshore.

Unscheduled maintenance is needed in case of turbine failure. Troubleshooting requires highly qualified technicians. This work is typically handled by a dedicated team of 3-6 technicians, waiting either on-shore or on SOV and ready to intervene.

This small team is transferred on the turbine quickly with toolboxes and small parts (e.g., sensors). Troubleshooting typically lasts less than 3 hours including diagnosis, part replacement and turbine rebooting. In only 10% of cases, troubleshooting requires replacement of large components, which will be done by another team another day.

When they do not repair turbines, troubleshooting teams typically support planning team or warehouse team.

In case of incident or bad weather, technicians can be accommodated in a shelter on the turbine for a couple of days.

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