Using electricity from wind turbines to power service vessels during construction and maintenance

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Acknowledgement

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It was carried out to satisfy the requirement of the course MM-MTH-5001 – Master's Thesis in Maritime Management, Technical Specialization, at the Faculty of Technology, Natural Sciences and Maritime Sciences at the University of South-Eastern Norway (USN).
The topic of this master thesis stemmed from my passion for the shipping industry. Being 30 credits assigned to this master thesis, it was a huge and time-consuming task. However, during this study, I received valuable information from my friends and colleagues working on board the service vessel. Our discussions on this subject and beyond were greatly useful for writing this master thesis. My deepest gratitude and appreciation goes to my supervisor Marius Tanum, for his rich feedback and supportive guidance throughout the process of writing this thesis. I would also like to sincerely thank all the people from different companies and organizations for their feedback on my research question. Lastly, I would like to thank my family for all their support and encouragement during the whole process of writing this master thesis.

Abstract

This master thesis is conducted based on an in-depth study on literature as well as a cases study with the aim of investigating whether the charging and operation of electrical service vessels such as Offshore Access Vessel (OAV) and Crew Transfer Vessel (CTV) is economically, technically and environmentally sustainable for using in the shipping industry.

In order to fulfil the aim of this thesis, a qualitative method in the form of a case study was performed. The chosen case studied the Offshore Wind Farm (OWF) service vessels that are responsible for the construction and maintenance phase of installing the turbines in the wind parks. The theoretical information in this thesis was gathered through reviewing different sources and talking to experts in this field. In addition, in order to better understand the research topic, a literature review was conducted. Initially, more than 1300 materials, such as scientific reports, articles, and books releated to the research topic, were extracted from the research engines. Later 29 articles aligned with the key research strings, namely: *electric service vessel, offshore wind farm, maintenance on wind turbine, technology offshore wind farm, power consumption hybrid vessel, recharging on-site,* and *wind turbine installation* were retrieved.

The outcome of this master thesis showed that it is technically feasible to charge the vessels in the wind farm under special circumstances such as weather conditions, availability of charging infrastructure, and approved permissions. In addition, using a battery solution is more environmentally friendly and can reduce up to 48 per cent of the CO_2 emissions. Furthermore, it was calculated that the shipping company could save more than 17 per cent of fuel costs compared to diesel power engines.

Abbreviations

Speed: 1 Knots = 1.852 km/t
Distances: 1 Nautical mile (NM) = 1852 meters

IMO	International Maritime Organization
OWF	Offshore Wind Farm
WTG	Wind Turbine Generator
ICE	Internal Combustion Engine
CTV	Crew Transfer Vessel
SOV	Service Operation Vessel
W2W	Walk To Work
JUV	Jack-Up Vessel
HVDC	High Voltage Direct Current
OSP	Offshore Sub-station Platform
OAV	Offshore Access Vessel
MGO	Marine Gas Oil
CSV	Construction Support Vessel
BESS	Battery Energy Storage System
AC	Alternating Current
DC	Direct Current
APS	Automatic Plug-in System
AIS	Automatic Identification System
RPM	Revolution Per Minutes
SCTV	Standard Crew Transfer Vessel
$\mathbf{CO_2}$	Carbon Dioxide
$\mathbf{NO_x}$	Nitrogen Oxides
$\mathbf{SO_x}$	Sulphur Oxides
MCC	Marine Coordination Centre
HCTV	Hybrid Crew Transfer Vessel
kWh	Kilowatt-hour

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1 Introduction

1.1 Background

The population of the world is continuously growing, and as this number increases, more and more energy is needed globally. Consuming energy can also bring significant challenges to the world and create a harmful impact on the environment. Climate change, air pollution and global warming are only some of these negative effects and require global attention and new technologies. This issue can be addressed by broad collaboration across all industrial sectors. One of these important sectors is the shipping industry. The maritime transport counts for 90 per cent of the world trade (*Ocean Shipping and Shipbuilding - OECD*, n.d.). The shipping industry significantly contributes to global climate change due to the fact that about three per cent of the global carbon dioxide emissions come from the shipping industry (*Shipping Pollution*, n.d.).

Furthermore, the regulation regarding pollution from combustion engines is going to be stricter in the future. The industry aims to cut emissions through knowledge, operational development and the use of new technology. However, the long-time perspective is to have a permanent switch to renewable energy sources with alternative fuels. This will be required to fulfil obligations imposed by regulations that already are implemented. The possible options are batteries in different sizes and weights or hybrid solutions that can be used to slowly eliminate the use of Internal Combustion Engines (ICEs). Some European shipping companies have already taken one step ahead and built vessels that use a hybrid combination of battery and diesel propulsion or use pure battery power to operate the vessel.

Today, most service vessels in the Offshore Wind Farm (OWF) spend many hours idle on the field with reduced load on the engines to keep the position and generate power for hotel load on board. Hotel loads describe everything that requires power, such as ventilations, pumps, lights and air conditions, except power for propulsion (Rawson & Tupper, 2001). Today the Crew Transfer Vessel (CTV) and Offshore Access Vessel (OAV) use Marine Gas Oil (MGO) as a fuel. for propulsion, hotel and crane operations. According to Haynes, 85 % of the cost of vessel ownership is related to fuel cost (Haynes, 2019).

Due to these environmental issues, safety requirements and operational costs, it is necessary that the industry finds new and more sustainable solutions in terms of energy management with the help of new or existing technologies.

Battery or Battery Energy Storage System (BESS) on board are ideal for vessels that sail short sea routes or fulfil peak power needs. The technology is experiencing rapid improvements in energy density and price for each kilowatt (kW) in this field. However, the technology is not yet capable of propulsion of large ships over long sea distances (Buitendijk, 2020).

1.2 Aim of the thesis

This study aims to investigate whether the charging and operation of electrical service vessels such as Offshore Access Vessel (OAV) and Crew Transfer Vessel (CTV) is economically, technically, and environmentally sustainable. The driving pattern that a service vessel has within 30 days must be mapped. This study seeks to solve the research question of whether a service vessel can operate in a wind farm by reducing fuel emissions to a minimum. The vessel's energy consumption will be measured to see if it is feasible to replace today's fossil source with a more sustainable energy mix. Today, the knowledge about the electric and hybrid charging of vessels in the offshore industry is limited. This study focuses on intervals of port approaches and fuel consumption of service vessels, preferably those that stay on the field in short and longer intervals. The routes that are primarily focused on are the ones that are based on the harbour. These are the vessels for mooring, provisions, and crew change at the beginning of the construction phase, where the installation preparation of wind turbines takes place.

This investigation can also help us find out how it can reduce the emissions and the cost of operating the vessel. Since the wind farm provides clean energy, it can be beneficial to use the same energy source to plan, prepare, and construct these turbines. This can also minimize the pollution coming from Marine Gas Oil (MGO), exhaust and other harmful substances.

Moreover, the possibility of powering offshore vessels from a nearby wind farm during the construction, maintenance, and offloading of cargo and humans is going to be researched. The vessel types investigated in this thesis are CTV and OAV.

The goal is to study and elaborate on the different possibilities and challenges related to battery or hybrid as an energy mode for the vessels. This work will mainly focus on Offshore Wind Farm (OWF) vessels responsible for assisting the construction phase and the Operation and Maintenance (O&M). This includes the pros and cons of a vessel using the battery as the power source. The challenges related to large operation service vessels outside the field will also be included. To find out the answer, the data from the vessel driving patterns, utilization of vessel sailings trip, and mapping of vessels over 30 days will be used to get an overview of daily sailing operations the service vessel has during the day.

1.3 Motivation

The decision of choosing this topic comes from the author's interest and the relevance of his current job as a navigational officer on a jack-up vessel responsible for installing wind turbines outside of the coast of Scotland. Furthermore, the author is highly concerned about the climate crisis that is going on in the world. The shipping industry as well as other industries, contribute to a lot of global greenhouse gas emissions. As an employee in this industry, the author feels responsible to raise awareness towards the issues that using diesel engines can bring to the environment.

Currently, a high diesel energy consumption is required to keep the vessel operational. There is a discussion regarding minimizing the use of fossil energy from non-renewable energy sources, including fossil fuel oil, coal, natural gas and nuclear. On the other hand, the climate activists desire to use more renewable energy such as solar, hydropower, wind, biomass and geothermal sources. This transition needs to be done within a short period of five to ten years. The study's objective will be to figure out how much fuel could be saved by using hybrid or battery instead of fossil fuel. The possibilities of using renewable energy as a propulsion source on vessels are there, but technology, price, and knowledge are still growing. This technology has a high potential for electricity production by utilizing wind power from OWF.

1.4 Structure of the thesis

This master thesis consists of six parts. Introduction, Literature review, Methods, Findings, ending with the Discussion and Conclusion parts.
This current chapter, introduction, provides an overview of the background of the research, aim of the thesis, motivation, structure and research questions.

The second section describes the research and elaborates on methods utilized during the work, the research review with the study of elements relevant to the thesis, the systematic literature separation and study, research question and objectives.
The third section intends to preview the thesis research strategy and methodology. This includes the systematic literature review.
The fourth section will give a view of the findings from the selected data and other useful information from the experts.
The findings will be compared with the literature review further in the discussion chapter.
In the last chapter, conclusion, the research question will be answered, followed by the limitation of the study.

1.5 Research question

The following research question is formulated for this master thesis:
RQ: Is it *economically*, *environmentally*, and *technically* sustainable to use electrical or hybrid driven vessels instead of fossil fuel driven service vessels in the wind park construction and maintenance phase?

To define the problem in more details and to better understand the research topic, a literature review is going to be conducted. The theoretical information will be gathered through reviewing different articles and talking to experts in this field.
To compare the results, the following aspects will be quantified and classified:

- Operating conditions.
- Vessel duty cycles.
- Engines load cycle.
- Classify types of suitable vessels at the windfarm
- Electrical powering compared to the traditional combustion engine.
- Practical and economical powering of vessel
- Environmental aspects of wind farm charging

In order to narrow down the scope of the thesis, the following assumptions are taken into consideration when estimating the efficiency of hybrid and electric vessels.

- It is always power available at the wind farm for sharing power with the service vessels
- The vessel is idle when it receives power from the wind farm.
- The speed is uniformly distributed between 0–0.3 knots when idle or on standby in OWF.
- The battery range is between 0 – 100 %, instead of 30 – 72 %, which is more typical for battery vessels.
- The mass of the battery package increases the energy consumption by 25 per cent on the CTVs.
- The fuel class for diesel engines are MGO.
- The energy prices are taken from the average price in 2021. The energy prices to recharge vessels in wind farms are assumed to be 50 per cent compared to recharge in port.
- In the transit and idle time calculations, the power and engine load are assumed to be constant for OAVs. CTVs in idle engine power mode use 18 litres MDO per hour and 450 litres per hour.
- Average power prices for 2021 will be used for calculations.

2 Literature review

Literature research is a process of finding already published literature. In this thesis, the useful information is obtained from academic papers and literature reviews. The findings are categorized into different topics: definitions, construction phase, maintenance & operation, work permit and restrictions, battery, and lastly, dynamic position.

2.1 Definitions

Vessels are divided into different commodities to travel from port to windfarm. They carry important tools and technicians with high skills to do services, installation, and inspection on wind farms before wind turbines are constructed. This vessel sails to the wind farm so that the wind turbine can be completed quickly and safely and generate power early to the grid (Łebkowski, 2020).

The wind farm service vessel is a sub-industry that falls under a particular vessel category that is optimized to operate in the Offshore Wind Farm (OWF). These vessels enter the wind farm and approach turbines to fulfil strict rules and procedures. The vessel's size and speed may vary depending on weather and distance to WTG assets.

2.1.1 Wind Turbine Generators (WTG)

Offshore windmills in the are called Wind Turbine Generators (WTG). They are located in the so-called Offshore Wind Farm (OWF) (Holmefjord et al., 2020). Wind turbines have been built larger and larger in the last decades. The most powerful offshore WTG in the world can produce power up to 14 MW (IAE, 2019). It is expected that the capacity of each turbine will reach between 15 to 20 MW in 2030 (GE Renewable, n.d.). The increase in the turbine size and numbers has put tremendous pressure on capital costs since larger turbines create more construction challenges and require larger foundations. In the OWF, there are mainly between 6 – 200 turbines, and all turbines are connected to an Offshore Sub-station Platform (OSP).

The wind market offshore has since 2016 grown from 2.2 GW to 6.1 GW in 2020 of newly commissioned turbines. New annual installations are expected to pass the milestone of 20 GW in 2025 (RE globals, 2021). Usually, the voltage generated from the wind turbine is 6.6

kV. In order to charge the battery installed on board the CTV units at minimal wind strength, it is vital to choose a specific voltage level. It is also essential to select a suitable transformer and unidirectional electricity converter to charge the batteries installed on board (Łebkowski, 2020).

Compared to onshore, the offshore wind turbines have some advantages, such as more wind, no size constraints, and no noise pollution at sea. They can also capture stronger wind and take advantage of larger and more sustainable areas (Tian et al., 2022).

The distance to the wind farm depends on the location and does not have any standard range from shore. However, most of them are over 20 km away from shore. The average distance between a port and wind farm in the UK is 80 km, and the distance between each turbine tower is two km on average (Łebkowski, 2020).

2.1.2 Offshore Support Vessel

There are many different vessels on the field during construction time, namely survey vessels, cable layer vessels, construction vessels, Jack-up vessels (JUV), Crew Transfer Vessels (CTV), standby vessels, and Offshore Access Vessels (OAV). OAV includes Service Operation Vessel (SOV), Walk to Work vessel (W2W), and Construction Support Vessel (CSV).

Figure 1 CTW pushing onto the boat landing in Borssele wind farm in the Netherlands

OSVs are usually another group of vessels that keep it easy to stay “on-site with technicians and tools”, which consist of CTV and OAV. The most popular types of vessels categorized in service vessel are single-hull which have one keel. CSV, W2W and SOV are types of single hulls vessels. CTV has a different design with two keels as the catamaran. When the CTV approaches the boat landing, the technicians can use the ladder to climb up to the turbine platform. Loading and unloading of the tools will be performed with a crane installed on the turbine platform, as shown in Figure 1. OAV will provide accommodation for the WTG commissioning technicians. Technicians will use the vessels’ walk-to-work gangway system to access the WTG structure for commission activity. In the pictures below, different types of vessels used in the OWF construction is shown. The first picture on the left is an Offshore Access Vessel (OAV). The second one shows a Cable Laying Vessel (CLV). The third one is a Jack-up Vessel (JUV), and the fourth one illustrates a Crew Transfer Vessel (CTV)

*Figure 2 Sample photos of vessels used at offshore wind farm construction (Siemens Gamsea, n.d.) (*NKT Victoria*, n.d.)*

During commission of wind parks outside the Scotland, there are three vessels (one OAV, and two CTVs) supporting the building process (Buljan, 2021; Durakovic, 2021). Each windfarm is under 30 kilometres off the coast. However, the number of vessels depends on the complexity of a wind farm construction. An average of one CTV is required for the operation and maintenance phase that can sail between port and wind turbine with technicians (Łebkowski, 2020).

2.1.3 Offshore Sub-Station Platform (OSP)

The offshore Substation platform (shown in Figure 3) is an integral part of a power system where the power generated from wind turbines is received through an inner grid cable to the Substation. The voltage from wind turbines is medium voltage. The power will be transformed to a higher voltage and later exported from an external grid cable to shore (Robak & Raczkowski, 2018).

Figure 3 Offshore Sub-Station Moray East (Moray East OWF, 2020)

2.2 Construction phase

WTGs are constructed on a foundation or Transition Pieces (TP) with a tower, nacelle and three blades (see Figure 5). Depending on the used generator, the power that one offshore turbine can generate in the field is 3 to 14 MW. It is possible to use more than one specific generator model or brand in the field, but most of them use the same type in a wind park.

The figure below (Figure 4) shows how cables in the windfarm are installed at the seabed. As it is illustrated, the inter-array cable goes from turbine to substation, and the export cable goes from the substation to shore after transformation. The inter-array cables can be looped through several turbines before connecting to the substation in order to maximise export capability (Nordsee One, n.d.).

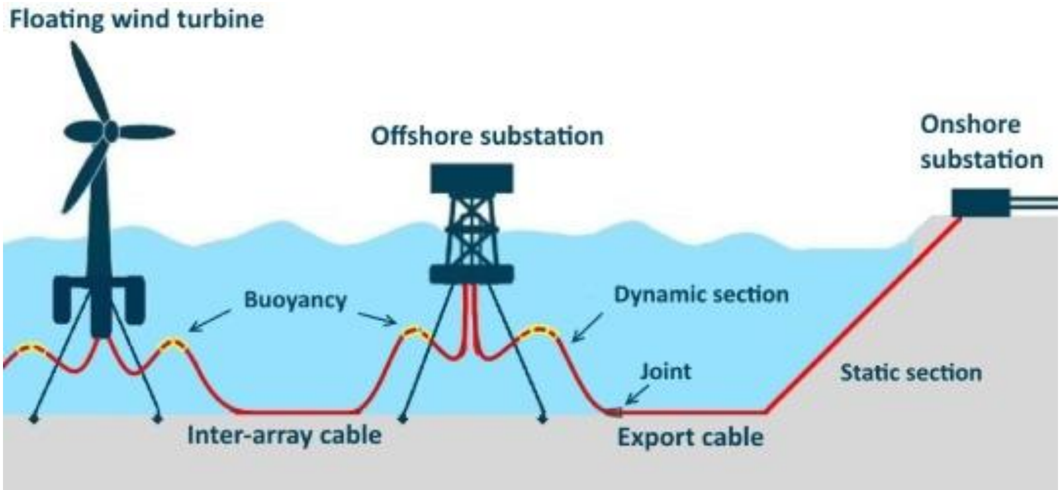


Figure 4 Cable arrangement in an offshore wind farm (Lerch et al., 2021)

WTG is connected to several turbines, and a cable connects them to an Offshore Substation Platform (OSP) (see Figure 4). This transformation station converts the energy from WTG through an inter-array cable to Higher Voltage Direct Current (HVDC) and transports it to shore by export cables (Lerch et al., 2021).

