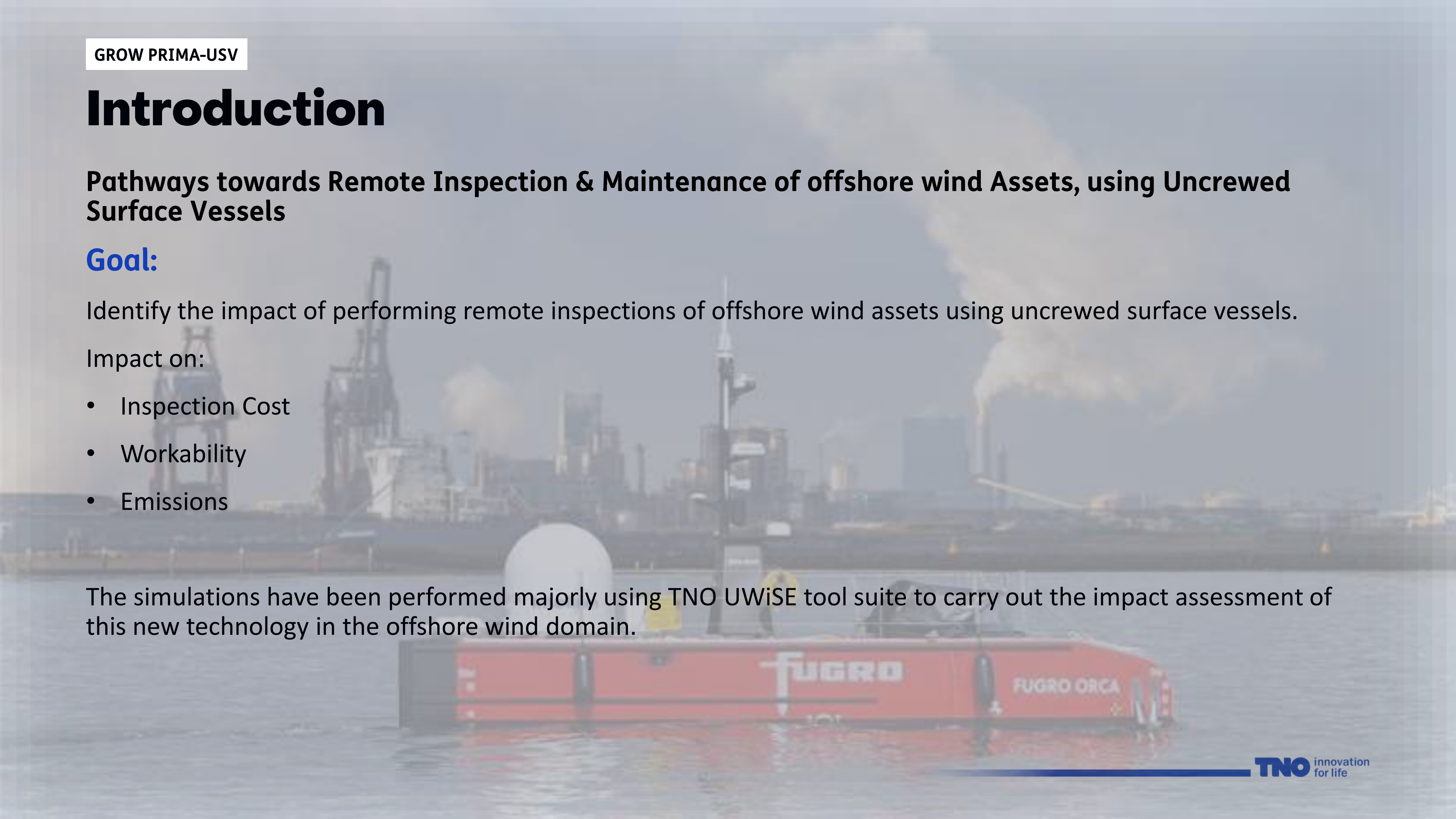
A use case-based evaluation for enhancing wind farm operations using USVs

Fugro | TNO | Vattenfall

GROW PRIMA-USV

Introduction



Pathways towards Remote Inspection & Maintenance of offshore wind Assets, using Uncrewed Surface Vessels

Goal:

Identify the impact of performing remote inspections of offshore wind assets using uncrewed surface vessels.

Impact on:

- Inspection Cost
- Workability
- Emissions

The simulations have been performed majorly using TNO UWiSE tool suite to carry out the impact assessment of this new technology in the offshore wind domain.

Introduction

Project Partners:

Fugro: Fugro has developed a suite of uncrewed surface vessels that has been successfully deployed in offshore sites for remote surveying and detailed inspection using the on-board eROV. Fugro's Blue Essence USV had conducted the world's first fully remote inspection of offshore wind farm assets in Aberdeen with Blue Volta (e-ROV) together with Vattenfall and ORE Catapult in 2023 (https://www.fugro.com/news/business-news/2023/fugro-blue-essence-completes-worlds-first-fully-remote-offshore-wind-rov-inspection)

TNO Wind Energy: TNO's role in the wind energy challenge comprises the development of new technologies, advising industrial partners, governments and investors. TNO aims to achieve a reduction in the costs of wind energy and an increase in the returns on investment by developing and demonstrating innovations that support the industry. TNO has developed a set of strategic simulation tools to evaluate offshore wind maintenance scenarios, namely UWiSE. In this project, TNO has been the project co-Ordinator, has performed analysis and reported the main findings.

(https://uwise.tno.nl/)

Vattenfall: Vattenfall is a wind farm operator with a strong portfolio of both onshore and offshore wind farms across several European countries. In the Netherlands, Vattenfall has onshore wind farms and offshore wind farms – Hollandse Kust Zuid (HKZ) I-IV with a total capacity of 1500 MW. Recently, they have won the tender for Ijmuiden Ver –Beta site with a capacity of 2GW. (https://group.vattenfall.com/nl/newsroom/persbericht/2024/vattenfall-en-copenhagen-infrastructure-partners-winnen-tender-windpark-op-zee-ijmuiden-ver)

Scenarios

To evaluate the effectiveness of an USV compared to the traditional way, 6 scenarios have been defined. A ROV inspection, an MBES inspection, and a combined ROV and MBES inspection for both USV and traditional vessel. All 6 scenarios were simulated on 2 different wind farms for the years 2004 to 2014.