The wind farm uses several vessels to develop, install and commission a turbine. The average time for construction is between 1 to 4 years, depending on the number of turbines.
Short distances between turbines are suitable for electrical vessels during construction and maintenance. CTV and OSV can manoeuvre between turbines without using high power consumption over time. All wind parks are marked on navigational charts as a no-go area for unauthorized vessels or personnel.

Offshore Access Vessels will maintain small and middle-sized turbine components to avoid high costs for the transportation time and have a quick response infield. This type of vessel can stay in the offshore field for two to three weeks, providing shelter and accommodation for the crew and technicians (Neves-Moreira et al., 2021).

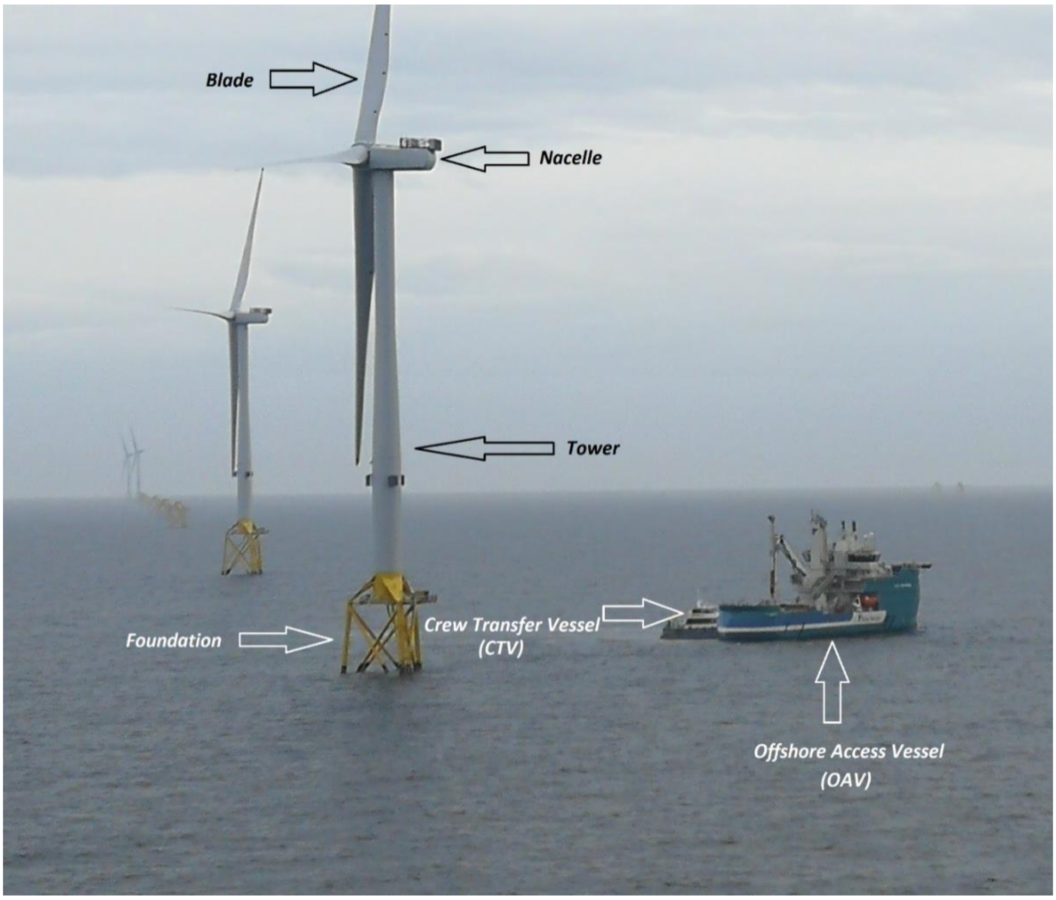


Figure 5 Wind turbines with service vessel during the construction phase.

The number of vessels in the field during the construction phase is shown in Figure 6

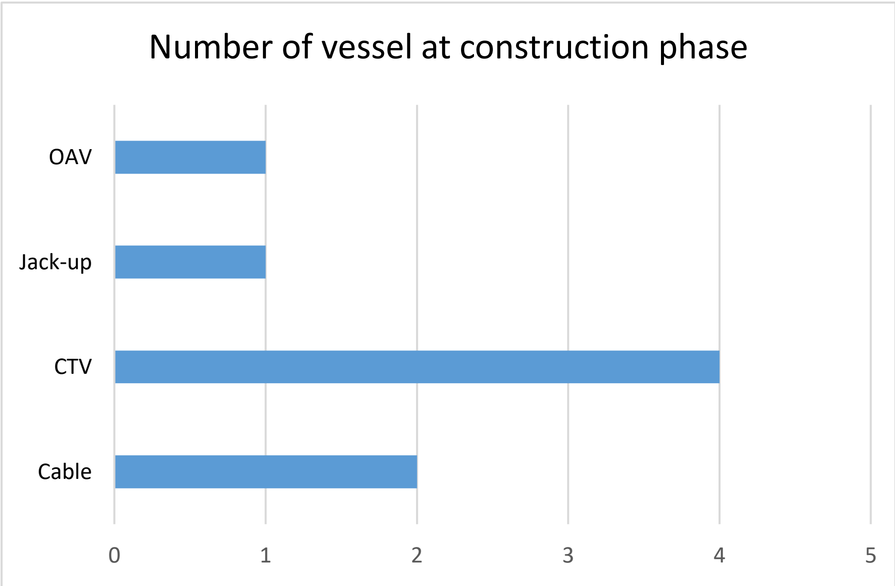


Figure 6 Total number of vessels in the field during the construction phase (own production)

2.3 Charging

The shipping company, NOS, has announced the idea of using a new hybrid CTV with the possibility to recharge batteries directly from the wind turbine when they are waiting in the field (NOS, n.d.). Tidal Transit also pitched the idea of electric CTV in 2017 (Hambro, 2020) (see Figure 7). Recently, the shipping company, Cwind, has been working on a new type of CTV that can save time, money and the planet by introducing the world’s first Hybrid SES (CWind, n.d.).

Charging stations in port can be cable and plug based, pantograph tower-based, ferry charger based, automatic plugin-based system, and DC charging instead of AC. Today’s ports have been equipped with shore power system for a long time so that smaller vessels can receive shore power to keep the vessels in operation. In a significant operation, to facilitate the power grid around the harbour, fast charging can also enable the charging of hybrid ships and possibly electric vessels (Kumar et al., 2019).

The CTV can operate on a battery when the speed range is between 10 and 15 knots, according to the shipping company HST. When using a hybrid system, there will be 50 % less main engine operations (*HST Marine High Speed Transfers*, n.d.). Corvus Energy delivered a battery package to HST Ella, where they mentioned the annual savings of CO_2 emission reduction of about 30 % with a battery capacity of 188 kWh. The battery operation gives the possibility for peak shaving and zero-emission operations (*HST Ella*, n.d.).

Figure 7 Tidal transit electrical CTV. (Hambro, 2020)

The charging issue for service vessels is nearly similar in port compared to the offshore in terms of how this fleet can power up the battery in a short time to manage the schedule without any delay. Due to the charging challenges in port, Kumar et al.(2019) introduced an alternative method of battery charging with the best power capacity for modern vessels due to activity. Today two charging methods for vessels exist; slow charging and fast charging. Kumar described these two charging methods for different time consumption. The slow method will take around eight hours or more, while the fast charging is accomplished within one hour or less. Kumar also described the power output and specifications that can be given to the vessel from the shore side.

2.4 Maintenance and operations

In a wind farm several vessels are in place to maintain the turbines and keep them operational in case something goes wrong and the turbines stop producing power. The Jack-up vessels are used for more extensive maintenance where major components such as gearbox, blades or nacelle should be replaced (Sperstad et al., 2016).

According to Gutierrez-Alcoba et al. (2019), there are two types of maintenance tasks on wind turbines; preventive and corrective maintenance. Preventive maintenance is described as a service to prevent failures and prolong the lifetime. Corrective maintenance is needed when the wind turbine is down, and more maintenance is required to be operational again. This article gives a better perspective on when different vessels need to be hired for specific maintenance on the wind turbine. There is also good information about the cost of using different types of vessels, the optimal speed and the sailing distance required until the vessel is safely back on the field.

Today, the Crew Transfer Vessels (CTVs) are used to deliver urgent tools and carry technicians from OAV or harbour to WTG where further maintenance is required. The CTV's service speed during transit is usually between 20 and 40 knots if the sea state and weather allow it. CTVs are divided into two groups: Advanced CTVs (ACTV) and Standard CTVs (SCTV). The ACTV is designed for a higher travel speed and higher wave height class for technician transfer compared to the SCTV (Sperstad et al., 2016).

Annual inspection and service is usually carried out at the wind park to follow up necessary maintenance regulated by the wind turbine factory. Since the service interval is annual, the wind park operators need to carry high skilled technicians to the field. Before chartering the vessels, the number of turbines and the maximum passenger a CTV is certified to carry to the field will be taken into consideration. Until January 2022, the passenger limit for CTVs was set to 12 technicians in the United Kingdom, despite the size of the vessel. Today the passenger limit for vessels over 500 Gross tonnage is 60 industrial workers (Durakovic, 2022). The total cost of operation and maintenance at the wind turbines is high, and the service vessel makes up to 73 % cost of the windfarm when they are hiring vessels (Junginger et al., 2004).

The transit time is included in the technicians' working hours, and the shifts already start when the vessel leaves the ports (Dalgic, Lazakis, Dinwoodie, et al., 2015). In this case, they do not need to work less or more than the normal working hours. It is desired to keep the transit time as short as possible. Therefore it can sometimes result in higher CTV speed (Stålhane et al., 2019).

2.4.1 Lifetime turbine generator

Offshore wind farm lifetime is dependent on different factors. A wind turbine can operate many years before the turbine, blade, tower or nacelle are required to be exchanged. Most often, the wind turbine has a design life of 20 years after construction, but generally, the wind turbine has a lifetime between 20-25 years. The UK regulations have set a fixed-term lease and planning permission for a wind turbine built on pillars at the seabed (Thomson & Harrison, 2015). Dalgic, Lazakis, & Turan (2015) claimed a 20 to 25 years lifetime for offshore wind farms if maintenance is regularly followed. Sometimes the maintenance of the wind park is postponed due to the bad weather condition until the weather windows are below the acceptable limit for offshore service vessels.

2.5 Work permit and restrictions

There exist regulations for the vessels that can approach the wind park. In order to enter the safety zone, the vessels need a permit, and if something is wrong or unclear, a red light might be given to the vessels.

Additionally, every vessel operating on the offshore wind farm needs a work permit to stay inside the windfarm or enter the 500-meter safety zone around the turbine foundations or perform any work on the turbines. In addition, all personnel working inside the wind farm need to complete a safety briefing in advance and upload the certificate. All the personnel need to be approved by the wind farm operator before the vessel can depart from the port (Thomsen, 2014).

Furthermore, it is required that the wind speed, sea state and wave period remain below a given threshold to enter the field. If the sea state and the windspeed are above the limit, the technician needs to stop the operation, secure the components and restart the operation when the weather is stable (Breton & Moe, 2009; Rippel et al., 2021). The weather limit for CTVs should be below 2.0 meters for sailing and 1.5 meters to safely access the turbines, depending on the vessel's type, hull, and freeboard (Dalgic, Lazakis, & Turan, 2015). Scholtz-Reiter et al. (2011) also pointed out that bad weather conditions significantly impact installation time and usually cause delays in logistics and construction of the wind turbines. Another important aspect is that the weather changes quickly and waiting for suitable weather conditions can be costly for the wind farm company.

2.6 Battery

The concept of charging in the offshore field is forecasted to reduce fuel costs by 20 % and emissions by 30 % (Matthew Spaniol, 2019). The technology is still in the research phase, but it is planned to be used in offshore charging at the wind farm, fish farms, and floating solar panels to keep this possible for recharging electric vessels. (Spaniol & Hansen, 2021). The article describes the possibility of wireless charging (induction) in the field since this has high efficiency, and the battery can be replaced or swapped by a fully charged one. A moored vessel makes battery swapping possible. The swapped battery would transfer the energy faster and is an excellent alternative to traditional charging. The article also includes information about installing a charging point at a structure below the surface. Spaniol and Hansen (2021) estimate that offshore charging technology near the wind farm will be available earliest 2028. Another solution to reduce emissions and consumption is to use diesel-electric propulsion, also called hybrid.

2.6.1 Hybrid

Batteries have been used for many decades in the maritime industry as energy storage. They are particularly useful in situations with periodic load (i.e. control of thrusters, motors and cranes) where they can be used for power peak shaving. The use of electrical drive can contribute to environmental protection by cutting emissions, reducing exhaust, vibration and noise compared to diesel engines. Using hybrid driven vessels can also save a lot of money on fuel consumption. Hybrid systems on board the vessel increase in itself the safety and reliability of the vessel due to the extra source of backup power compared to traditional diesel engines (Łebkowski, 2020).

The hybrid vessels use two sources of power for propulsion: energy generated by combustion generators and energy from battery storage onboard (Łebkowski, 2020). The vessel can also have different types of battery technology. Hybrid Electric Ships (HES) can only be charged by ICE during low loading operations, where the ship's engine generates power for the battery. In order to charge the vessel by a shore cable, a Plug-in Hybrid Electric Ship (PHES) is required to top up the battery (Mutarraf et al., 2022). However, a wireless charging can be used to transfer power, where it does not require any physical connection to transfer the energy.

Haynes (2019) described a scenario where a vessel uses a hybrid system to sail back and forth between port and wind farm. He points out that the vessel can easily reach all turbines after schedule if the trip is planned in advance. Furthermore, Haynes writes that the low-speed limit regulation close to shore may affect the sailing in a positive way for electrical propulsion; therefore, the sailing range can be longer. He assumed the standby waiting time for up to eight hours, which was well suited for a fully electric vessel.

Gorbunova & Anissmov (2020) investigated the ability to use wind power to connect the urban infrastructure. In 2019 they found out that the share of energy sources reached 22 % for wind industry to electric-powered vehicles.

2.7 Dynamic Position (DP)

In the last decade, the uptake and development of battery-powered vessels have been slow. Nevertheless, recent technology has brought advancements to these types of energy power vessels. There has also been improvements regarding ideal ship designs that can save the ship's resistance during sailing and operation in the field. Holmefjord et al (2020). calculated the fuel savings for the Service Operation Vessel (SOV), Edda Passat, owned by Norwegian shipping company Østensjø. During DP operation with variable-speed engines, this vessel uses 21 % less fuel compared to using a conventional AC grid with a fixed frequency. This vessel uses newer technology on the engine where consumption varies depending on the engine's load and the speed.

Furthermore, Holmefjord et al. mention the different aspects of the DP working class. Most of the time, SOV operates on a DP1 class mode up to 70% of the total hour outside the field and the DP2 class close to the turbine. In this operation, the vessel has low power consumption (Holmefjord et al., 2020). The operational profile for SOV during the turbine task is illustrated in Figure 8. The DP1- scenarios are shown with the light blue dashed line, and the DP2-scenarios are shown with the dark blue line. The engines in DP2-scenarios operate at non-optimal Revolution Per Minute to expand the available power. As it is clear, the engine speed of most of the station-keeping operations is below 1350 rpm. Both DP classes save a lot of fuel (up to 24 %) with variable speed engines.

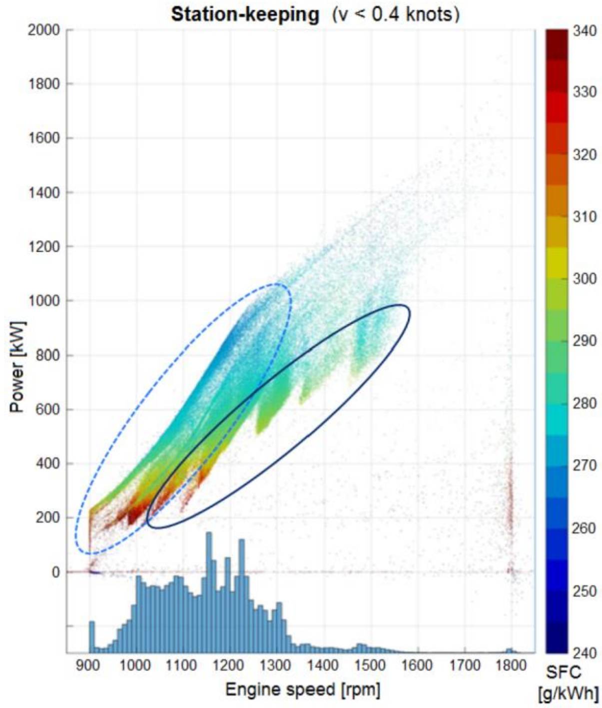


Figure 8 Specific fuel consumption for SOV vessel (Holmefjord et al., 2020)

A review for an OAV was presented by Li, where a hydrodynamic coupling, here an offshore gangway, is used to give technicians easy access to floating wind turbines (Li, 2021). The gangway operation between two floating structures may be risky when a sudden movement occurs, and technicians fall into the water or the gangway breaks. However, on a fixed monopile foundation, the gangway is steady and does not have that much movement compared to floating turbines and OAV. This article has been built in a good way regarding the possibility to see cases where a power connection to a floating wind turbine may be feasible when staying on DP.

According to Peralta P. et al. (2019), using hybrid technology on larger vessels operating on DP decreases the CO_2 emission. They calculated the CO_2 emission saved while using hybrid sources during different DP operations of supply vessels when manoeuvring inside oil field. Moreover, Bui et al. (2021) presented different energy consumption of marine vessels on DP mode. In their article, they talked about Engine Management System (EMS) development to check whether it is possible for individual power sources to run closer to their optimal output power. They listed seven different modes for DP: Harbour, harbour loading, transit, DP loading, DP standby, emergency and black start. The figures below (Figure 9, and Figure 10) show the load profile and the power which is necessary for hybrid electric marine vessels during a typical operation day, as well as comments on operational mode for DP vessel.

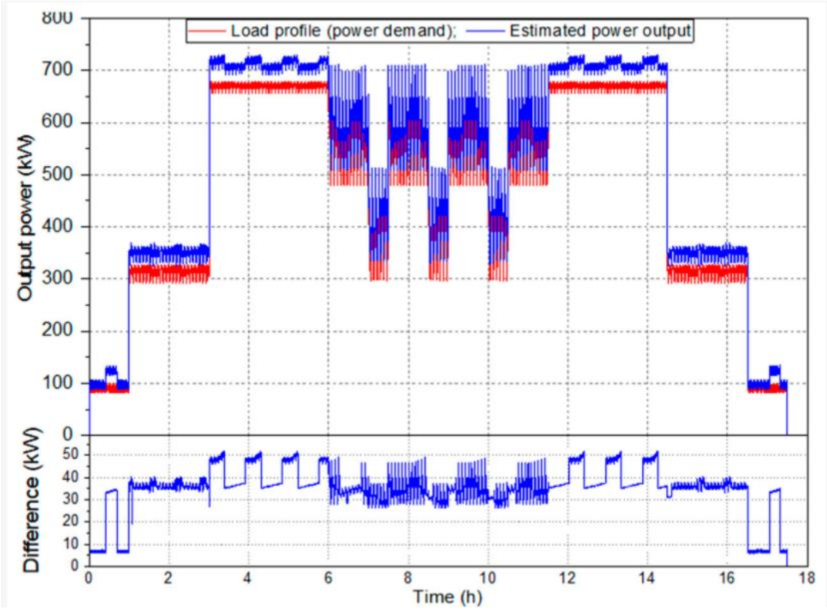


Figure 9 Load profile and estimated necessary power of the Hybrid Electric Marine Vessel (Bui et al., 2021)

The vessels usually use low energy at the port and high energy while unloading and loading. The vessel can potentially turn into different DP modes, under special circumstances, to remain still while performing different tasks such as transporting goods. Therefore, it is necessary that the EMS control strategy be flexible enough to switch the system during different operation modes, take care of the propulsion system performance, and efficiently handle the power flows between them.

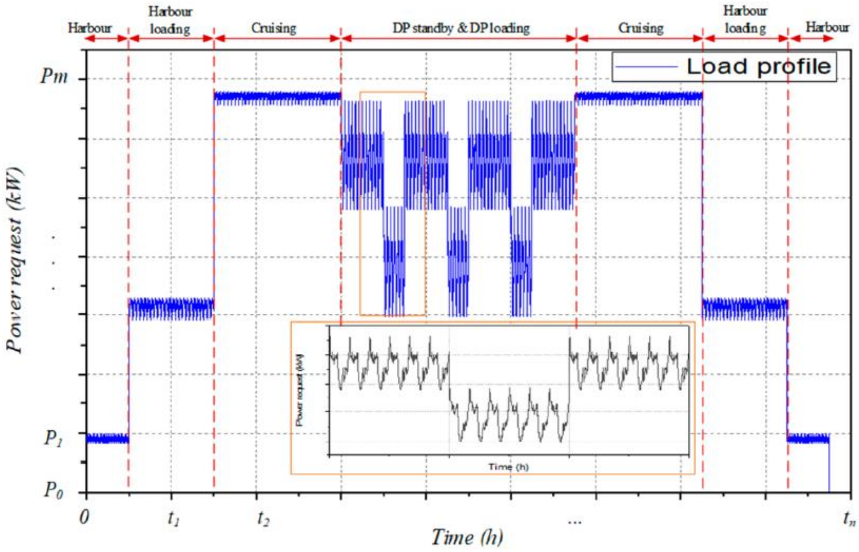


Figure 10 A representative load profile with comments on operation mode for a DP vessel (Bui et al., 2021).

3 Research method

3.1 General introduction

The methodology gives a base for conducting research and evaluating knowledge claims. The method chapter highlights applied methodology that is important for thesis writing.
Different approaches are usually reviewed in order to build a research method.
The method's purpose is to help other researchers communicate and share their knowledge as an experience. The method is a suitable means of communication for researchers who have much experience in one field and other researchers who are good in other areas (Harboe, 2013).

Research method is the process that is used to collect different data to conduct a study. The research method contains specific measures that need to be included in the study. Generally, the research method is an "umbrella term" for several issues that need to be outlined (Bell et al., 2019).

The scope of this thesis has been limited to a literature review about economic, environmental and technological aspects of using electrical or hybrid vessels in wind farms. The power consumption of the vessel is going to be calculated during transit and manoeuvring between wind turbine and to/from port. The data is collected from the actual consumption of service vessels in the wind farm.

3.2 Research design

"A research design is concerned with turning a research question, a hypothesis or even a lunch or idea into a manageable project" (Hammond & Wellington, 2013, p. 131).

A research design is the basis of the framework that a researcher uses to find the research problem. The research question is built up from the formulation of these questions with different types of data collection, analysing and interpreting the data and finally providing a logical discussion and conclusion. This research design was developed based on the purpose, research question and assumptions in this thesis.

In order to find rich data and information to answer the research questions, qualitative research was selected. Qualitative researches provide different insights and knowledge of a specific topic to the writer and researchers without a specific need for numerical data

(Mouazan, 2016). There are different approaches used in a qualitative method, such as case study, questionnaire, or interview. This thesis is written based on both a literature review and a case study.

3.3 Data collection method

Secondary data is defined as data collected by others and can be either qualitative or quantitative data. Firstly, the qualitative secondary data sources can be categorized as a text, whereas quantitative secondary data may be statistics, annual reports, accountings or others (Sheu et al., 2006).

For this thesis, quantitative secondary data was collected from an open database called Marine Traffic. This database contains historical Automatic Identification System (AIS) information about how the vessels move and includes data about ship and service vessels' speed, destination and duration. In particular, the raw vessel data was extracted from two different wind parks outside of Scotland in the UK.

In general, data that is collected are built up from literature such as academic sources and offshore wind press announcements where information about milestones during construction and time frame have been released. Online published specifications from the shipping company about the vessel details were also used. Technical information about the wind park was found on the owners' homepage and via sending emails to the main offices.

3.3.1 Method for finding and selecting literature

To find the relevant sources and articles about wind turbine power generation and the opportunity of having hybrid vessel in OWF, a thorough research was done using different search engines.

The literature review focused on combinations of five keywords such as *electric service vessel, offshore wind farm, maintenance on wind turbine, technology offshore wind farm, power consumption hybrid vessel, recharging on site,* and *wind turbine installation.* Moreover, the search included additional synonyms of these terms and their Norwegian translations. Various search engines were used, namely: Google Scholar, Scopus, Science Direct, Research Gate, and the search engine Oria at the University of South-Eastern Norway.

These search engines and snowball methods resulted in 1342 articles and text in total. The articles with the most relevant topics related to Hybrid vessels, Recharging batteries, Turbine charging, Offshore wind farm or Battery energy storage system were retrieved. Following the research procedure to find relevant information, the Prisma procedure checklist model was used. Finally, a total number of 29 articles were used to obtain a better understanding of the thesis topic. In addition, some news pages related to the construction process of turbines and the milestones were skimmed.

The most important information about turbines is the point at which WTG starts to generate power to the grid. For service vessel activity, Marine Traffic is used to find out how long these vessels are waiting in the field. This data was also used to find the speed range that vessels are operating at during transit from port to offshore wind park and between turbines. The use of engine power specifications for service vessels is going to be found from shipping company homepages. Later, these specifications will be compared with the vessel speed to find out the total consumption for 30 days trip to/from harbour and OWF.

3.3.2 Case study

A case study is an empirical research method and usually covers special characteristics. They cover the entire aspects of a social phenomenon, use qualitative methods, have specific field of study, and focus on all the features within the field of study (Harboe, 2013). A case is a lot of what we read through news, articles and other forms of texts that make it easy to understand. It describes a topic clearly and straightforwardly to give the reader clarity on the main points (Mills et al., 2010).

The common purpose for all the cases is to represent the reality of a situation with crosscurrents and rough edges. So, nothing will be unclear to the reader. They are in-depth investigations of one specific organization or one single person, group or community (McLeod, 2007). The function of a case study is to obtain deeper insights from the defined fields of study (Hartley, 2004). *"In the case study, the analysis is the close examination of the pieces of information in the case that you think may illuminate the main issue"* (Ellet, 2018, p. 25).

Significantly, a case study is generally used where there is a need to understand the complexity of a process or facility. The use of case study gives the researcher an important dimension where the number of cases needs to be investigated to get a better perspective of collected data (Gomm et al., 2009). In this thesis, a case study was chosen to closely study the use of hybrid and battery vessels in offshore wind farm. This is because the technology is relatively new and has not been implemented at wind farms yet.

This research is built upon multiple assumptions, such as: charging is possible offshore, and the range of the vessel is large enough to cover sailing from port to the field. The definition of the field of study is a prerequisite for case studies. There are three types of case studies; unique case study, exemplary case study, and multiple case design (Harboe, 2013).

In unique case studies, the researcher conducts a thorough study of a single group and their behaviour, while in the multiple case design, the researcher might study two or more cases simultaneously. The exemplary case studies are typically performed to give a general view of the case (Hartley, 2004). In this thesis, a multiple case design is used to highlight different aspects of the process and eliminate contrast across the context.

According to Ellet (2018), argument and discussion are essential for case writing. He also pointed out that the case methods require a lot of reading, discussion, and case writing. Good knowledge is also needed to give meaning to the research questions that are going to be answered. In this thesis, arguments from different writers and experts will be compared and further discussed in the discussion section.

To find the total Port Calls for six different service vessels during 30 days in the construction phase and O&M phase, historical data from Table 1 is extracted for each vessel (four from the construction phase and two from the operation and maintenance phase). To give a better understanding, the transit activity between the wind farm and port, specific speed and average time spent in port for bunkering, provisions or crew change is calculated. The calculation contains the emission from vessels, total energy consumption, and the energy price comparison between diesel and electricity.

The harbour the service vessel uses during O&M operation in Moray East Offshore wind farm is Fraserburgh in the UK. For Seagreen offshore wind farm, the Montrose harbour is an operational base for three CTVs by night and one OAV for fuel bunkering and provision of supplies. The data received from colleagues is based on two identical CTVs that are mapped by Marine Traffic. During the data connection, it was not possible to find the fuel consumption of the CTV in idle with reduced engine loads. Only the consumption at service speed is known.

Construction Phase	Name of the vessel	Class of the vessel
	Acta Centaurus	OAV
	HST Harri	CTV
	Manor Enterprise	Hybrid CTV smaller size
	Seacat Volunteer	CTV
Operation & Maintenance	**Name of the vessel**	**Class of the vessel**
	Esvagt Alba	OAV
	Seacat Weatherly	CTV

*Table 1 Vessels mapped for 30 days by Marine Traffic (*MarineTraffic, *n.d.).*

3.4 Data analysis method

The official statistical data used in this study is categorized as interval data. Such data is often used when analysing the time a vessel spends on the sea (*MarineTraffic*, n.d.). The vessel activity data from Marine Traffic is used to see how much time the CTV and OAV spend in these four categories during the construction and O&M phase of the Offshore Wind Farm:

- **Time underway:** *The vessel sail between port and wind farm, or inside the field with speeds above 0.3 knots.*
- **Time waiting:** *When the vessel is in an anchoring position, waiting for a crew change, order or better weather conditions.*
- **Time idle:** *When the vessel is waiting inside the field with speeds below 0.3 knots.*
- **Time in port:** *The vessel is moored in a harbour and stationary.*

It was necessary with a paid premium account to access the Marine Traffic Pro services, such as historical data over the last 30 days. Hence, the time a vessel is underway, on standby or idle will be helpful to further calculate the fuel consumption and CO_2 calculation.

Microsoft Excel is a leading software for analytics and spreadsheets. The interval data from Marine Traffic was manually typed into an Excel spreadsheet, and a 30-days data from the 15th of February to the 17th of March in 2022 was included. The raw data was already classified into four categories (mentioned above), and from this data, the fuel consumption was calculated based on an average fuel consumption factor.

The raw data must be processed and analysed before it can be used, therefore a strictly sorting must be made in order to structure the data. In order to make the data used in this thesis more understandable, the first step was to organize this data by dividing vessels into different groups based on their types and the OWF they belong to. Another important factor for this analysis was to give the reader a meaning for how the key values in the data fit into the theory (Denscombe, 2009).

4 Findings

The case presented in this master thesis will take a closer look at the fuel consumption and emission of service vessels working in the wind farm during the construction and maintenance phase of wind turbines. The purpose of this case study is to elaborate on the different possibilities and challenges related to the use of battery or hybrid as an energy mode for the vessels. This thesis has mainly focused on the OWF vessels that are responsible for the operation in the construction and maintenance phase of building turbines. In the offshore wind farm, OAV and CTV are mainly assisting the transportation of technicians and tools.

Offshore Access Vessel (OAV) are larger than CTV and have better operational capability than CTV (Dalgic, Lazakis, Dinwoodie, et al., 2015). OAVs are often used as a storage vessel to store tools and spare parts for technicians living on board. OAVs have also a dynamic gangway that can stabilise the vessels movement, which is safer for the technicians when they are walking directly from the vessel to the wind turbine. Otherwise, they would need to climb down from the OAV to the CTV via the ladder on the boat landing.

4.1 Offshore Service Vessel operation characteristic

Before the construction phase is completed on the wind farm, an OAV will stay in the field and then utilized during the O&M phase. The vessel will provide accommodation for service technicians and uses the gangway system for transferring technicians to and from the different turbine platforms. The vessel is mostly on DP during transferring between turbine platforms.

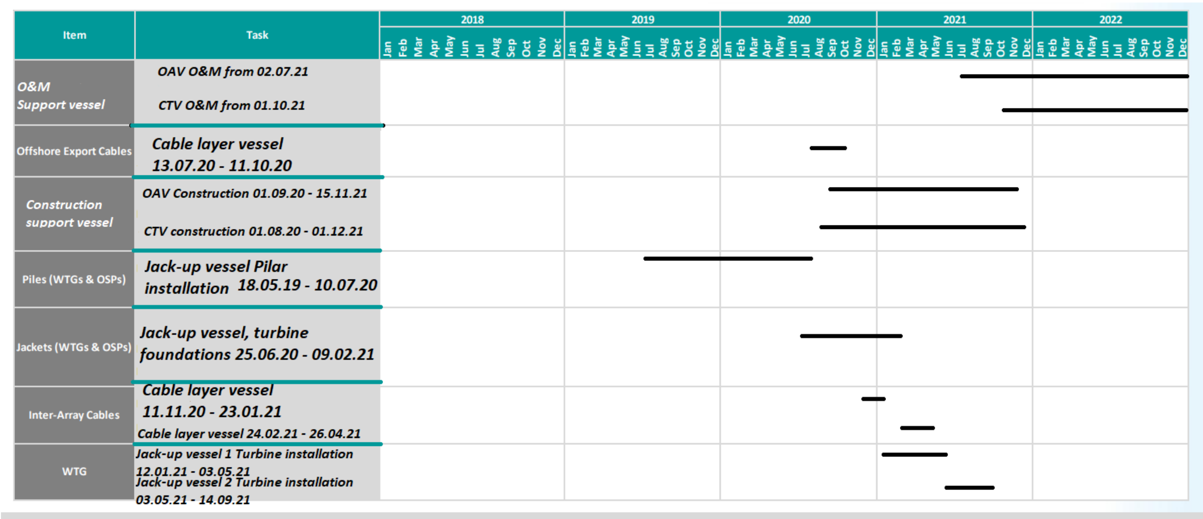


Figure 11 Timeline for service vessel in offshore wind farm during construction (own production)

A CTV will also be assisting the OAV with transportation between the port and wind farm during the construction and O&M phase. These vessels stay at the port at nighttime and operate during the daytime.

The figure above (Figure 11) illustrates a timeline during construction of the wind park where different types of vessels are in use with different expected milestones. For example, the Inter-array cable vessel worked in the field between August 2020 and July 2021. The Jack-up vessels, Jackets (WTG & OSP), are in the field from jackets installation phase until WTG installation (from July 2020 to September 2021). OAV and CTV are in the field when the first jackets are in place (from August 2020 to end of November 2021).

Ørsted and Maersk have developed a charging buoy for the vessel as OAV and CTV. This buoy is connected to the wind turbine foundations and the vessels by using a power cable winched on board, as seen in Figure 12 (Maersk Supply, 2020). The buoy acts as a mooring spot with a clean electric power supply, thoroughly removing emissions and reducing idle vessels' costs. This buoy supports the transition to green energy (Stilstrom, 2020).

Figure 12 Charging buoy (Stilstrom, 2020)

The MJR Power and Automation company in the UK has been awarded government funding for the charging system of their offshore electrical vessel. This system is installed on a turbine platform where charging cables can be lowered down to a CTV with a winch. When the vessel is connected, it can leave the foundation and keep a distance of 10 meters away (MJR, 2021). Figure 13 shows the way a CTV can be recharged in the field.

John Haynes has studied a Crew Transfer Vessel’s function regarding sailing and waiting. He has given an example of a CTV during 12 hours of use during a day, where two hour goes for low speed, two hours for full speed, and eight hours for standby or manoeuvre free time. For the remaining 12 hours of the day, it will stay alongside the port (Haynes, 2019).

Figure 13 Charging concept from MJR Power & Automation (Events, 2021)

Łebkowski studied a CTV for 16 days where a substation was visited every trip and the speed profile for the same vessel. Sixteen days of using diesel will have an energy consumption of 300 MWh. That means the CO_2 Emission by diesel was 80 tons. The diesel-generated vessel mentioned here was using an average of 400 litres per hour (Łebkowski, 2020). However, the article showed that the diesel engines consume 3,54 times more fuel when there is 12,096 kg of extra mass. Eight-package battery of 1106 kWh was installed onboard to provide the opportunity of driving on the hybrid mode. As it is seen, the extra mass on board increases the vessel’s draft and fuel consumption.

Based on Corvus Energy, a battery package for managing a CTV, as Łebkowski described, will be a four-pack of six strings (14 modules/string) which can store 14448 kWh energy. This package has a mass of 122.2 tonnes, is 10.6 m long, 1.4 m wide, and 2.9 m high (Corvus Blue Whale, n.d.).