- **Scenario 1**: Subsea inspection traditional ROV (Baseline)
- **Scenario 2**: Subsea inspection traditional MBES (Baseline)
- **Scenario 3**: Subsea inspection USV -ROV
- **Scenario 4**: Subsea inspection USV -MBES
- **Scenario 5**: Scenario 1 + Scenario 2 (Baseline)
- **Scenario 6**: Subsea inspection USV -MBES + ROV

Uncrewed Surface Vessel (USV)

Fugro

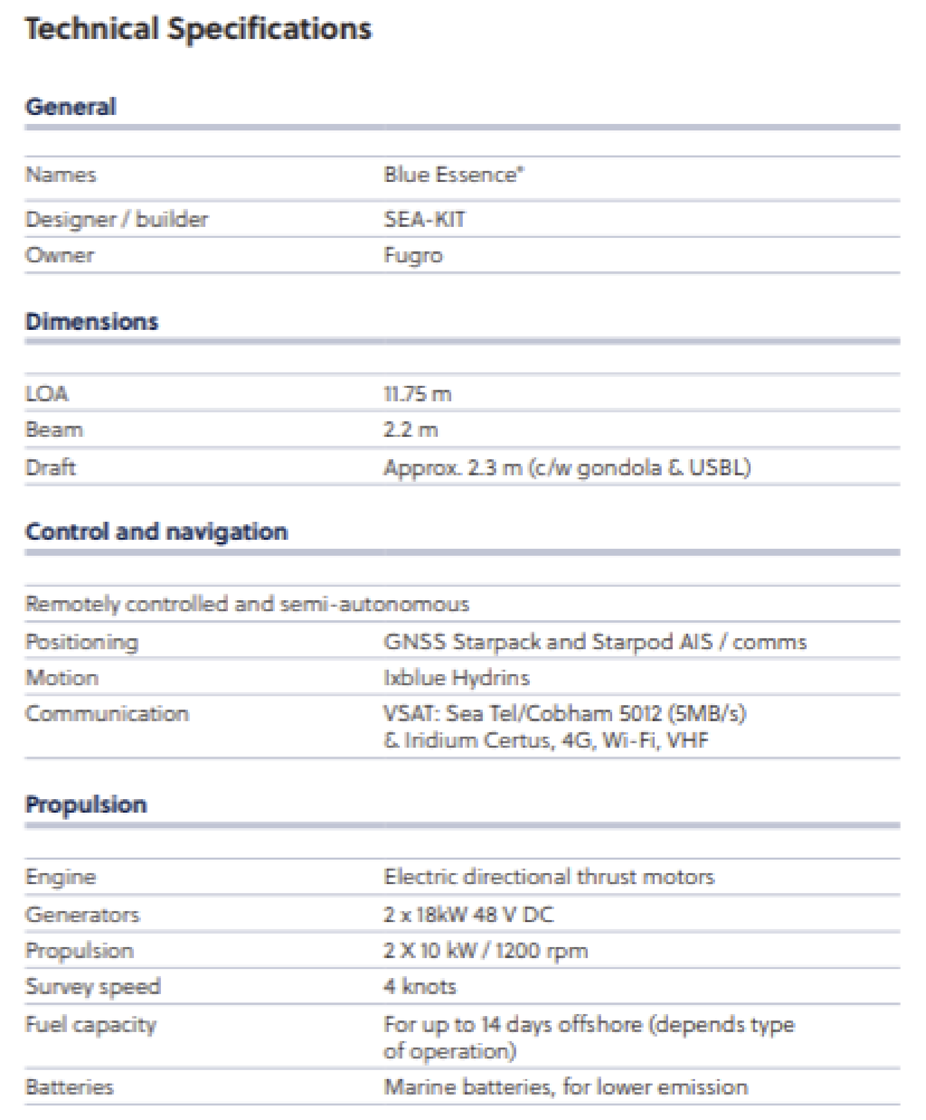
Blue Essence 12m USV

Fugro Blue Essence® is a next generation uncrewed surface vessel (USV) for safe and efficient inspection,construction support, hydrographic and geophysical surveys.

- Reduced HSSE exposure & risks
- Sustainable operations – reduced fuel consumption up to 95%
- Optimized and efficient data acquisition and analysis
- Real-time insights to support informed decision making

GROW PRIMA-USV

Blue Essence Features



Technical Specifications

General

Names	Blue Essence®
Designer / builder	SEA-KIT
Owner	Fugro

Dimensions

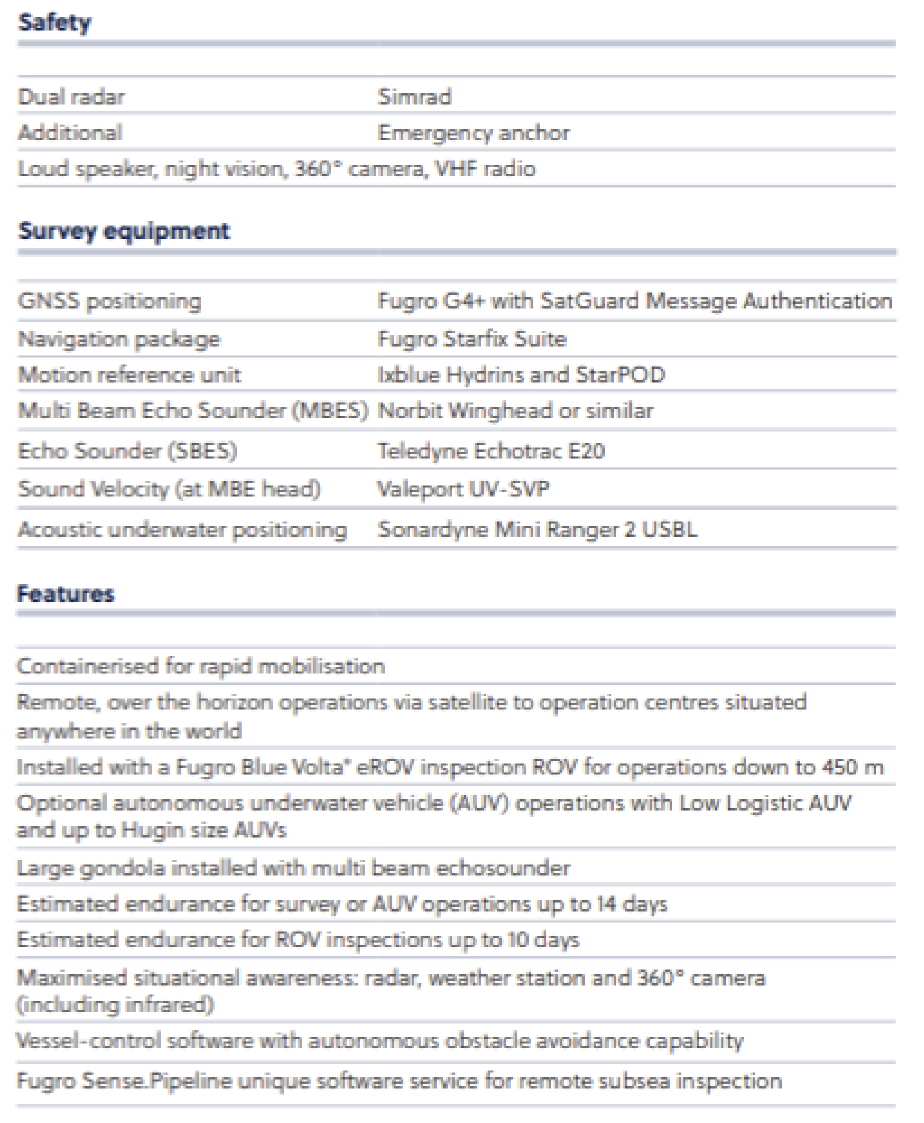
LOA	11.75 m
Beam	2.2 m
Draft	Approx. 2.3 m (c/w gondola & USBL)

Control and navigation

Remotely controlled and semi-autonomous	
Positioning	GNSS Starpack and Starpod AIS / comms
Motion	Ixblue Hydrins
Communication	VSAT: Sea Tel/Cobham 5012 (5MB/s) & Iridium Certus, 4G, Wi-Fi, VHF

Propulsion

Engine	Electric directional thrust motors
Generators	2 x 18kW 48 V DC
Propulsion	2 X 10 kW / 1200 rpm
Survey speed	4 knots
Fuel capacity	For up to 14 days offshore (depends type of operation)
Batteries	Marine batteries, for lower emission



Safety

Dual radar	Simrad
Additional	Emergency anchor
Loud speaker, night vision, 360° camera, VHF radio	

Survey equipment

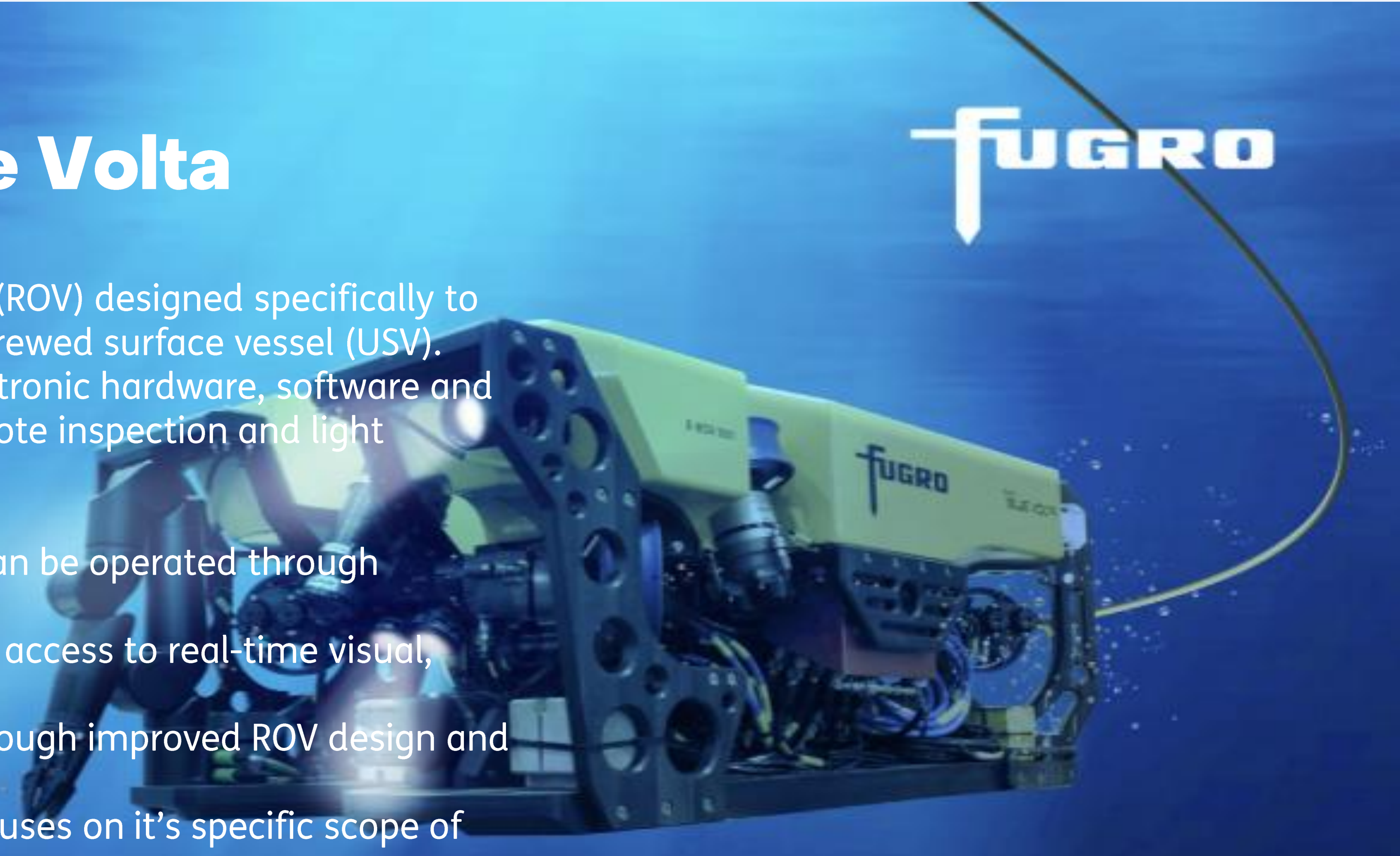
GNSS positioning	Fugro G4+ with SatGuard Message Authentication
Navigation package	Fugro Starfix Suite
Motion reference unit	Ixblue Hydrins and StarPOD
Multi Beam Echo Sounder (MBES)	Norbit Winghead or similar
Echo Sounder (SBES)	Teledyne Echotrac E20
Sound Velocity (at MBE head)	Valeport UV-SVP
Acoustic underwater positioning	Sonardyne Mini Ranger 2 USBL