Some scientific publications specialized in wind farm, mention the possibility of recharging vessels by wind turbines (Forster, 2020). This is a great news for people who are interested in this technology. Ørsted has also published information on how a charging connection with a line diagram is arranged up from turbine to vessel. He presented there that the voltage for charging can easily reach up to 132 kV when charging from the offshore buoy, connected via a sub-station at the field (Sæmundsen & Henriksen, 2020).

4.2 Operation and maintenance

There are four maintenance intervals annually on 100 wind turbine generators on the Moray East Windfarm. The first maintenance takes 60 hours. The second one takes 100 hours and will perform extra maintenance on 52 wind turbine generators. The third maintenance, which is a corrective task, takes three hours. The technicians need to inspect each turbine five times per year. Finally, for the last corrective task, maintenance time is set to 7.5 hours, and this is three times per year for each turbine. It means that all turbines need to be inspected eight times per year (Gutierrez-Alcoba et al., 2019).

Producing electricity from a wind turbine naturally requires wind to rotate the turbine blades. According to energy companies SSG, the summer of 2021 was one of the minor windy seasons in large parts of the UK and Ireland in 70 years. The average wind speed was 7.8 m/s in the second quarter of 2021 (Stevens, 2021).

The power generated from the turbine depends on the wind speed. It starts to produce electricity when the wind speed exceeds the cut-in speed that is typically 3-4 m/s, where the blades begin to rotate. If the wind speed exceeds the cut-out speed (24 m/s), the wind generator will use the brake in the nacelle to stop the blades and avoid any breakdown. The generator is designed for a wind speed between 12-17 m/s to generate as much power as possible (Acakpovi et al., 2020).

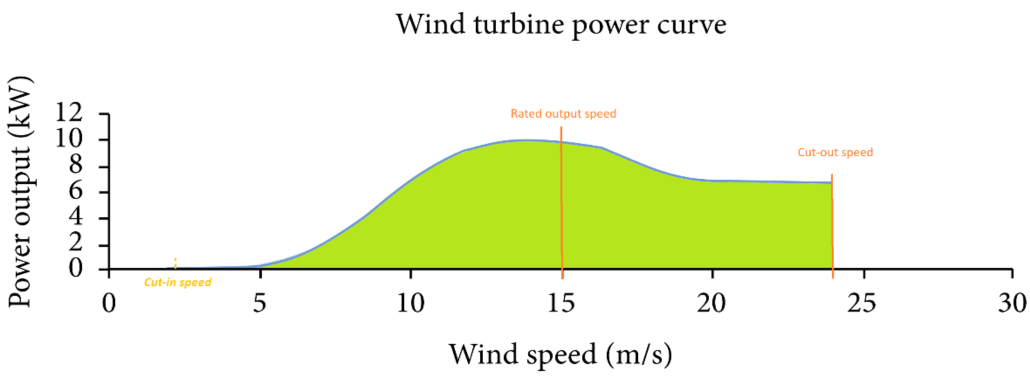


Figure 14 Illustrative power curve for a 7 MW wind Turbine (Acakpovi et al., 2020)

If a critical failure on a wind turbine needs to be fixed and requires two-shift work, the OAV can return to the wind farm and be on standby with the technicians until the damage is fixed. The OAV can operate at a higher sea state and wind speed than the CTV, but they need to approach the turbine from a safe drift-off direction. This is a safety feature in case any technical failure happens on the vessel so that the OAV will drift away from the wind turbine.

4.2.1 Structure design for charging from offshore wind turbine

It is a different structure design given at wind turbine to make any approach easy and safe for the marine crew to recharge vessel at the same time as a technician transfer on the turbine. The design of the turbine foundation to meet CTV criteria for charging is listed by Nilsen**do** and should be at least: economics, feasibility, power transfer capacity, crew safety and minimal connection time (Nilsen, 2021).

4.2.2 Battery Energy Storage System

An offshore Battery Energy Storage System (BESS) can allow the vessels to recharge even when the wind speed is below the wind turbine cut-in speed. A BESS solution can be a flexible power source for the electrical grid and even power the vessel after the wind farm construction is completed (Acosta et al., 2021). The literature has documented that the BESS can be placed at the seabed level to avoid the use of space on the substation or the wind turbine foundation.

Factors that can affect the charging time in the harbour may be the availability of port space and pilots, and the tide restrictions to enter the port. With high draft vessels like an OAV, the tide differences in the harbour will affect charging time and, thereby, the port stay (Zhang et al., 2019). The average draft for OAV varies from five to eight meters (Acta Marine, 2019). High tide is an advantage for the high draft vessel arriving at the harbour. Otherwise, the high draft vessels need to wait until the next high tide at anchorage. During the mapping of offshore service vessels at Marine Traffic, this has happened several times for the vessel Acta Centaurus.

4.3 Fuel and emissions

The International Maritime Organization (IMO) ensures that the countries' rules and regulations are followed and that these rules are being implemented. Some of the rules set an emission limit for Sulphur Oxide (SO_x) and Nitrous Oxide (NO_x). Marine Gas Oil with a SO_x

content below 0,1 % is today mandatory in Emission Control Areas (ECA). The limit for NO_x was 75 per cent in 2021.

4.3.1 The emission factor

The study by Lindstad et al (2017) showed the CO_2 emission factor of 3.206 on MGO on fuel consumption and 179.5 gram/kWh of CO_2 emissions for diesel engines. Also, Ji & El-Halwagi (2020) used 3.206 (litre CO_2 /litre Fuel) on MGO. Since the literature shows the CO_2 emission factor for MGO to be 3.206, these numbers will be used for the calculations.

4.3.2 CO_2 emission formula calculation

The formula for calculating the mass of CO_2 emissions can be found in the Appendix chapter. This formula shows how much the vessel and shipping company can save the environment by switching from oil/gas to green electricity. This set of calculations is made with the help of a professor at the university. The molecule mass has been taken out from the periodic table.

4.4 Fuel consumption.

The diesel consumption for the crew transfer vessel is set to 350 litres per hour by specifications. This does not include the time that the vessel is idle or on standby. An actual engine data was received from colleagues working on CTV shown at Figure 15. The consumption of each engine is about nine litres per hour. This means that two engines consume 18 litres per hour during waiting time. Consumption of CTV during the transit and delivering the technicians and tools to the turbine is 238 litres per hour for each engine.

4.4.1 Fuel Price

The fuel used on the vessels in this master thesis is Marine Gas Oil (MGO). The fuel price is taken from the Rotterdam Bunkers and IMO MEPC 62 report, which includes different prices of fuels around the world. The MDO Prices were taken out from 9th May 2022 for this thesis. (*Rotterdam Bunker Prices*, n.d.).

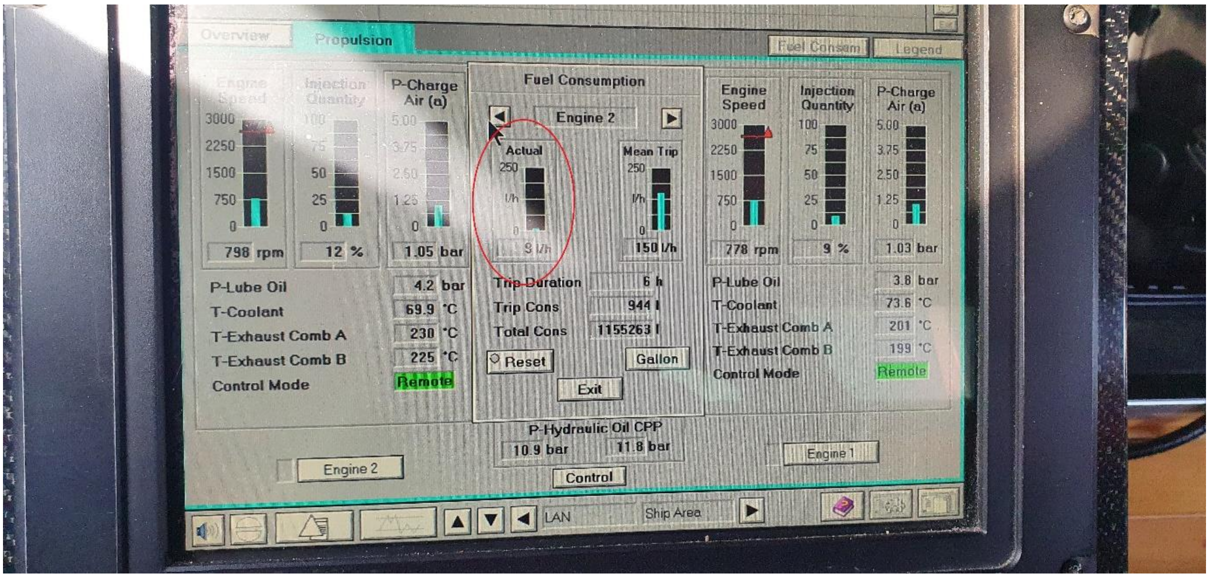


Figure 15 Engine data from the CTV during standby on field consumption 9 l/h

4.4.2 The connection to shore

After the wind turbine construction is over, it takes several days to produce power. The turbine needs to be checked and calibrated. Different sensors in the turbine need to be connected to a grid before generating the power. In Borssele offshore wind farm, outside the Netherlands, a turbine installation was completed on the 13th of April (Durakovic, 2020). A few weeks later, the same turbine began to produce electricity for the first time on the 28th of April (Skopljak, 2020). This time was short due to the ongoing pandemic Covid-19 when there were restrictions, and the technicians had to keep a social distance during installations.

4.5 DP operation & Engine Load

4.5.1 DP Operation

Many of the vessels hired to perform work on site will wait for weather, technicians or green light to approach the turbine. In the meantime, the vessel stays on DP mode to keep the distance in the field.

It is important for offshore vessels like OAV, JUV and Cable layers to remember the various safety regulations. One example is the Dynamic Positioning (DP) which requires manoeuvring to stay inside the wind farm. This mode keeps the vessel in the same position over the ground to avoid drifting during wind, weather and sea.

There are two DP classes for OAV, JUV and Cable layer. The first one is DP1 which is an economic DP class, and its energy consumption is low. There is no requirement for DP1 mode redundancy, and thus loss of position may occur in case of a single fault. DP2 requires redundancy in all of the components responsible for keeping the vessel operational (see Figure 16) (thrusters, generators, and switchboards) (Holmefjord et al., 2020).

<table>
<tr><th colspan="3" rowspan="2">Subsystem or component</th><th colspan="5">Minimum requirements for Class Notation</th></tr>
<tr><th>DP 0</th><th>DP 1</th><th>DP 2</th><th colspan="2">DP 3</th></tr>
<tr><td rowspan="6">Power system</td><td colspan="2">Generators and prime mover</td><td colspan="2">–</td><td>Redundant</td><td colspan="2">Redundant, separate compartments</td></tr>
<tr><td colspan="2">Main switchboards</td><td colspan="2">1</td><td>2</td><td colspan="2">2 in separate compartments</td></tr>
<tr><td colspan="2">Bus-tie breaker between busbar sections</td><td colspan="2">–</td><td>2 NO [1]</td><td colspan="2">2 NO</td></tr>
<tr><td colspan="2">Distribution system</td><td colspan="2">–</td><td>Redundant</td><td colspan="2">Redundant, through separate compartments</td></tr>
<tr><td colspan="2">Power management (see B.2.5)</td><td colspan="2">–</td><td>Redundant</td><td colspan="2">Redundant, separate compartments</td></tr>
<tr><td colspan="2">UPS for DP control system</td><td>–</td><td>1</td><td>2</td><td colspan="2">2+1 in separate compartments</td></tr>
<tr><td>Thruster system</td><td colspan="2">Arrangement of thruster</td><td colspan="2">–</td><td>Redundant</td><td colspan="2">Redundant, separate compartments</td></tr>
<tr><td colspan="3">DP-relevant Auxiliary Systems</td><td colspan="2"></td><td>Redundant [2]</td><td colspan="2">Redundant, separate compartments, provided WCF is not exceeded</td></tr>
<tr><td rowspan="2">DP-Control system</td><td colspan="2">No. of computer systems</td><td colspan="2">1</td><td>2</td><td colspan="2">2+1 in separate compartments</td></tr>
<tr><td colspan="2">Independent joystick with auto heading</td><td>–</td><td>1</td><td>1</td><td colspan="2">1</td></tr>
<tr><td rowspan="4">Sensors</td><td colspan="2">Position reference systems</td><td>1</td><td>2</td><td>3</td><td colspan="2">3 whereof 1 connected to back-up control system</td></tr>
<tr><td rowspan="3">Vessel's sensors</td><td>Wind</td><td colspan="2">1</td><td>2</td><td>2</td><td rowspan="3">One of each connected to back-up control system</td></tr>
<tr><td>VRS</td><td colspan="2">1</td><td>3</td><td>3</td></tr>
<tr><td>Gyro</td><td colspan="2">1</td><td>3 [4]</td><td>3</td></tr>
</table>

Figure 16 Rules for vessel to maintain DP Class (Germanicher Lloyd, 2013, p. 14)

To fulfil the DP2 classes for power redundancy, either a second generator set needs to be running, or a battery pack should be used for the second energy source.

Before the OAV enters the wind farm it is required to complete the DP checklist in advance to check if all the systems are operating well (Holmefjord et al., 2020). A green light to enter the wind farm can be given by Marine Coordination Centre (MCC) when a valid permit and DP checklist is completed. MCC is responsible for the monitoring and co-ordinate all projects related marine vessel inside OWF (Spengler, n.d.).

4.6 Engine Load and consumption

4.6.1 Crew Transfer Vessel calculation

The specific data for a CTV fuel consumption is calculated below.

PRINCIPAL DIMENSIONS

Length o.a.	25,75 m
Breadth o.a.	10,40 m
Draft	2,34 m
GRT	81,58
Max. deck load	1,5 ton/m^2 Max. 15 ton total
Free deck space	90 m2
Max. Deadweight	20 ton
Maximum speed	25 knots - 450 L/h
Service speed	21 knots - 350 L/h
Range	1200 Nm at 21 knots

*Figure 17 Specifications of CTV with fuel consumption (*Offshore Wielingen, *n.d.)*

Example for calculation: Diesel has an energy density of 45 Mj/Kg- which means 12.5 kWh/kg. An average size CTV operating on the field uses approximately 350 litre per hour at 21 knots service speed– that means 350l/h x 0.85 kg/l = 297,5 kg/h (3718,8 kWh/h).

When the speed on the CTV increases to the maximum speed of 25 knots, the consumption will increase to 450 l/h regarding the specification for a CTV in OWF. The 25 knots speed gives the mass of diesel consumed per hour: 450 l/h x 0.85 kg/l =382,5 kg/h. That means the energy consumption will be: 382,5 kg/h x 12,5 kWh/kg = 4781,3 kWh. This consumption increases above 1000 kWh to increase the speed by four knots. If the vessel uses 3.42 MWh per hour, a 350-litre diesel pr hour is saved.

Based on the collected data from Marine Traffic, Figure 18, the hybrid vessels are used more often than the vessels with only Internal Combustion Engines.

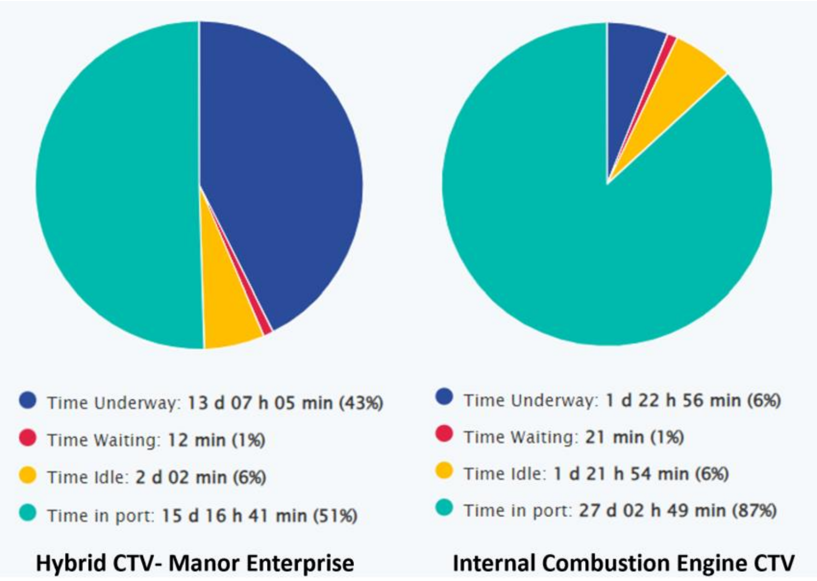


Figure 18 Hybrid CTV activity VS Internal combustion engine CTV

There are two modes of engine loads for the CTV. The first one is the operational mode, where the vessel is either in transit or pushing onto the boat landing. The second one is when the vessel is on standby or drifting. As shown in Figure 19, the engine load for a CTV in transit at 25 knots or pushing onto the boat landing is 80 % of the maximum load. The engine load is lower in the standby mode.

Based on the energy consumption calculated above, the CTVs need the largest package of battery (based on battery specification of Blue Whale) in order to have enough range to reach offshore wind. The battery pack should be Corvus Blue Whale 4 pack of 6 strings (14 modules/string). This type of battery has a 14,448 kWh energy storage capacity and a mass of 122,200 kg (*Corvus Blue Whale*, n.d.). Most of the CTVs have catamaran hulls and limited space for installing batteries. The packages in each ponton will mostly block the engine room for inspection. On the other hand, the Gross Tonnage of Volunteer is 100.2 tons, so the installation will result in doubling the weight and, therefore, using more energy than diesel engines used today. The energy consumption is calculated to increase by 25 %.