Features

- Containerised for rapid mobilisation
- Remote, over the horizon operations via satellite to operation centres situated anywhere in the world
- Installed with a Fugro Blue Volta® eROV inspection ROV for operations down to 450 m
- Optional autonomous underwater vehicle (AUV) operations with Low Logistic AUV and up to Hugin size AUVs
- Large gondola installed with multi beam echosounder
- Estimated endurance for survey or AUV operations up to 14 days
- Estimated endurance for ROV inspections up to 10 days
- Maximised situational awareness: radar, weather station and 360° camera (including infrared)
- Vessel-control software with autonomous obstacle avoidance capability
- Fugro Sense.Pipeline unique software service for remote subsea inspection

GROW PRIMA-USV

Fugro e-ROV: Blue Volta

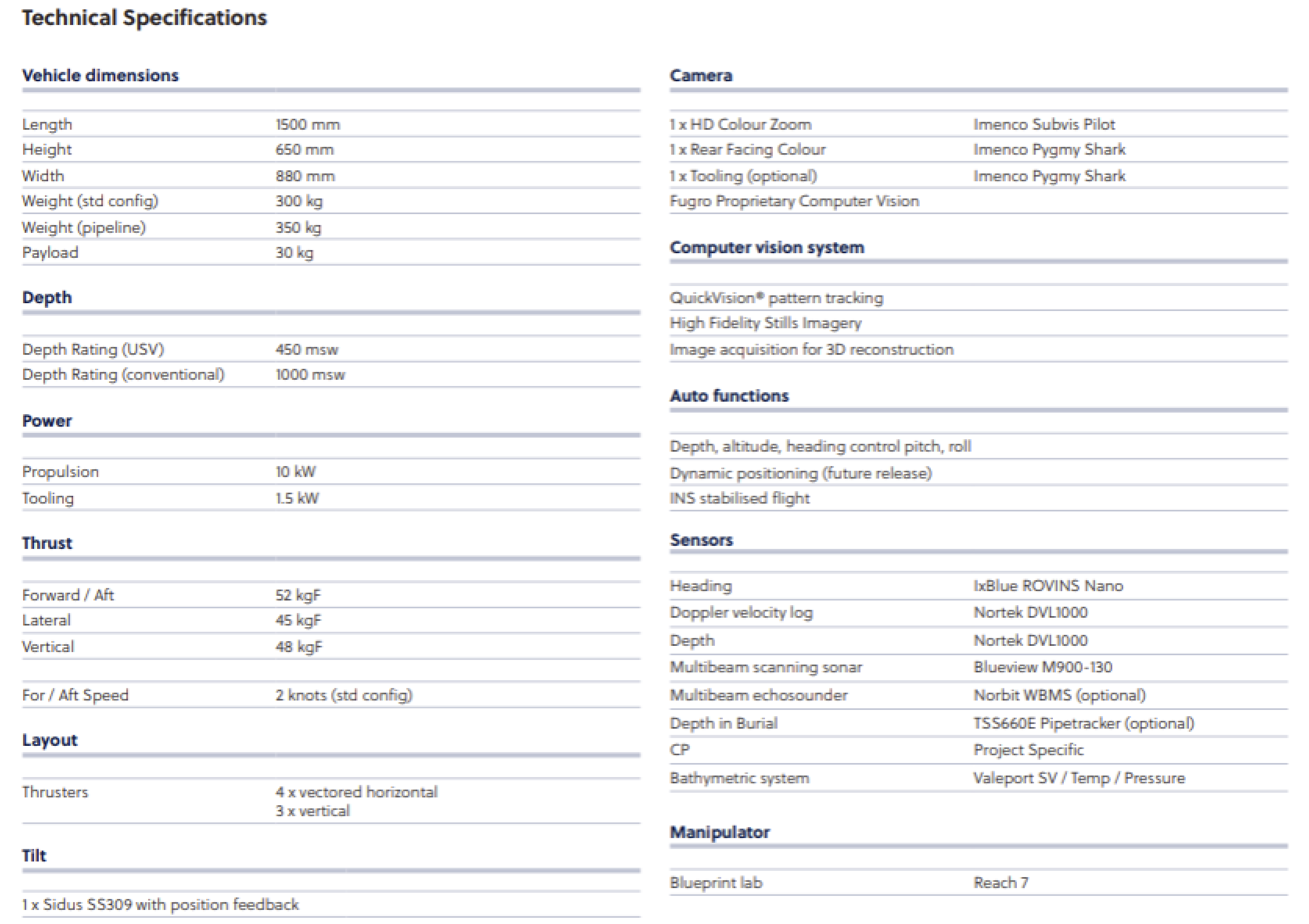


An advanced remotely operated vehicle (ROV) designed specifically to be integrated and deployed from an uncrewed surface vessel (USV). Fugro Blue Volta® applies the latest electronic hardware, software and flight control to carry out a range of remote inspection and light intervention tasks.

- Reduced HSSE exposure as the ROV can be operated through onshore remote operations centres
- Accelerated decision making through access to real-time visual, navigation and inspection data
- Access to higher quality Geo-data through improved ROV design and flight stability
- Increased productivity as the ROV focuses on it’s specific scope of work

GROW PRIMA-USV

Blue Volta Features



Technical Specifications

Vehicle dimensions

Length	1500 mm
Height	650 mm
Width	880 mm
Weight (std config)	300 kg
Weight (pipeline)	350 kg
Payload	30 kg

Depth

Depth Rating (USV)	450 msw
Depth Rating (conventional)	1000 msw

Power

Propulsion	10 kW
Tooling	1.5 kW

Thrust

Forward / Aft	52 kgF
Lateral	45 kgF
Vertical	48 kgF

For / Aft Speed	2 knots (std config)

Layout

Thrusters	4 x vectored horizontal 3 x vertical

Tilt

1 x Sidus SS309 with position feedback

Camera

1 x HD Colour Zoom	Imenco Subvis Pilot
1 x Rear Facing Colour	Imenco Pygmy Shark
1 x Tooling (optional)	Imenco Pygmy Shark
Fugro Proprietary Computer Vision	

Computer vision system

QuickVision® pattern tracking

High Fidelity Stills Imagery

Image acquisition for 3D reconstruction

Auto functions

Depth, altitude, heading control pitch, roll

Dynamic positioning (future release)

INS stabilised flight

Sensors

Heading	IxBlue ROVINS Nano
Doppler velocity log	Nortek DVL1000
Depth	Nortek DVL1000
Multibeam scanning sonar	Blueview M900-130
Multibeam echosounder	Norbit WBMS (optional)
Depth in Burial	TSS660E Pipetracker (optional)
CP	Project Specific
Bathymetric system	Valeport SV / Temp / Pressure