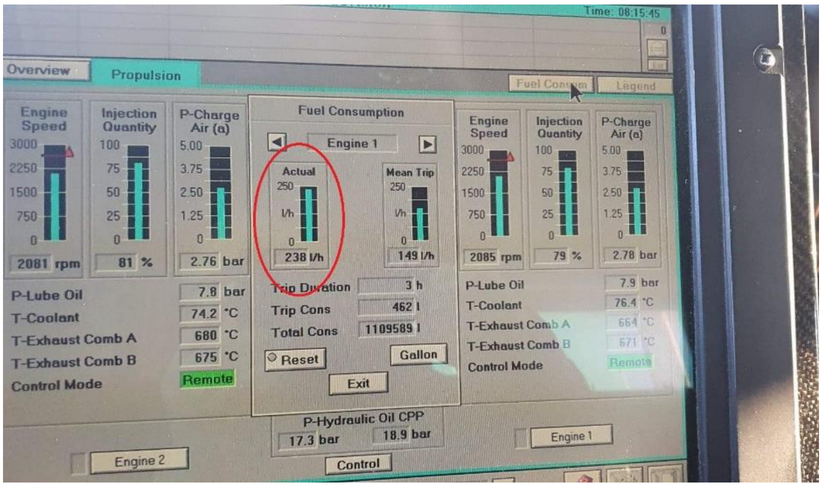


Figure 19 Engine load for CTV during transit and pushing to TP

The consumption at 80 % load is 238-litre diesel per hour. Since a CTV has two sets of engines, the consumption will be approximately 476 litres per hour.

The picture from the motor data was taken during the vessel travel between the WTGs, three hours after departure from the ports. The average fuel consumption of the engine is: *149 l/h x 2 = 298 l/h.*

After one day of travel and standby, the vessel needs bunkering, and they usually refill the tank with 4200 to 4800 liters of fuel in one day (between 10 – 13 hours).

4.6.2 Offshore Access Vessel calculations

The vessel, Acta Centaurus, operating at DP, uses approximately 8 m^3 FUEL per day, as shown in Figure 20, which means the mass is: 8000 l/d x 0.85 kg/l = 6800 kg/d.

The energy is also calculated as: 6800 kg/d x 12.5 kWh/kg = 85000 kWh/d

$$Power\ used\ per\ hour = \frac{85000\ kW/d}{24\ h/d} = 3541.6\ kWh$$

The calculation above shows that the power consumption of a OAV is higher than CTV.

Autonomy:	approx. 30 days
MAIN DIMENSIONS	
Length O.A:	93.4 m
Breadth moulded:	18.0 m
Depth moulded:	7.6 m
Draught design:	5.6 m
GRT:	6050 mT
Deadweight @ design draught:	2600 mT
Weather deck (Deck A) area:	500 m²
Main Deck area:	500 m²
Weather deck (Deck A) max load:	250 mT
Main Deck max load:	650 mT

Reference systems:	3x Wind sensor 3x Motion reference unit 3x Position reference system (2x DGPS + 2x CyScan)
Station keeping ERN:	[99, 99, 97, 95]
SPEED	
Max. speed (@ 5.5 m draught):	12 knots
Max. DP speed (@ 5.5 m draught):	10 knots
CAPACITIES	
Fuel oil:	800 m³
CTV fuel:	180 m³
Consumption in DP mode:	8 m³/day approximate
Lub oil/hyd. Oil etc.:	40 m³
Fresh water:	840 m³
Water ballast:	1970 m³
Containers:	24 TEU divided over 2 deck levels

Figure 20 Specifications of OAV (Acta Marine, 2019)

4.6.3 Jack-Up Vessel calculations

During DP positioning and Jacking up, three engines are in use for a JUV. The jacking operation takes around 2-3 hours in the field. During crane operation, it is enough to use one main engine to generate enough power for the crane. During jacking operation, the engine load is between 50 – 60 %.

The fuel consumption of an average size jack-up vessel during crane operation is seven tons per day (see Figure 21). This means:

$$Consumption\ in\ litre = \frac{7000\ kg/d}{0.85\ kg/l} = 8235{,}3\ l/day$$

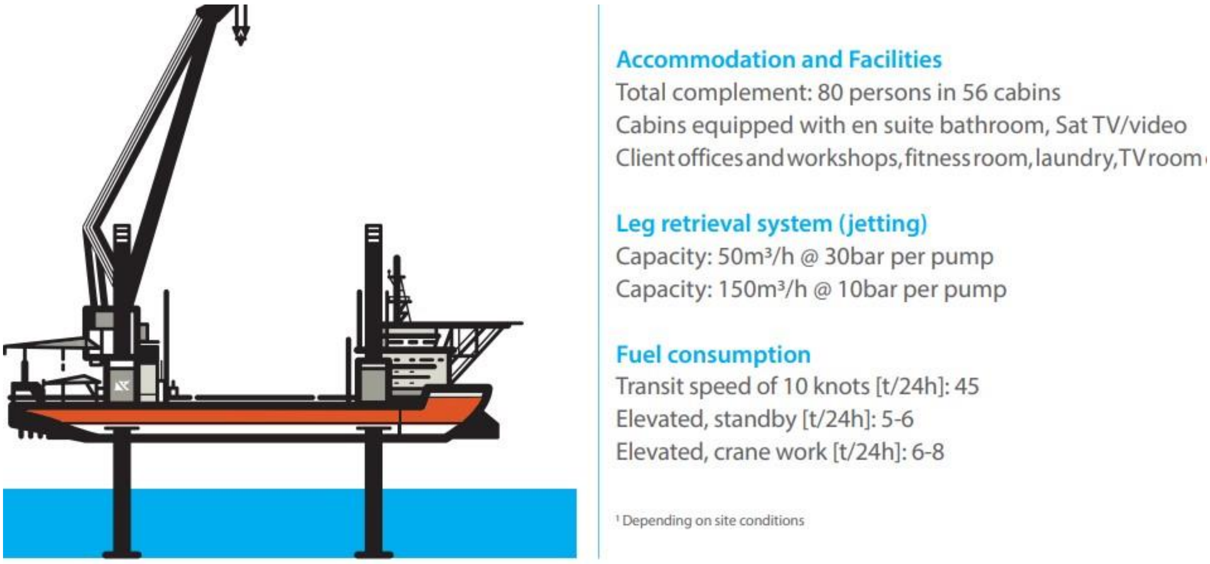
The energy used for the jack-up vessel during crane operations per day:

$$Energy\ used\ per\ day = 7000\ kg/d * 12{,}5\ kWh/kg = 87500\ kW/day$$

The energy used per hour for the jack-up vessel during crane operations:

$$Energy\ used\ per\ hour = \frac{87500\ kW/day}{24\ h/day} = 3645.8\ kWh$$

The responsibility for a Jack-up vessel during the construction phase is to carry several towers, nacelles and blades from the port and install them in offshore fields. Figure 22 and Figure 23 show the fuel consumption for the different jack-up vessel activities during the



turbine installation.

Figure 21 Specifications of a jack-up vessel (Windcarrier, n.d.)

4.6.4 Cable Layer Installation vessel calculations

Cable Layer vessels have a consumption of 10 m^3 per day during operations. That includes the use of three engines to maintain the position and, at the same time, provide power for the cable carousel on deck.

Fuel consumption of an average size cable layer vessel during DP operation is 10 m^3/day.
$10{,}000\ liter/day\ x\ 0.85\ kg/l\ =\ 8{,}500\ kg/day$
The energy used for the cable laying operation per day is:

$$Energy\ used\ per\ day = 8{,}500\ kg/d * 12.5\ kWh/kg = 106{,}250\ kW/day$$

The energy used for the cable laying operation per hour is:

$$Energy\ used\ per\ hour = \frac{106{,}250\ kW/day}{24\ h/day} = 4427.08\ kWh$$

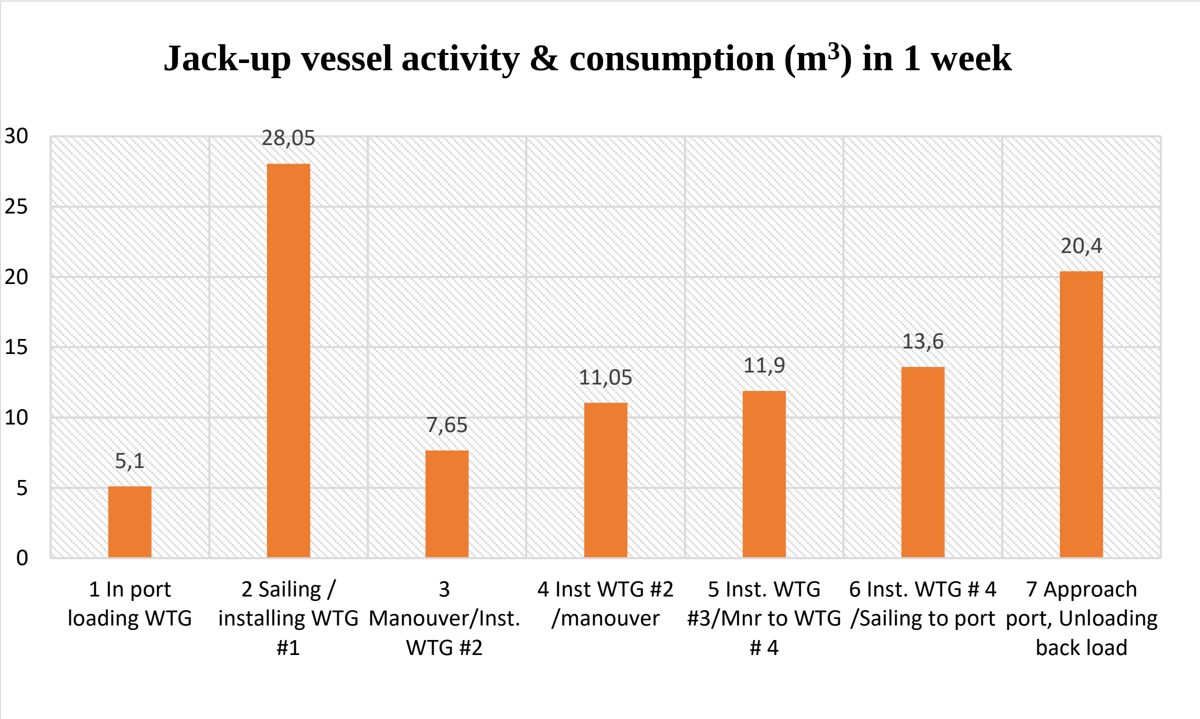


Figure 22 Example for Jack-Up vessel activity in days showing fuel consumption during the construction phase.

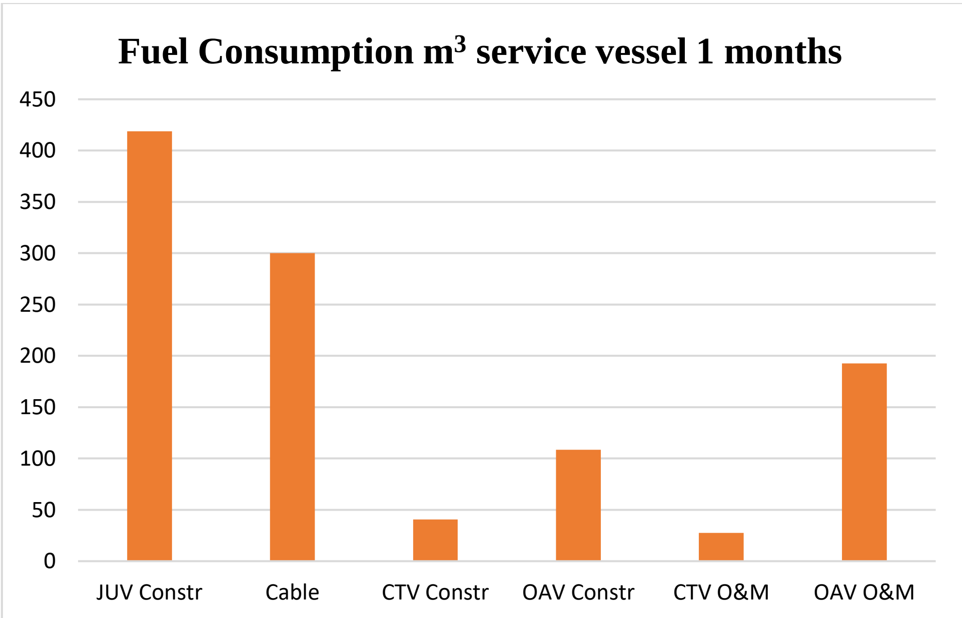


Figure 23 Fuel consumption 30 days in m^3

4.7 Different cases

4.7.1 Consumption and emission calculation of vessels mapped on Marine Traffic

CASE 1 fuel consumption based on today's activity using actual engines:

In order to calculate the emission of selected vessels in Marine Traffic, historical data during 30 days was used and is summarized in Table 2. The OAV uses eight m^3 fuel per day in DP mode. In this calculation, the vessel consumes eight m^3 of fuel at transit. The CTV consumes 450 l/hour for three vessels under transit. Based on the data received from the captain, the CTV uses 18 l/hour of fuels to be pushed onto the boat landing. The fourth crew transfer vessel is a hybrid-powered type and is smaller than the other three types of the CTVs described earlier. The hybrid CTV has a consumption of 215.42 l/hour. Moreover, consumption on idle mode is zero. All calculation in the tables below is performed in excel.

$CO_2\ emissions\ (tonn)\ =\ amount\ of\ fuel\ (m^3)\ \cdot\ emissions\ factor\ (ton\ CO_2/m^3)$			
Type	**# vessels**	**Consumption in m^3**	**Emission CO_2 in Tons**
Offshore Access Vessel (construction)	1	33.55 m^3 at transit speed 31.70 m^3 in Idle at OWF 43.33 m^3 on DP anchorage 108.58 m^3 in 30 days	$33.55 \cdot 3.206 = 107.56\ tons$ $31.70 \cdot 3.206 = 101.63\ tons$ $43.33 \cdot 3.206 = 138.92\ tons$ $Totaly\ =\ 348.12\ tons\ CO_2$ $emission\ in\ 30\ days$
Crew Transfer vessel at construction phase	3	39.54 m^3 @ Service speed 1.04 m^3 @ Idle Totally 40.57 m^3 in 30 days	$39.54 \cdot 3.206 = 126.75\ tons$ $1.04 \cdot 3.206 = 3.33\ tons$ $Totaly\ =\ 130.08\ tons\ CO_2$ $emission\ by\ 30\ days\ activity$
Consumption and CO_2 emission in construction phase	4	Total fuel consumption calculated during the construction phase $108.58\ m^3 + 40.57\ m^3$ $= 149.16\ m^3$	Total CO_2 emission calculated in construction phase $348.12\ +\ 130.08\ = 478.19\ t$ by 30 days activity.

CTV O&M phase	1	26.90 m^3 @ service speed 0.70 m^3 @ Idle 27.60 m^3 @ 30 Days	$26{,}90 \cdot 3.206 = 86.24\ tons$ $0.70 \cdot 3.206 = 2.24\ tons$ $Totaly\ =\ 88.49\ tons\ CO_2$ $emission\ by\ 30\ days\ activity$
OAV O&M phase	1	46.94 m^3 @ Transit speed 145.70 m^3@ Idle on DP 192.64 m^3 @ 30 days	$46.94 \cdot 3.206 = 150.50\ tons$ $145.70 \cdot 3.206 = 467.11\ tons$ $Totaly\ =\ 617.62\ tons\ CO_2$ $emission\ by\ 30\ days\ activity$
Consumption and CO_2 emission at O&M phase	2	Total fuel consumption calculated at O&M Phase =27.60 m^3+ 192.64 M^3 =220.25 m^3	Total CO_2 emission calculated in O&M phase = 88.49 tons +617.62 tons = 706.11 tons
Consumption and CO_2 emission	6	Total fuel consumption calculated at construction and O&M Phase 149.16 m^3 + 220.25 m^3 = 369.40 m^3	Total CO_2 emissions calculated in both phases 478.19 ton + 706.11 ton = 1184.31 ton

Table 2 Fuel and emissions calculations of service vessel - own production based on (Veidenheimer, 2014)

CASE 2 The fuel and emissions saving if all vessels are hybrid and switch off their engines on the idle time on Marine Traffic:

The table below will take a closer look at the fuel consumption and CO_2 saving where possible. The consumption of the OAV at standby in anchorage is included in the table. The calculation is based on the assumption that the vessel can connect to the power sources in the field while on standby without consuming any fuel.

Fuel consumption			
Construction Phase	**Consumption**	**Emission**	**Total saving**
OAV Vessel Underway/Standby	33.55 m^3 at transit + 43.33 m^3 on DP anchorage = 76.88 m^3	107.56 tons CO_2 transit + 138.93 ton CO_2 at anchorage = 249.49 ton CO_2 produced	-
OAV Vessel Idle saving possible	31.70 m^3 of fuel saved with shore power on field	101.63 ton CO_2 saved with power or battery mode on field	29.19 % Saved when connected shore power or battery on field.
CTV Transit Construction phase	39.54 m^3 fuel consumed during transit	126.75 tons CO_2 emission produced during transit	-
CTV idle at construction phase	1.04 m^3 of fuel saved at idle mode on field	3.33 tons CO_2 saved at idle mode on field with battery mode	2.56 % Saved when connected to shore power or battery on field.
Total saving at idle mode during construction phase	31.70 m^3 + 1.04 m^3 = 32.74 m^3 of fuel	101.63 ton + 3.33 ton = 104.96 ton CO_2 Saved	21.95 % saved during construction at idle mode.
Operation and maintenance phase			
OAV Vessel Underway	46.94 m^3 at transit consumed.	150.50 tons CO_2 transit	-
OAV Vessel idle	145.70 m^3 of fuel saved.	467.11 tons CO_2 saved	75.63 % saved

CTV Transit	26.90 m^3 fuel consumed	86.24 Tons CO_2 produced	-
CTV Idle	0.70 m^3 fuel saved.	2.24 tons CO_2 saved	2.54 % saved
Total saving at idle mode during O&M phase	145.70 m^3 + 0.70 m^3 = 146.40 m^3 fuel saved	467.11 tons + 2.24 = 469.36 tons CO_2 saved.	66.47 % saved during O&M phase at idle.
Total saving at construction and O&M phase.	32.74 m^3 + 146.40 m^3 = 179.14 m^3 fuel saved	104.96 tons + 469.36 = 574.32 tons CO_2 saved.	48.49 % saved during construction and O&M phase.

Table 3 Calculations of fuel consumption and emissions savings for vessels with zero emissions at idle mode in field.

CASE 3 Energy consumption calculations from* Table 3 *+ 25 per cent resistance of the increased weight on board CTV:

At 25 knots speed, the mass of fuel consumption is: 450 l/h x 0.85 kg/l =382.5 kg/h.
The Diesel produces 12.5 kWh/kg. The energy consumption will be: 382.5 kg/h x 12.5 kWh/kg = 4781.3 kWh.

Energy consumption with 25 % weight:

$$Energy\ consumption\ =\ 4781.3\ kWh\ \cdot 1.25$$

$$Energy\ consumption\ = 5976.63\ kWh\ at\ Underway\ mode$$

$$\text{Weight of fuels at idle}\ =\ 18\ \text{l/h}\ \cdot\ 0.85\ kg/l\ =\ 15.3\ kg/h$$

$$Energy\ consumption\ of\ idle\ mode\ =\ 15.3\ kg/h\ \cdot 12.5\ kg/kWh = 191.25\ kWh$$

Energy consumption 30 days (15.02 – 17.03.2022):

The calculation of Seacat Weatherly will be:

Underway consumption: $5976.56 \text{ kW} \cdot \text{ houe underway} = 357{,}298.83 \text{ kW}$

Idle consumption: $191.25 \text{ kWh} \cdot \text{ hour idle } = 7439.63 \text{ kW}$

Total consumption: $364{,}738.46 \text{ kW}$

Table 4 below shows the services vessels energy consumption for activities:

Energy consumption vessel 14.03.2022		
Vessel	**Underway (kW/hour)**	**Idle(kW/hour)**
CTV	5976.56	191.25
OAV	3541.67	3541.67
Hybrid CTV	2861.05	191.25

Table 4 Energy consumption service vessels

4.7.2 Time activity for OAV and CTV

Table 5 shows the time activity for different vessels mapped from Marine Traffic in 30 days.

Time activity vessel 15.02.2022 – 17.03.2022				
Vessel	**Underway (dd hh:mm)/ % of time**	**Idle (dd hh:mm)/ % of time**	**In port (dd hh:mm)/ % of time**	**Waiting (dd hh:mm)/ % of time**
CTV Seacat Weatherly	2 d 15:05 8 %	1 d 18:58 6 %	26 d 18:58 86 %	- -
OAV Esvagt Alba	7 d 05:33 23 %	20 d 23:44 68 %	2 d 18:43 9 %	- -
CTV Seacat Volunteer	1 d 22:56 6 %	1 d 21:54 6 %	27 d 02:49 87 %	0 d 00:21 1 %
CTV HST Harri	0 d 12:33 2 %	0 d 00:27 1 %	30 d 10:11 98 %	0 d 00:49 1 %

HCTV Manor Enterprise	13 d 07:05 43 %	2 d 02:02 6 %	15 d 16:41 51 %	0 d 00:12 1 %
OAV Acta Centaurus	2 d 07:57 8 %	6 d 01:39 20 %	16 d 21:17 54 %	5 d 17:07 18 %

Table 5 Time activity duration 30 days for service vessels

Fuel consumption and fuel price

Table 6 shows the fuel prices during 30 days of service vessels mapped. Calculated from MGO prices in Rotterdam 9th of May 2022 .

Fuel consumption and Emission of ICE for service vessels

The total Fuel consumption between 15.02.22 – 17.03.2022.

Fuel prices from Rotterdam bunkers = 1188.5 \$/MT–Currency rates \$ to € = 0.96137

(*Rotterdam Bunker Prices*, n.d.)

Consumption = time * fuel consumption per hour

1 MT = 1.1023 Tons, to m^3 = 1.1023 *0.85 kg/m^3 =0.94 m^3 cost 1188.5 \$/m^3

$$Fuel\ prices\ in\ €\ per\ \mathrm{m}^3 = 1188.5\ \$/m^3 \cdot 0.96137 = 1{,}1426\ €/\mathrm{m}^3$$

* Manor Enterprise using hybrid battery during idle time.

Vessel	**Underway m^3** **Fuel price**	**Idle m^3** **Fuel price**	**Total kWh** **Total price €**	**Emission**
CTV Seacat Weatherly	26.90 m^3 30,738.48 €	0.70 m^3 800.04 €	27.60 m^3 31,538.52 €	88.49 Ton
OAV Esvagt Alba	46.94 m^3 53,638.17 €	145.70 m^3 166,475.11 €	192.64 m^3 220,113.28 €	617.62 Ton
CTV Seacat Volunteer	18,71 m^3 21,380.68 €	1.03 m^3 1,175.04 €	19.74 m^3 22,555.72 €	63.29 Ton
CTV HST Harri	2.67 m^3 3,050.71 €	0.01 m^3 10.28 €	2.68 m^3 3060.99 €	8.59 Ton
HCTV Manor Enterprise	18.15 m^3 20,741.09 €	0 m^3* 0 €*	18.15 m^3 20,741.09 €	58.20 Ton

OAV Acta Centaurus	76.88 m^3 87,845.99 €	31.70 m^3 36,220.05 €	108.58 m^3 124,066.04 €	348.12 Ton
Total Consumed/ Total cost	190.27 m^3 217,395.13 €	179.14 m^3 204,680.52 €	369.40 m^3 422,075.64 €	1,184.31 Ton

Table 6 Calculations of the MGO prices for operating service vessels in OWF over 30 days

Energy consumption and electricity price

The total energy consumption on in 30 days, 15.02.2022 – 17.03.2022

Taken from average energy prices for the UK in 2021 = 0.12 £/kWh (NORDPOOL, n.d.)

Consumption = time * energy consumption

Energy $in\ €\ per\ kWh\ = 0.12 \cdot 1.1754 = 0.141018$ at harbour shore connection

Energy price in wind farm = $\frac{energy\ prices\ in\ port}{2} \rightarrow \frac{0.141018}{2} = 0.070509\ €/kW$

Energy price for all vessels after average price 2021=price*consumed energy = actual price charging.

Vessel	**Underway Kw** **Energy Price**	**Idle OWF kW** **Energy price /2**	**Total Kwh** **Total price €**
CTV Seacat Weatherly	357,298.83 kW 50,396.29 €	7,439.63 kW 524.67 €	364,738.45 kW 50,920.96 €
OAV Esvagt Alba	498,784.72 kW 70,352.59 €	1,548,062.50 kW 109,175.56 €	2,046,847.22 kW 179,528.15 €
CTV Seacat Volunteer	248,525.39 kW 35,054.01 €	10,926.75 kW 770.60 €	259,452.14 kW 35,824.61 €
CTV HST Harri	35,460.94 kW 5,001.69 €	95.63 kW 6.74 €	35,556.56 kW 5,008.44 €

HCTV Manor Enterprise	241,090.88 kW 34,005.39 €	12,316,50 kW 868.61 €	253,407.38 kW 34,874.00 €
OAV Acta Centaurus	356,468.75 kW 50,279.20 €	43,050 kW 3,036.08 €	399,519.13 kW 53,315.29 €
Energy consumed Energy cost	1,737,629.51 kW 245,089.17 €	1,621,891.38 kW 114,382.27 €	3,359,520.89 kW 359,471.43 €

Table 7 Calculations of the energy prices for operating service vessels in OWF over 30 days

Battery vs diesel

Saved to use Electricity instead of Diesel after activity from 15.02.2022 – 17.03.2022
Energy price for all vessels average 2021 =price*consumed energy = actual price
Price differences = price of consumed electric power – price of consumed fuel
* Manor Enterprise using hybrid battery during idle time for fuel consumption

Vessel	**Electric €** **Fuel price €**	**Idle m^3** **Fuel price €**	**Total Kwh** **Total price €**	**€ Saved** **% Saved**
CTV Seacat Weatherly	50,396.29 € 30,738.48 €	524.67 € 800.04 €	50,920.96 € 31,538.52 €	-19,382.44 € -38.06%
OAV Esvagt Alba	70,352.59 € 53,638.17 €	109,175.56 € 166,475.11 €	179,528.15 € 220,113.28 €	45,585.13 € 22.61 %
CTV Seacat Volunteer	35,054.01 € 21,380.68 €	770.60 € 1,175.04 €	35,824.61 € 22,555.72 €	-13,268.89 € -37.04 %
CTV HST Harri	5,001.69 € 3,050.71 €	6.74 € 10.28 €	5,008.44 € 3060.99 €	-1947.44 € -38.88 %
HCTV Manor Enterprise	34,005.39 € 20,741.09 €	868.61 € 0 €*	34,874.00 € 20,741.09 €	-14,132.91 € -40.53 %

OAV Acta Centaurus	50,279.20 € 87,845.99 €	3,036.08 € 36,220.05 €	53,315.29 € 124,066.04 €	70,750.75 € 132.88 %
Energy prices	245,089.17 € 217,395.13 €	114,382.27 € 204,680.52 €	359,471.43 € 422,075.64 €	62,604.21 € 17.42 %

Table 8 Table showing the savings for using electricity instead of MGO over 30 days in OWF

As shown in Table 8, using batteries is more expensive for the CTV, compared to the fuel, and not economically beneficial. For an OAV, the electrification will lead to saving of up to 132 per cent or 70,751 € for 30 days of activity.

5 Result & Discussion

This master thesis aimed to find out the economic, technical and environmental aspects of using hybrid or electrical driven vessels in the wind park. Based on the reviewed literature and the researched case study, the findings are going to be discussed in this chapter. This master thesis has looked at various service vessels' work tasks and driving patterns in the wind turbine field. The wind turbines' maintenance and construction have also been considered.

Using renewable sources by the energy industry has never been such a hot and critical topic as it is today. There is an increased focus on developing sustainable and renewable energy worldwide (Bui et al., 2021). Based on the findings in this thesis, and according to Łebkowski (2020), currently, the service vessels used in the wind turbines' construction and maintenance phase consume high MGO, which is resulting in many harmful environmental effects. However, different aspects of this new technology and the source of producing this energy for the vessels should also be taken into account. The details of using these types of vessels are going to be discussed further.

5.1 Wind strength to produce power from the turbine

Delivering service at an offshore wind farm might usually be affected by weather conditions. This can delay important maintenance and energy production tasks for the power grids.

According to Łebkowski (2020), if the wind strength is not enough, the vessels cannot be recharged due to the lack of energy produced by the turbines. The turbine voltage level is usually 6.6 kV. After being transformed in the substation, the power grid's power voltage level can be from a few kilovolts to several hundred kilovolts. A solution might be to send the power in the opposite direction from shore to the wind park. In the construction phase, the electrical cable will deliver the power from the installed turbines to the shore almost three weeks after the installation is completed.

Sruthy et al. (2021) presented that the electric vessels can use the floating charging station and dock to recharge the batteries on standby while waiting for the technicians. This can take up to eight hours. The floating charging station is designed to deliver from 750 kW to 1000 kW power to service vessels such as CTV at idle mode. During the idle time, the CTV has a net energy consumption of between 150 and 200 kWh in the wind field. This corresponds to a consumption of 18 litres fuels per hour.

Producing power from a wind turbine naturally requires wind to rotate the turbine's blades. In the summer of 2021, there was not a lot of wind in general across the UK and Ireland (Stevens, 2021). This resulted in a shortage of power required for charging vessels and made the charging time longer. The best weather condition for charging CTV is when the weather is stable and not so windy so that the CTV can sail towards the turbine. The ideal wind speed to produce power is between 12-17 m/s. Moreover, the cut-in speed for a turbine is between 3-4 m/s, and the cut-out speed is above 24 m/s (Acakpovi et al., 2020).

When power production in the wind farm is lowest due to the bad wind conditions, there should be a solution for the hybrid boats to still charge the batteries on board. Łebkowski (2020) raised this issue and provided a solution to solve this problem. He proposed the hybrid solution of using diesel engines. He pointed out that the battery technology is feasible for the vessels that have the opportunity to be recharged in the field. Otherwise, they should reduce their speed to save enough energy to be able to sail toward the wind farms located farther from the shore.

Contrary to his solution, Casey (2022) had another solution of using external power from the sun or the Battery Energy Storage System on the seabed. This solution might be interesting to be further investigated for charging the vessels, especially when the wind level is very low, as this happened in 2021 (Stevens, 2021).

5.2 Charging points in offshore wind parks

Maersk and Ørsted have developed a good solution for charging on a wind turbine field. This concept is buoy based, where it can give enormous vessel power and, at the same time, anchor the ship to the seabed without the use of engine power (Maersk Supply, 2020; MJR, 2021). This solution is well suited for OAVs since they can stay up to four hours in the same position based on Marine Traffic data about Esvagt Alba.

A bad weather condition can give a good opportunity for an OAV to stay close to a wind farm and be powered up by a charging buoy. Even when the vessel remains outside the field, mooring into a charging buoy during high wind is possible. For smaller vessels such as a

CTV, the company, MJR, has developed a solution by using a power cable in the drum attached to the turbine platform. A remote device can easily control a cable drum to lower the power cable down to the CTV when pushed onto the boat landing.

Spanol (2019) forecasted that using electrical charging can bring a 20 per cent reduction in fuel cost and 30 per cent reduction in emission. Despite his argument, the findings from this thesis (Table 3) show that using shore connection for hybrid vessels in the field can cut between 22 to 76 per cent of the fuel and emission for each service vessel during 30 days mapping.

5.3 Charging in the port

According to Kumar (2019), using fast charging technology is a suitable and quick solution for charging these electric vessels. He pointed out that this technology can reduce the charging time from eight hours to one hour. Furthermore, Haynes (2019) argues that full battery charging is usually done in the morning before the departure starts. It has also been found that the shore power connection is available mainly in the big ports in Europe.

Based on our findings from Marine Traffic, a CTV often has a port stay of less than one hour before the next departure. From the 22 port calls for the Manor Enterprise vessel, six of them had a berth of less than one hour in port before the next departure. This means that many of them would not be able to be fully charged, especially when an urgent task happens on the wind farm.

5.4 Hybrid charging on board

As mentioned in the findings chapter, hybrid vessels are more frequently used than the vessels with only Internal Combustion Engines. A hybrid vessel, called Manor Enterprise, spent nearly 16 days outside the port for construction activity during 30 days, while the vessel with the diesel engine was only out for about three days during the same period. As it was shown in Table 5, Manor Enterprise was mostly active on the 14th of March. Based on this, it seems that the wind farm mainly prefers to use more sustainable options such as hybrid vessels.

Charging the battery onboard will consume more fuel since the vessels use a bit more load to produce enough energy for charging the batteries during transit and standby. To get the sufficient energy to drive on the electric mode, it is necessary to use Battery Energy Storage Systems to avoid the engines to start which can result in high power consumption. Another reason for a high-power consumption, found in this thesis, can be the use of quick-charging mode when the vessel is connected to the charging station.

5.5 Consumption of vessel

Hambro (2020) claimed that the global growth of offshore wind must lead to zero-emission goals. The infrastructure for charging without cutting the local city power should be considered when installing the onshore power supply for larger vessels that consume a higher source of energy. Hambro conducted research on about 370 CTVs and found out that the consumption for each CTV is about 2000 litres per day.

However, based on the calculations made in this thesis, the findings show that this type of vessel uses 2708 litres of fuels during one working day on the wind farm. In addition, from the case study findings and after discussing the topic with experts, it can be presented that the CTV consumes between 4500 and 4800 litres of fuels during a working day on the wind turbine field.

5.6 Distance to the wind farm and the relation between battery and speed

The average distance between the shore and the wind farm is between 11 and 44 nautical miles (Łebkowski, 2020). In contrary to Łebkowski, Hambro claims the distance to be 20 nautical miles. However, based on the results in this thesis, the measured distance from Fraserburgh to Moray East has found to be 27 nautical miles. Furthermore, the second wind farm, called Seagreen, has a distance of 15 nautical miles from the coast of Montrose.

When it comes to the speed, the data from the Marine Traffic shows that the service vessels usually have a speed of over 21 knots. This is a typical service speed used to quickly get to the field with the crew, technicians and relevant tools. There is an exponential relation between speed and fuel consumption, in a way that the higher speed the vessel has, the more fuel or energy it needs to consume. At low speed, the vessel can travel longer because of the non-linear connection between fuel consumption and speed, and the fact that it can save more fuel.

Furthermore, the battery weight would also affect the energy consumption. The vessels that have a bigger or heavier battery should naturally sail faster to perform their duties on time. This requires more energy consumption because of the drag and resistance in the water. Łebkowski (2020) present the extra weight of battery will increased draft of the vessel.

5.7 DP vessel fuel saving

During the use of Dynamic Positioning (DP), diesel engines are preferred as a stable source of power generation in the field. The machines are running with reduced load and, if possible, with minimum numbers of generators online to minimize fuel consumption. Holmefjord et al. (2020) described an increased fuel consumption when transitioning from DP1 mode to DP2. They claimed that the fuel consumption is 24 per cent less when the OAV is staying on DP1 compared to DP2. They also mentioned that the time the OAV vessel is staying inside the wind farm with DP2 class is 12 hours in the daytime, while during the nighttime, the vessel waits outside the OWF on standby in DP1 mode to save fuel. For simplifying the DP fuel and energy calculations in this thesis, the change in DP mode during the day has not been taken into consideration.

5.8 Sources of error

During the data collection period of service vessels on the Moray East and Seagreen offshore wind fields, the vessels had less activity than the month before. At the Seagreen offshore wind farm, there were significant delays in transporting the turbine foundations from the Middle East due to the Covid-19 interruptions in the factory producing wind turbine foundations (Lea, 2022). Delays had ripple effects on the service vessels since they had to stay still in the port. The other source of error is that the vessel OAV Acta Centaurus was often lying at the anchorage on DP. Therefore, the its status in Marine Traffic was classified as Standby instead of Idle. Acta Centaurus had the AIS status set to "Restricted manoeuvrability" instead of "At anchor".

Figure 24 Jack-up vessel in front of the foundation for wind park

5.9 Advantages and disadvantages of battery power on board.

Battery	
Advantages	**Disadvantage**
- No sound or vibration from the engine - Energy prices in cheaper compared to Diesel prices - Quick acceleration compared to ICE - Reduced tax on battery vessels than the ICE vessel	- Reduced sailing range compared to diesel engine - High battery component cost. - Battery cooling demand to avoid overheating - Longer charging time compared to diesel bunkering - Lack of charging opportunity in all ports - Total weight increase due to the extra battery weight - Require special fire sprinklers in case of fire.