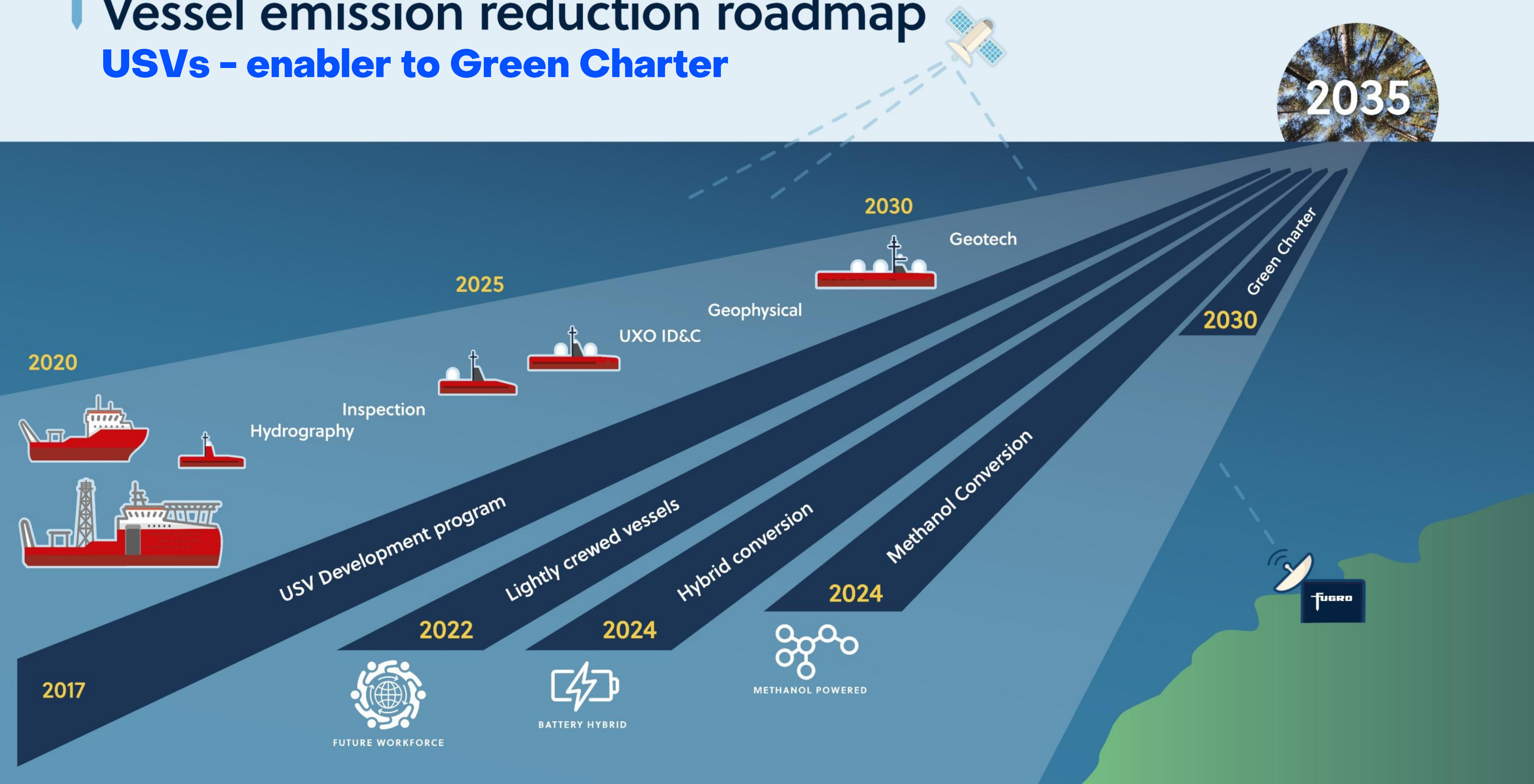
Manipulator

Blueprint lab	Reach 7

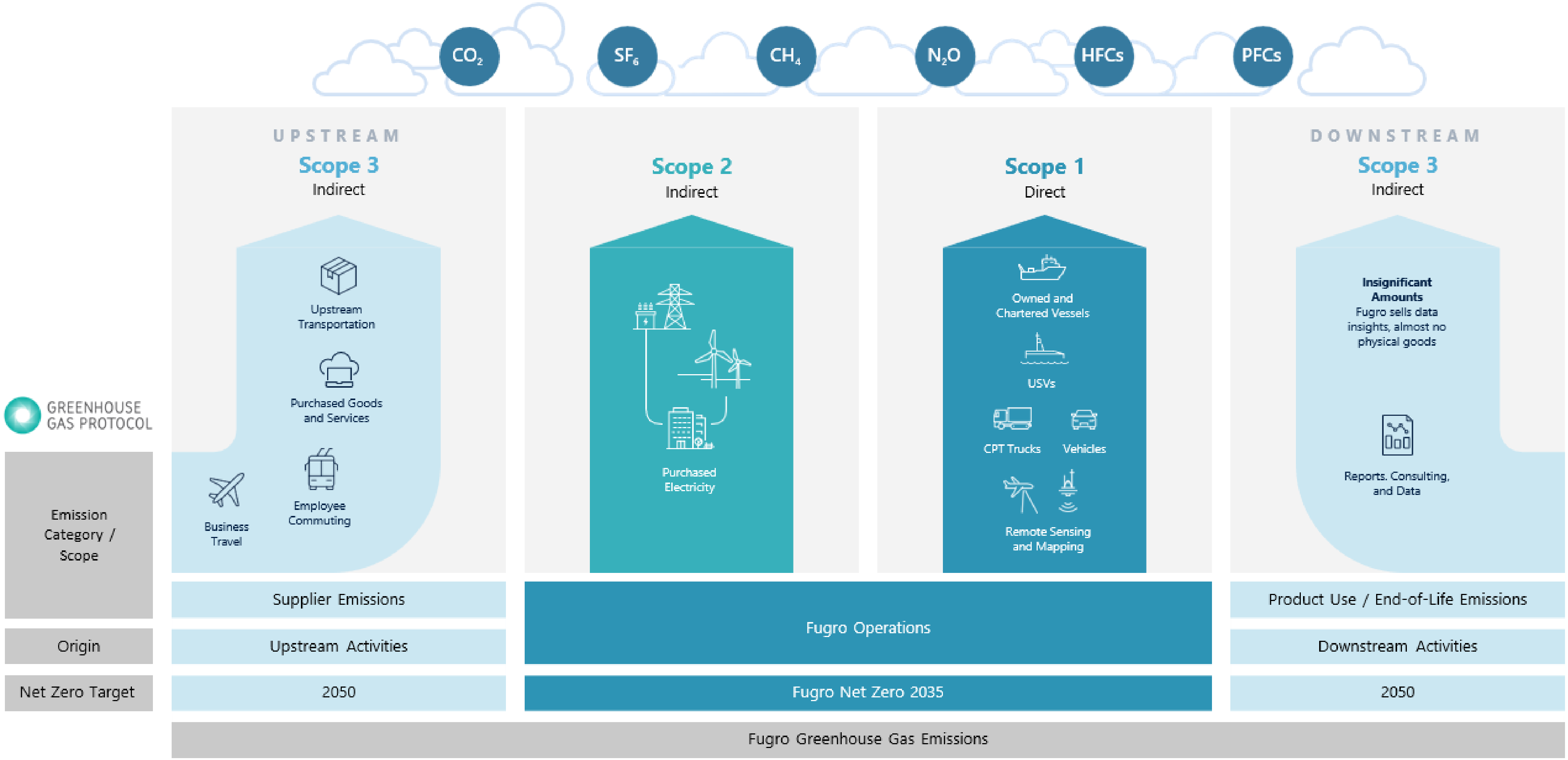
Fugro USV Emissions Savings

Vessel emission reduction roadmap

USVs – enabler to Green Charter



Fugro's Commitment in Carbon reductions



CO_2 SF_6 CH_4 N_2O HFCs PFCs

GREENHOUSE GAS PROTOCOL

UPSTREAM
Scope 3
Indirect

Upstream Transportation

Purchased Goods and Services

Business Travel

Employee Commuting

Scope 2
Indirect

Purchased Electricity

Scope 1
Direct

Owned and Chartered Vessels

USVs

CPT Trucks

Vehicles

Remote Sensing and Mapping

DOWNSTREAM
Scope 3
Indirect

Insignificant Amounts
Fugro sells data insights, almost no physical goods

Reports, Consulting, and Data

Emission Category / Scope	Supplier Emissions	Fugro Operations	Product Use / End-of-Life Emissions
Origin	Upstream Activities		Downstream Activities
Net Zero Target	2050	Fugro Net Zero 2035	2050
	Fugro Greenhouse Gas Emissions		

Emissions Reduction in Project Phases

Mobilisation Phase

Lower emissions due to:

Reduced mob. operations- flights, hotels, etc.

No fuel consumption while in port

Operations Phase

90%-95% less fuel consumed:

Operational agility

USVs are Hybrid– Diesel + Batteries + eROV

Demobilisation

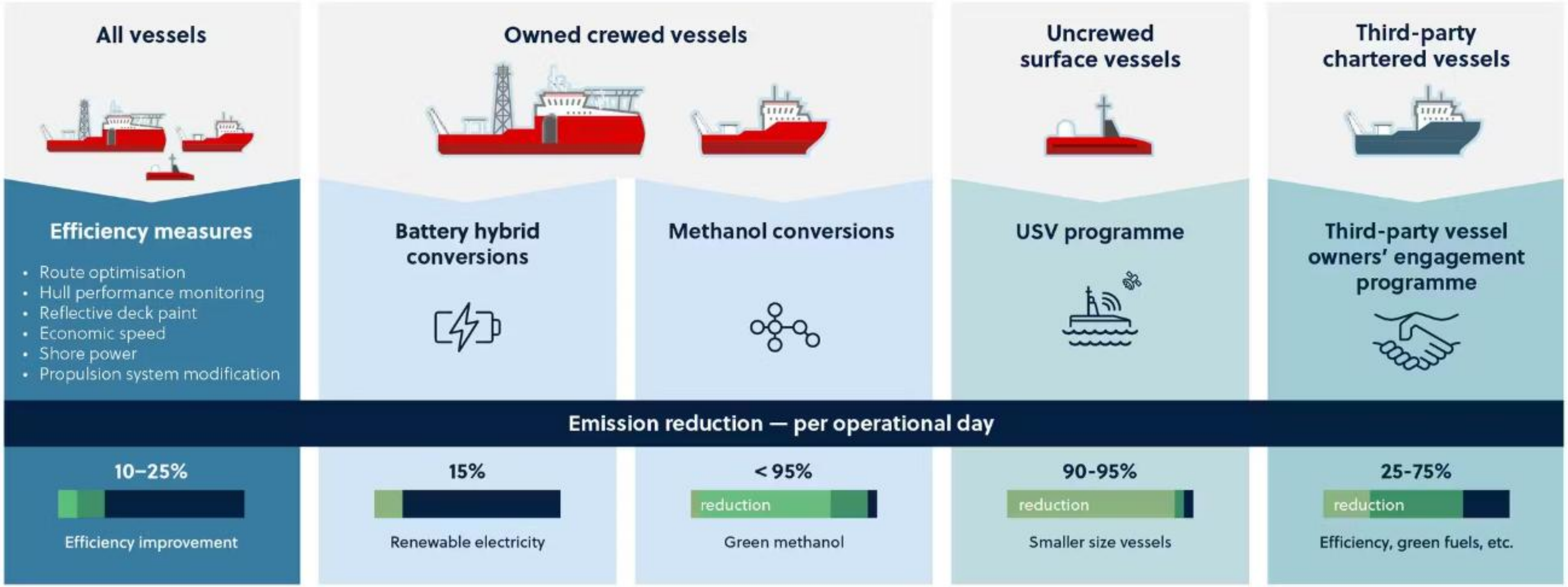
Lower emissions due to:

Lower Maintenance requirement

Reduced demob. operations- flights, hotels, etc.

No fuel consumption while in port

Vessels Carbon emission reduction Programme



All vessels

Efficiency measures

- Route optimisation
- Hull performance monitoring
- Reflective deck paint
- Economic speed
- Shore power
- Propulsion system modification

Owned crewed vessels

Battery hybrid conversions

Methanol conversions

Uncrewed surface vessels

USV programme

Third-party chartered vessels

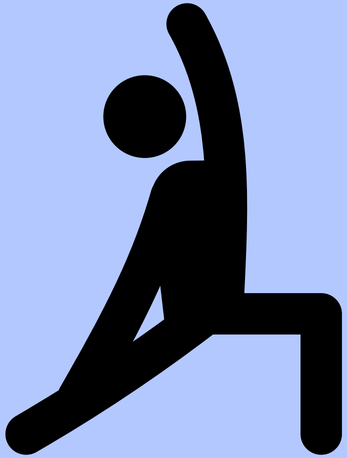
Third-party vessel owners' engagement programme

Emission reduction — per operational day

Efficiency measures	Battery hybrid conversions	Methanol conversions	USV programme	Third-party vessel owners' engagement programme
10–25%	15%	< 95% reduction	90-95% reduction	25-75% reduction
Efficiency improvement	Renewable electricity	Green methanol	Smaller size vessels	Efficiency, green fuels, etc.

• Social Benefits of USV

Social Benefits of Remote and Hybrid Working



- **Improved personnel well-being**
- **Improved mental health**
- **Enhanced work-life balance**
- **Greater work flexibility**
- **Increased job satisfaction**
- **Reduced physical strain**

- **Improved Safety**
- **Reduced exposure to offshore hazardous environment**
- **Lower accident risk**
- **Enhanced emergency response**
- **Improved ergonomics**
- **Real-time monitoring, yet maintaining safety protocols**

- **Inclusive environment**
- **Diverse recruitment of individuals with varied abilities, ages, and mobility, offering career opportunities beyond traditional offshore roles.**

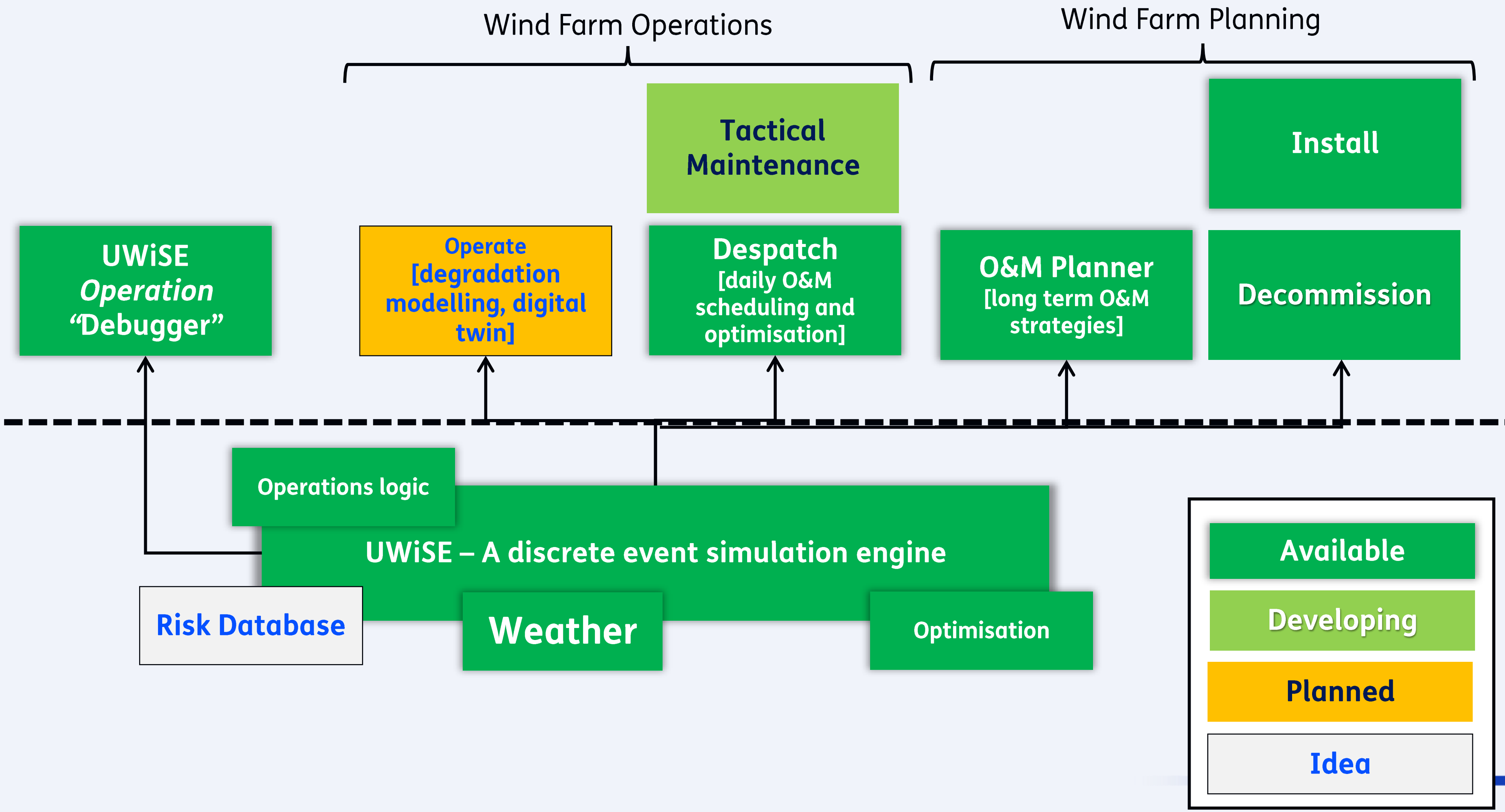
Reference: UK Gov (LINK)