Table 9 Advantages and disadvantages of battery vessels (Lindstad et al., 2017)

Hybrid	
Advantage	**Disadvantage**
- Less emission - Fast response to load changes - High efficiency - Less fuel consumption - Less spare part - Less vibration and noise - High reliability - Battery recharging possibility on board - Lighter weight compared to full electric vessels	- Emission tax - Require fire sprinklers for battery package.

Table 10 Advantages and disadvantages of using hybrid vessels (Haynes, 2019; Holmefjord et al., 2020; Łebkowski, 2020)

6 Conclusion

The concept of using more sustainable energy sources instead of fossil fuels has gained a lot of attention in recent years. The shipping industry is contributing to a significant amount of CO_2 emissions in the world. The intensive use of diesel vessels for transporting goods and passengers, and also assisting the construction and operation offshore has resulted in harmful global effects. Therefore this industry is trying to embrace different strategies to mitigate the greenhouse effects caused by activities offshore. One of the steps towards this green shift is using hybrid vessels instead of diesel-driven ones in the wind industry.

This master thesis tried to investigate the opportunities of using hybrid or battery vessels in offshore wind parks, the advantages and disadvantages of using hybrid vessels instead of diesel ones, CO_2 emissions by diesel vessels, and the cost of using the alternative solution.

Based on this study, and considering the main research question, it can be concluded that:

- From the environmental aspect, it was discovered that using hybrid vessels can reduce diesel consumption by 48 per cent and respectively the CO_2 emissions. During standby mode and reduced engine loads, the vessel can operate with battery energy, hence zero emissions. However, there are still discussions about mineral extraction and battery disposal at the end of their lifetime and their environmental effects.
- From the economic aspect, by using batteries, the shipping company can save more than 17 per cent on fuel costs compared to using MGO. Despite the budget savings advantage, using batteries on the CTVs can increase the total weight, and therefore more energy is needed to be consumed for the same sailing distance.
- Finally, from the technological aspect, charging the vessel in the wind farm is possible as long as the weather condition is good enough, a permit to enter the wind farm is given, and the charging port is in place. The battery technology can be beneficial in several aspects since it is noise and vibration free, more suitable for peak-power loads, and requires less maintenance.

6.1 Limitations

This study has some limitations that can be considered in further research. Firstly, the situation of the Covid-19 pandemic affected the process of collecting data since it was not easily possible to reach out to experts or companies in this industry. Secondly, since this technology is an ongoing field of research, with several test sites and prototypes in the pipe, there is not enough knowledge or sources available. Finally, there is a lot of information available about jack-up service vessels from different companies, including the company that the thesis author is working for. However, this valuable information and data could not be used due to information sharing privacy and security regulations.

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Appendix

From hydrocarbon (C_nH_{2n+2}) to carbon dioxide (CO_2)

We assume every C-atom in the hydrocarbons combusts to CO_2.

Oil is primarily hydrocarbons in long chains (gas in short chains)

Hydrocarbons have the formula C_nH_{2n}+2, where atomic mass for C is $m_C = 12$, and atomic mass for H is $m_H=1$

For n = 1 we get CH_4 (methane) so that the molecule mass will be $12 + 4 = 16$. Then 12/16 or 75% of the CH_4-weight is carbon.

For n = 10, we get $C_{10}H_{22}$, whose molecule mass is

$10 * 12 + 22 * 1 = 120 + 22 = 142$ So 120/142 or 84,5% of the $C_{10}H_{22}$-mass is carbon.

As n gets taller the proportion of carbon increases from 12/16 = 0.75 to 120/142 = 0.845 up to 0.857 (when n is very large).

If we chose n=5 as an average for diesel, we get 83% of the C_5H_{12}-mass is carbon. We will use this number in the following calculations.

MGO burns to CO_2 and H_2O

The atomic mass of oxygen is 16, so CO_2 has an atomic mass of 12 + 2 * 16 = 44. The proportion of carbon in carbon dioxide is 12/44 or 27%

Mass of CO_2 when we know carbon mass, we calculate like this.

$Weight\ of\ CO2 = Weight\ of\ carbon\ / \ 27\% = Weight\ of\ carbon * 3.67$

Mass of CO_2 when we know the mass of MGO, we can calculate like this

*Mass of CO_2=Mass of MGO/83%*3.67 = Mass of MGO * 4,4*

To calculate the mass of carbon dioxide = multiply the mass of MGO by 4,4.

If we have MGO volumes in litres and we want to calculate the mass of carbon dioxide, we use the mass of one litre MGO is 0,85 kg. So, we multiply volumes of MGO by 0,85 to get the mass of carbon dioxide. This sums up to

Mass of CO_2 *= Mass of MGO*0,85 * 4,4 = Mass of MGO*3,74*

To get the mass of carbon dioxide = multiply the volume of MGO by 3,74

(Unit; litre to kg or cubic metres to tons)

To get the volume of carbon dioxide = multiply the volume of MGO by 3,64

Here will 1 Liter of diesel will make 3.64 kg of CO2.

OAV Acta Centaurus

Quick Search: ACTA CENTAURUS ×   Select a Quick View   Add Filter

Ata/atd: 2022-02-14 to 2022... ×

Vessel Name	Port Call Type	Port Type	Port At Call	Ata/atd	Time At Port	Destination Port	Voyage Origin Port	Voyage Time Underway	Voyage Idle Time	Voyage Distance Travelled	Voyage Speed Average	Voyage Speed Max
ACTA CENTAUR...	ARRIVAL	Port	MONTROSE	2022-03-16 01:40 UTC	-	-	MONTROSE ANCH	1d 23h 7m	0.0	118 NM	6.9	9.6
ACTA CENTAUR...	DEPARTURE	Anchorage	MONTROSE ANCH	2022-03-14 02:33 UTC	3d 7h 21m	MONTROSE	-	-	-	-	-	-
ACTA CENTAUR...	ARRIVAL	Anchorage	MONTROSE ANCH	2022-03-10 19:12 UTC	-	-	MONTROSE	1h 2m	0.1	7 NM	6.4	7.2
ACTA CENTAUR...	DEPARTURE	Port	MONTROSE	2022-03-10 18:10 UTC	3d 42m	MONTROSE ANCH	-	-	-	-	-	-
ACTA CENTAUR...	ARRIVAL	Port	MONTROSE	2022-03-07 17:28 UTC	-	-	MONTROSE	3d 14h 6m	70.3	104 NM	6.9	10.3
ACTA CENTAUR...	DEPARTURE	Port	MONTROSE	2022-03-04 03:22 UTC	2d 1h 22m	MONTROSE	-	-	-	-	-	-
ACTA CENTAUR...	ARRIVAL	Port	MONTROSE	2022-03-02 02:00 UTC	-	-	MONTROSE ANCH	1d 3h 36m	0.0	131 NM	7.2	10.2
ACTA CENTAUR...	DEPARTURE	Anchorage	MONTROSE ANCH	2022-02-28 22:24 UTC	2d 2h 39m	MONTROSE	-	-	-	-	-	-
ACTA CENTAUR...	ARRIVAL	Anchorage	MONTROSE ANCH	2022-02-26 19:45 UTC	-	-	MONTROSE	1d 9h 54m	24.7	69 NM	7.6	10.2
ACTA CENTAUR...	DEPARTURE	Port	MONTROSE	2022-02-25 09:51 UTC	11d 20h 9m	MONTROSE ANCH	-	-	-	-	-	-

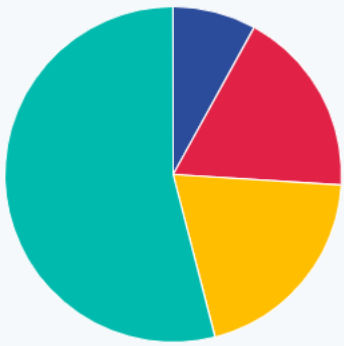
Found 10 records   Page 1 of 1   Rows per page: 20

Vessel Utilisation

Movement   Voyage related

Last 30 days   Last 12 months

Total Distance Travelled: **359 NM**
Average/Maintained Speed: **6.4 knots**



- Time Underway: **2 d 07 h 57 min (8%)**
- Time Waiting: **5 d 17 h 07 min (18%)**
- Time Idle: **6 d 01 h 39 min (20%)**
- Time in port: **16 d 21 h 17 min (54%)**

OAV Esvagt Alba

Vessel Name	Port Call Type	Port Type	Port At Call	Ata/atd	Time At Port	Destination Port	Voyage Origin Port	Voyage Time Underway	Voyage Idle Time	Voyage Distance Travelled	Voyage Speed Average	Voyage Speed Max
ESVAGT ALBA	DEPARTURE	Port	FRASERBUR...	2022-03-09 20:12 UTC	1d 16h 14m	-	-	-	-	-	-	-
ESVAGT ALBA	ARRIVAL	Port	FRASERBUR...	2022-03-08 03:58 UTC	-	-	FRASERBURGH	12d 7h 36m	216.1	630 NM	8.5	11.8
ESVAGT ALBA	ARRIVAL	Port	FRASERBUR...	2022-02-23 20:30 UTC	-	-	FRASERBURGH	8m	0.0	1 NM	5.3	7.1
ESVAGT ALBA	DEPARTURE	Port	FRASERBUR...	2022-02-23 20:22 UTC	1d 2h 48m	FRASERBUR...	-	-	-	-	-	-
ESVAGT ALBA	ARRIVAL	Port	FRASERBUR...	2022-02-22 17:34 UTC	-	-	FRASERBURGH	11d 18h 12m	221.0	464 NM	8.2	11.7

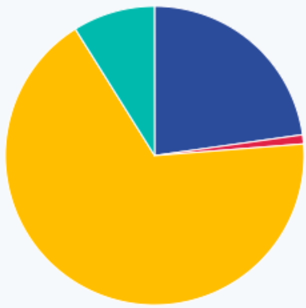
Found 5 records — Page 1 of 1 — Rows per page: 20

Vessel Utilisation

Movement | Voyage related

Last 30 days | Last 12 months

Total Distance Travelled: **1244 NM**
Average/Maintained Speed: **7.1 knots**



- Time Underway: **7 d 05 h 33 min (23%)**
- Time Waiting: **– (1%)**
- Time Idle: **20 d 23 h 44 min (68%)**
- Time in port: **2 d 18 h 43 min (9%)**

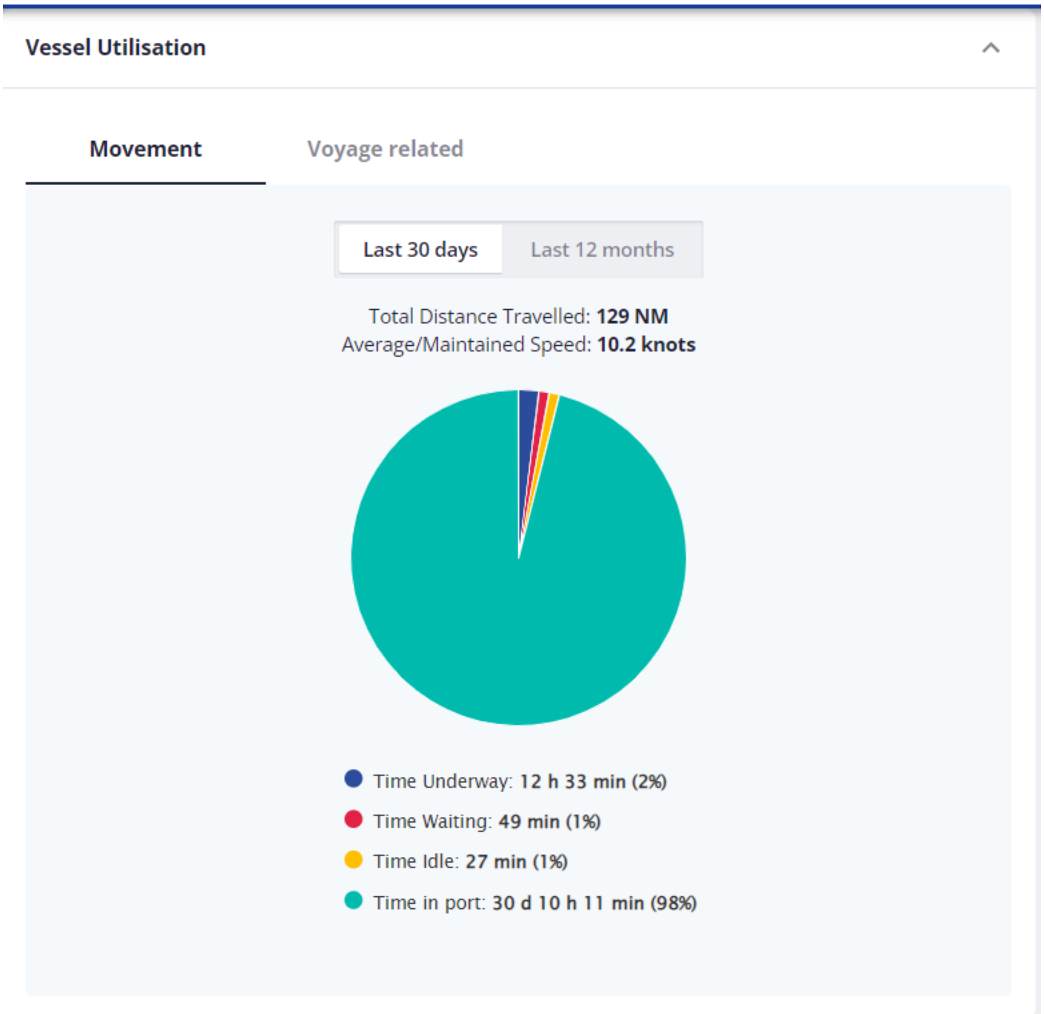
CTV HST Harri

MMSI: 232024313 × | Vessel Name: HST HARRI ×

Port Call Type	Port Type	Port At Call	Ata/atd	Time At Port	Destination Port	Voyage Origin Port	Voyage Time Underway	Voyage Distance Travelled	Leg Start Port/anch	Leg Time Underway	Leg Distance Travelled
ARRIVAL	Port	MONTROSE	2022-03-14 03:24 UTC	-	-	MONTROSE	42m	5 NM	MONTROSE	42m	5 NM
DEPARTURE	Port	MONTROSE	2022-03-14 02:42 UTC	6d 11h 22m	MONTROSE	-	-	-	-	-	-
ARRIVAL	Port	MONTROSE	2022-03-07 15:20 UTC	-	-	MONTROSE	2h 34m	52 NM	MONTROSE	2h 34m	52 NM
DEPARTURE	Port	MONTROSE	2022-03-07 12:46 UTC	6d 2h 23m	MONTROSE	-	-	-	-	-	-
ARRIVAL	Port	MONTROSE	2022-03-01 10:23 UTC	-	-	MONTROSE	2h 42m	58 NM	MONTROSE	2h 42m	58 NM
DEPARTURE	Port	MONTROSE	2022-03-01 07:41 UTC	18h 13m	MONTROSE	-	-	-	-	-	-
ARRIVAL	Port	MONTROSE	2022-02-28 13:28 UTC	-	-	MONTROSE ANCH	11m	14 NM	MONTROSE ANCH	11m	14 NM
DEPARTURE	Anchorage	MONTROSE ANCH	2022-02-28 13:17 UTC	1h 31m	MONTROSE	-	-	-	-	-	-
ARRIVAL	Anchorage	MONTROSE ANCH	2022-02-28 11:46 UTC	-	-	MONTROSE	17m	5 NM	MONTROSE	17m	5 NM
DEPARTURE	Port	MONTROSE	2022-02-28 11:29 UTC	18d 16h 49m	MONTROSE ANCH	-	-	-	-	-	-
DEPARTURE	Port	MONTROSE	2022-02-27 09:47 UTC	17d 15h 7m	MONTROSE	-	-	-	-	-	

Get Started

x



HCTV Manor Enterprise

Vessel Name	Port Call Type	Port Type	Port At Call	Ata/atd	Time At Port	Destination Port	Voyage Origin Port	Voyage Time Underway	Voyage Idle Time	Voyage Distance Travelled	Voyage Speed Average	Voyage Speed Max
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-16 18:28 UTC	1h 5m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-16 17:23 UTC	-	-	MONTROSE	11h 9m	6.1	63 NM	15.9	21.3
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-16 06:14 UTC	1h 7m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-16 05:07 UTC	-	-	MONTROSE	10h 19m	6.5	57 NM	16.3	21.6
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-15 18:48 UTC	1h 18m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-15 17:30 UTC	-	-	MONTROSE	11h 11m	6.3	65 NM	16.7	22.3
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-15 06:19 UTC	2h 4m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-15 04:15 UTC	-	-	MONTROSE	9h 35m	5.0	63 NM	16.1	20.6
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-14 18:40 UTC	29m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-14 18:11 UTC	-	-	MONTROSE	9h 16m	2.2	87 NM	13.8	22.1
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-14 08:55 UTC	4d 12h 57m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-09 19:58 UTC	-	-	MONTROSE	24m	0.1	4 NM	10.3	14.3
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-09 19:34 UTC	23m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-09 19:11 UTC	-	-	MONTROSE	1h 2m	0.6	4 NM	6.9	10.7
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-09 18:09 UTC	45m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-09 17:24 UTC	-	-	MONTROSE	46m	0.2	4 NM	7.1	9.5
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-09 16:38 UTC	1d 23h 17m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-07 17:21 UTC	-	-	MONTROSE	10h 55m	5.8	69 NM	17.3	23.9
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-07 06:26 UTC	2h 49m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-07 03:37 UTC	-	-	MONTROSE	8h 46m	3.2	66 NM	17.6	20.7

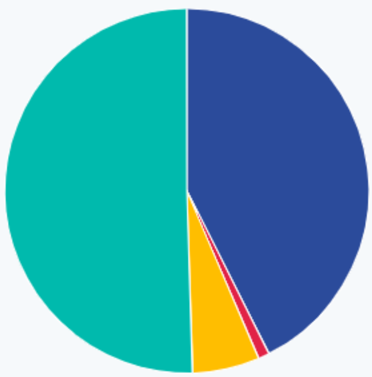
Get Started

Vessel Utilisation

Movement Voyage related

Last 30 days Last 12 months

Total Distance Travelled: **1008 NM**
Average/Maintained Speed: **3.1 knots**



- Time Underway: **13 d 07 h 05 min (43%)**
- Time Waiting: **12 min (1%)**
- Time Idle: **2 d 02 min (6%)**
- Time in port: **15 d 16 h 41 min (51%)**

Vessel Name	Port Call Type	Port Type	Port At Call	Ata/atd	Time At Port	Destination Port	Voyage Origin Port	Voyage Time Underway	Voyage Idle Time	Voyage Distance Travelled	Voyage Speed Average	Voyage Speed Max
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-06 18:51 UTC	58m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-06 17:53 UTC	-	-	MONTROSE	11h 38m	6.9	65 NM	16.9	23.2
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-06 06:15 UTC	4h 54m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-06 01:21 UTC	-	-	MONTROSE	4h 31m	0.1	68 NM	17.6	21.6
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-05 20:50 UTC	2h 46m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-05 18:04 UTC	-	-	MONTROSE	11h 22m	3.7	84 NM	17.9	22.6
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-05 06:42 UTC	12h 33m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-04 18:09 UTC	-	-	MONTROSE	10h 27m	4.4	74 NM	17.7	23.2
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-04 07:42 UTC	21m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-04 07:21 UTC	-	-	MONTROSE	21m	0.0	3 NM	6.5	10.6
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-04 07:00 UTC	7h 24m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-03 23:36 UTC	-	-	MONTROSE	3h 57m	0.5	53 NM	14.9	23.2
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-03 19:39 UTC	1h 9m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-03 18:30 UTC	-	-	BLYTH	34d 16h 2m	1.1	74 NM	14.5	21.8
MANOR ENTERPRISE	DEPARTURE	Anchora	MONTRO...	2022-03-03 13:17 UTC	23m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Anchora	MONTRO...	2022-03-03 12:54 UTC	-	-	MONTROSE	36m	0.2	3 NM	7.1	11.1
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-03 12:18 UTC	22h 33m	MONTROS...	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-02 13:45 UTC	-	-	MONTROSE	7h 34m	1.8	68 NM	19.0	22.7
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-02 06:11 UTC	23m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-02 05:48 UTC	-	-	MONTROSE	10h 52m	6.2	70 NM	18.7	22.6

Get Started

Vessel Name	Port Call Type	Port Type	Port At Call	Ata/atd	Time At Port	Destination Port	Voyage Origin Port	Voyage Time Underway	Voyage Idle Time	Voyage Distance Travelled	Voyage Speed Average	Voyage Speed Max
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-01 18:56 UTC	33m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-03-01 18:23 UTC	-	-	MONTROSE	6h 11m	2.9	58 NM	19.1	22.7
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-03-01 12:12 UTC	9d 19h 9m	MONTROSE	-	-	-	-	-	-
MANOR ENTERPRISE	ARRIVAL	Port	MONTRO...	2022-02-19 17:03 UTC	-	-	MONTROSE	2h 35m	0.6	36 NM	16.8	20.5
MANOR ENTERPRISE	DEPARTURE	Port	MONTRO...	2022-02-19 14:28 UTC	6d 2h 37m	MONTROSE	-	-	-	-	-	-

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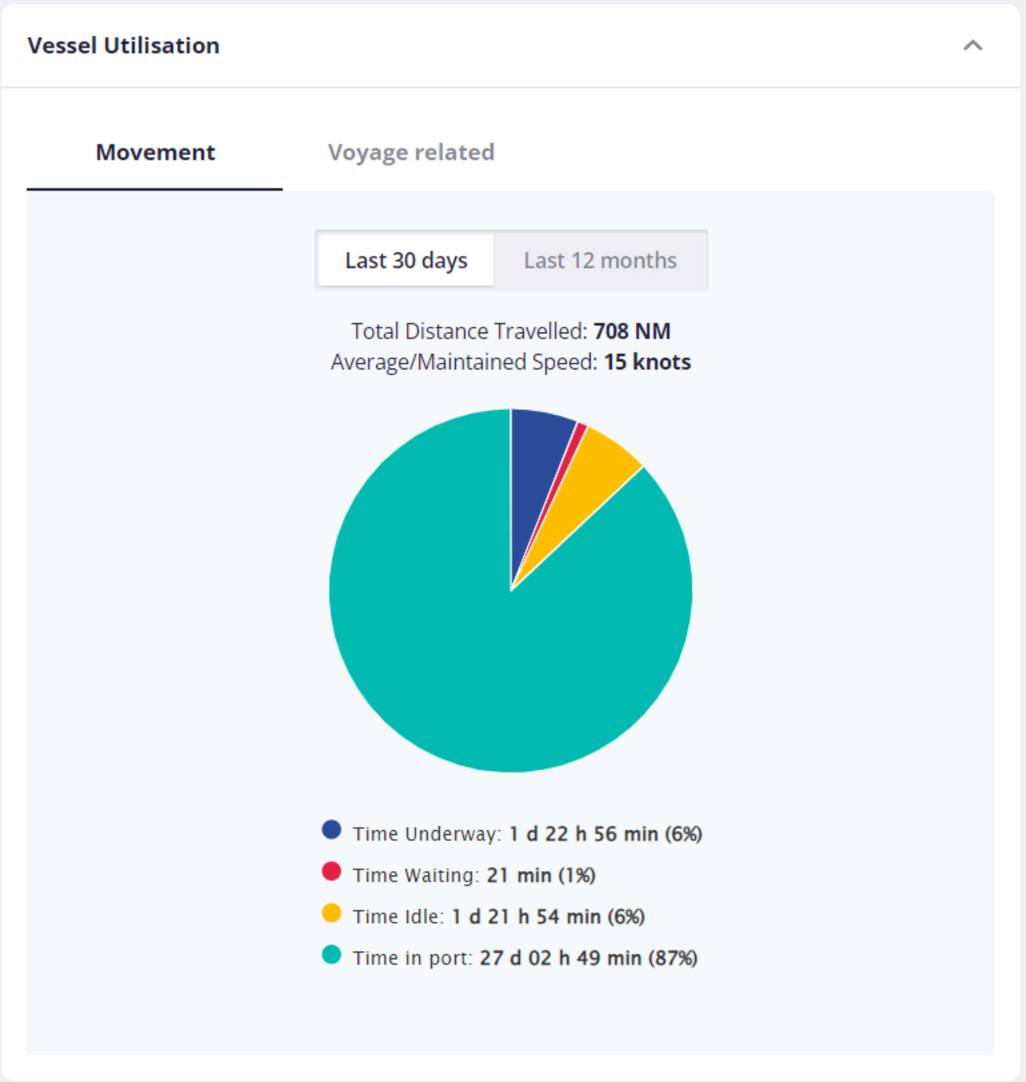
CTV Seacat Volunteer

Vessel Name	Port Call Type	Port Type	Port At Call	Ata/atd	Time At Port	Destination Port	Voyage Origin Port	Voyage Time Underway	Voyage Idle Time	Voyage Distance Travelled	Voyage Speed Average	Voyage Speed Max
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-03-16 17:06 UTC	-	-	MONTROSE	9h 12m	6.0	63 NM	19.6	23.5
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-03-16 07:54 UTC	13h 40m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-03-15 18:14 UTC	-	-	MONTROSE	10h 17m	6.5	66 NM	17.7	23.7
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-03-15 07:57 UTC	12h 35m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-03-14 19:22 UTC	-	-	MONTROSE	7h 7m	3.5	67 NM	18.7	23.8
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-03-14 12:15 UTC	6d 20h 48m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-03-07 15:27 UTC	-	-	MONTROSE	9h 17m	5.5	66 NM	20.4	24.5
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-03-07 06:10 UTC	11h 48m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-03-06 18:22 UTC	-	-	MONTROSE	10h 47m	7.6	68 NM	21.3	24.4
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-03-06 07:35 UTC	14h 7m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-03-05 17:28 UTC	-	-	MONTROSE	9h 49m	5.7	76 NM	20.0	25.6
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-03-05 07:39 UTC	19h 55m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-03-04 11:44 UTC	-	-	MONTROSE	5h 40m	2.5	58 NM	19.7	25.6
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-03-04 06:04 UTC	1d 15h 46m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-03-02 14:18 UTC	-	-	MONTROSE	8h 2m	4.7	62 NM	20.3	25.2
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-03-02 06:16 UTC	12h 10m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-03-01 18:06 UTC	-	-	MONTROSE	10h 52m	6.1	73 NM	17.7	24.6
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-03-01 07:14 UTC	15h 17m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-02-28 15:57 UTC	-	-	MONTROSE ANCH	35m	0.4	9 NM	9.1	16.1
SEACAT VOLUNTEER	DEPARTURE	Anchorage	MONTROSE ANCH	2022-02-28 15:22 UTC	16m	MONTROSE	-	-	-	-	-	

Get Started

Vessel Name	Port Call Type	Port Type	Port At Call	Ata/atd	Time At Port	Destination Port	Voyage Origin Port	Voyage Time Underway	Voyage Idle Time	Voyage Distance Travelled	Voyage Speed Average	Voyage Speed Max
SEACAT VOLUNTEER	ARRIVAL	Anchorage	MONTROSE ANCH	2022-02-28 15:06 UTC	-	-	MONTROSE	29m	0.0	3 NM	6.2	6.8
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-02-28 14:37 UTC	2d 21h 14m	MONTROSE A...	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-02-25 17:23 UTC	-	-	MONTROSE	9h 27m	5.3	70 NM	19.8	24.4
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-02-25 07:56 UTC	19h 58m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-02-24 11:58 UTC	-	-	MONTROSE	42m	0.3	6 NM	13.1	23.1
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-02-24 11:16 UTC	2h 37m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-02-24 08:39 UTC	-	-	MONTROSE ANCH	11m	0.0	9 NM	14.1	22.2
SEACAT VOLUNTEER	DEPARTURE	Anchorage	MONTROSE ANCH	2022-02-24 08:28 UTC	31m	MONTROSE	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Anchorage	MONTROSE ANCH	2022-02-24 07:57 UTC	-	-	MONTROSE	17m	0.1	4 NM	14.4	16.4
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-02-24 07:40 UTC	4d 14h 34m	MONTROSE A...	-	-	-	-	-	-
SEACAT VOLUNTEER	ARRIVAL	Port	MONTROSE	2022-02-19 17:06 UTC	-	-	MONTROSE	5h 58m	2.6	61 NM	20.0	24.4
SEACAT VOLUNTEER	DEPARTURE	Port	MONTROSE	2022-02-19 11:08 UTC	5d 19h 31m	MONTROSE	-	-	-	-	-	-

Found 32 records Page 2 of 2 Rows per page: 20



CTV Seacat Weatherly

Vessel Name	Port Call Type	Port Type	Port At Call	Ata/atd	Time At Port	Destination Port	Voyage Origin Port	Voyage Time Underway	Voyage Idle Time	Voyage Distance Travelled	Voyage Speed Average	Voyage Speed Max
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-03-16 17:41 UTC	-	-	FRASERBURGH	10h 40m	3.7	141 NM	20.6	26.8
SEACAT WEATHER...	DEPARTURE	Port	FRASERBUR...	2022-03-16 07:01 UTC	1d 13h 32m	FRASERBUR...	-	-	-	-	-	-
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-03-14 17:29 UTC	-	-	FRASERBURGH	7h 47m	3.5	89 NM	20.9	25.7
SEACAT WEATHER...	DEPARTURE	Port	FRASERBUR...	2022-03-14 09:42 UTC	6d 16h 8m	FRASERBUR...	-	-	-	-	-	-
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-03-07 17:34 UTC	-	-	FRASERBURGH	10h 48m	5.5	115 NM	22.3	26.7
SEACAT WEATHER...	DEPARTURE	Port	FRASERBUR...	2022-03-07 06:46 UTC	13h 45m	FRASERBUR...	-	-	-	-	-	-
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-03-06 17:01 UTC	-	-	FRASERBURGH	9h 53m	4.6	108 NM	22.1	26.3
SEACAT WEATHER...	DEPARTURE	Port	FRASERBUR...	2022-03-06 07:08 UTC	12h 57m	FRASERBUR...	-	-	-	-	-	-
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-03-05 18:11 UTC	-	-	FRASERBURGH	11h 31m	3.8	142 NM	19.1	27.6
SEACAT WEATHER...	DEPARTURE	Port	FRASERBUR...	2022-03-05 06:40 UTC	12h 52m	FRASERBUR...	-	-	-	-	-	-
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-03-04 17:48 UTC	-	-	FRASERBURGH	11h 5m	4.2	126 NM	19.4	26.2
SEACAT WEATHER...	DEPARTURE	Port	FRASERBUR...	2022-03-04 06:43 UTC	1d 17h 17m	FRASERBUR...	-	-	-	-	-	-
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-03-02 13:26 UTC	-	-	FRASERBURGH	7h 16m	2.1	101 NM	20.5	25.8
SEACAT WEATHER...	DEPARTURE	Port	FRASERBUR...	2022-03-02 06:10 UTC	12h 10m	FRASERBUR...	-	-	-	-	-	-
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-03-01 18:00 UTC	-	-	FRASERBURGH	9h 52m	4.6	89 NM	17.9	24.6
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-03-01 08:09 UTC	-	-	FRASERBURGH	1m	0.0	1 NM	3.9	3.9
SEACAT WEATHER...	DEPARTURE	Port	FRASERBUR...	2022-03-01 08:08 UTC	9d 21h 43m	FRASERBUR...	-	-	-	-	-	-
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-02-19 10:25 UTC	-	-	BUCKIE	1h 37m	0.0	35 NM	21.2	26.0
SEACAT WEATHER...	DEPARTURE	Port	BUCKIE	2022-02-19 08:48 UTC	18h 39m	FRASERBUR...	-	-	-	-	-	-
SEACAT WEATHER...	ARRIVAL	Port	BUCKIE	2022-02-18 14:09 UTC	-	-	FRASERBURGH	7h 20m	1.9	100 NM	19.8	25.8

Get Started

Vessel Name	Port Call Type	Port Type	Port At Call	Ata/atd	Time At Port	Destination Port	Voyage Origin Port	Voyage Time Underway	Voyage Idle Time	Voyage Distance Travelled	Voyage Speed Average	Voyage Speed Max
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-02-18 06:51 UTC	-	-	FRASERBURGH	2m	0.0	1 NM	0.0	0.0
SEACAT WEATHER...	DEPARTURE	Port	FRASERBUR...	2022-02-18 06:49 UTC	1d 13h 5m	BUCKIE	-	-	-	-	-	-
SEACAT WEATHER...	ARRIVAL	Port	FRASERBUR...	2022-02-16 17:44 UTC	-	-	FRASERBURGH	10h 45m	5.0	103 NM	19.4	26.5
SEACAT WEATHER...	DEPARTURE	Port	FRASERBUR...	2022-02-16 06:59 UTC	2d 10h 17m	FRASERBUR...	-	-	-	-	-	-

Found 24 records

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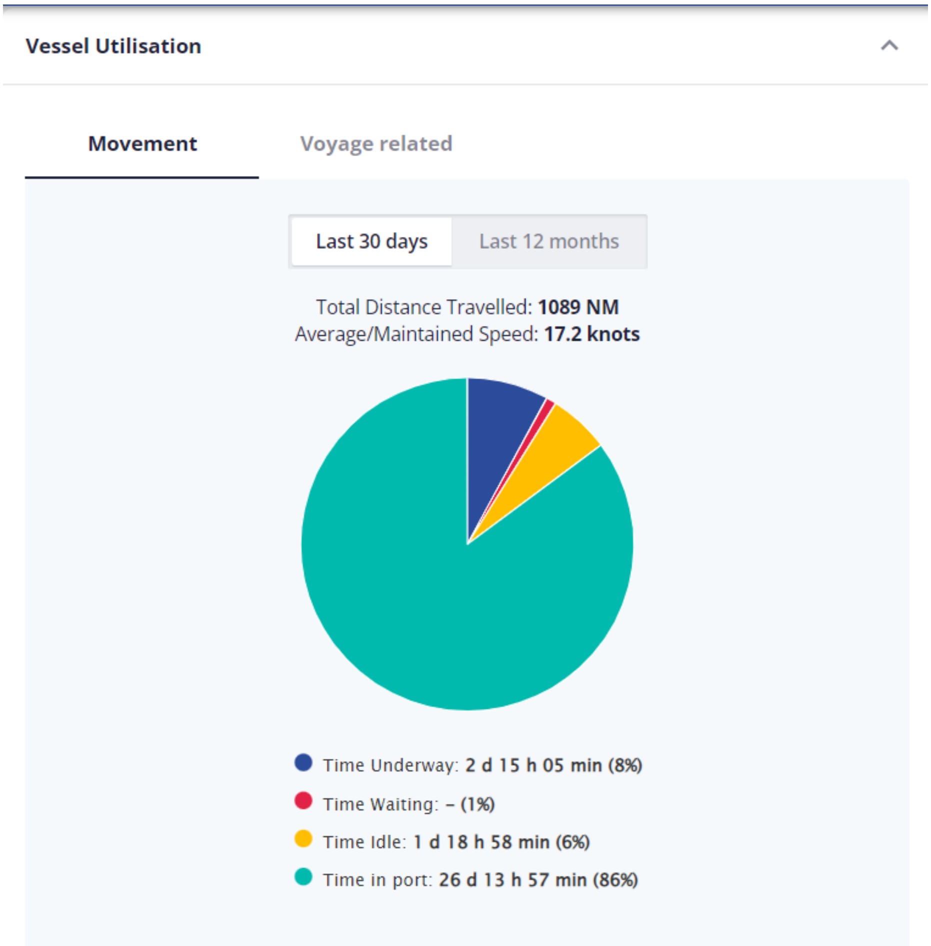
Vessel Utilisation
Movement
Voyage related
Last 30 days
Last 12 months
Total Distance Travelled: 1089 NM
Average/Maintained Speed: 17.2 knots
Time Underway: 2 d 15 h 05 min (8%)
Time Waiting: – (1%)
Time Idle: 1 d 18 h 58 min (6%)
Time in port: 26 d 13 h 57 min (86%)