UWiSE

TNO

Unified Wind farm Simulation Environment (UWiSE)

The software landscape:



Wind Farm Operations

Wind Farm Planning

Tactical Maintenance

Install

UWiSE *Operation* “Debugger”

Operate [degradation modelling, digital twin]

Despatch [daily O&M scheduling and optimisation]

O&M Planner [long term O&M strategies]

Decommission

Operations logic

UWiSE – A discrete event simulation engine

Risk Database

Weather

Optimisation

🟩 Available

🟩 Developing

🟨 Planned

⬜ Idea

Front-end

Simple, easy to use, professionally programmed

Back-end

One standard simulation engine.
Additional parts needed for managing multiple simulations and optimisation.

Why is decision support needed in offshore wind I,O&M,D?

High impact on the Levelized Cost Of Electricity (LCOE):

- **Installation** → 8-12% of LCOE
- **Operations & Maintenance (O&M)** → 28-35% of LCOE
- **Decommissioning** → ~60-70% of installation costs*

Decision-making uncertainty due to:

- Weather
- Cost of downtime
- Number of stakeholders
- Data availability
- Empiricism

What can UWiSE O&M Planner do?

Help **design and optimize the O&M strategy for an offshore wind (& solar-PV) farm by evaluating scenarios** in terms of KPIs like:

- Wind farm availability
- O&M cost breakdown
- Others, e.g. resource utilization, delays, energy & revenue loss, etc...

The following strategic dilemmas may be solved with O&M Planner:

- Optimal number of vessels & technicians
- Optimal scheduled maintenance strategy
- Corrective vs condition-based maintenance strategy
- Harbour & equipment selection
- Spare part inventory policy
- and more...

O&M Planner’s key aspects

1. Map-based User Interface

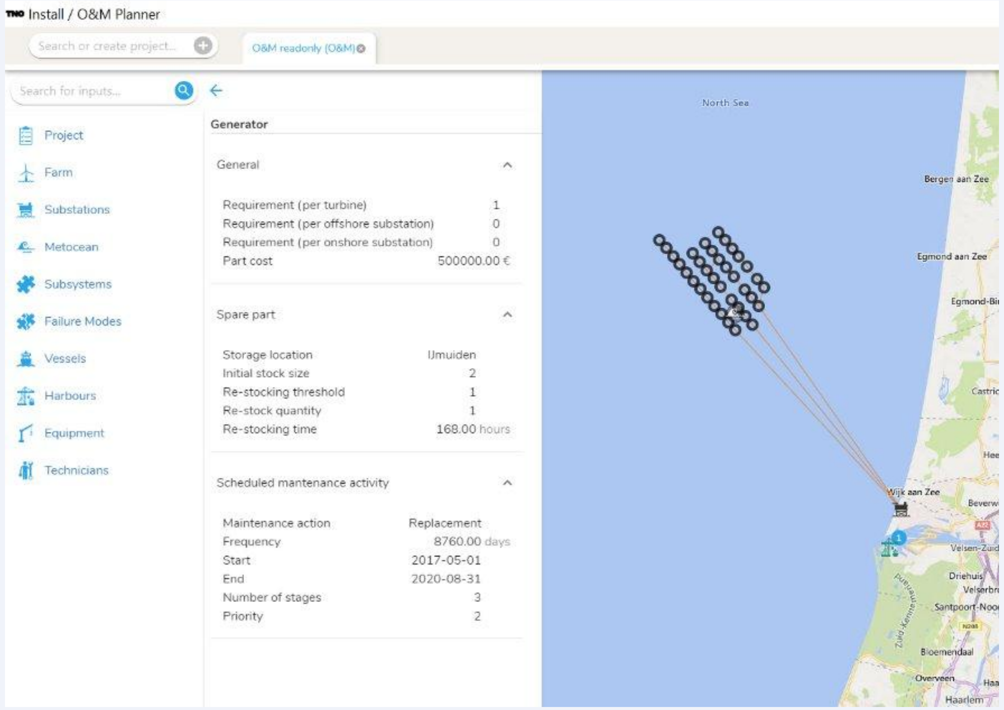
- Review project information from the map

2. Powerful simulation logic

- Failure generation based on Weibull distributions
- Scheduled/corrective/condition-based maintenance
- Detailed process diagram templates
- Access restrictions and weather windows

3. Model flexibility

- The user can choose the desired level of detail
- Can be used in different phases of an OWF lifecycle (from development until late maturity)



Generator

General

Requirement (per turbine)	1
Requirement (per offshore substation)	0
Requirement (per onshore substation)	0
Part cost	500000.00 €

Spare part

Storage location	IJmuiden
Initial stock size	2
Re-stocking threshold	1
Re-stock quantity	1
Re-stocking time	168.00 hours

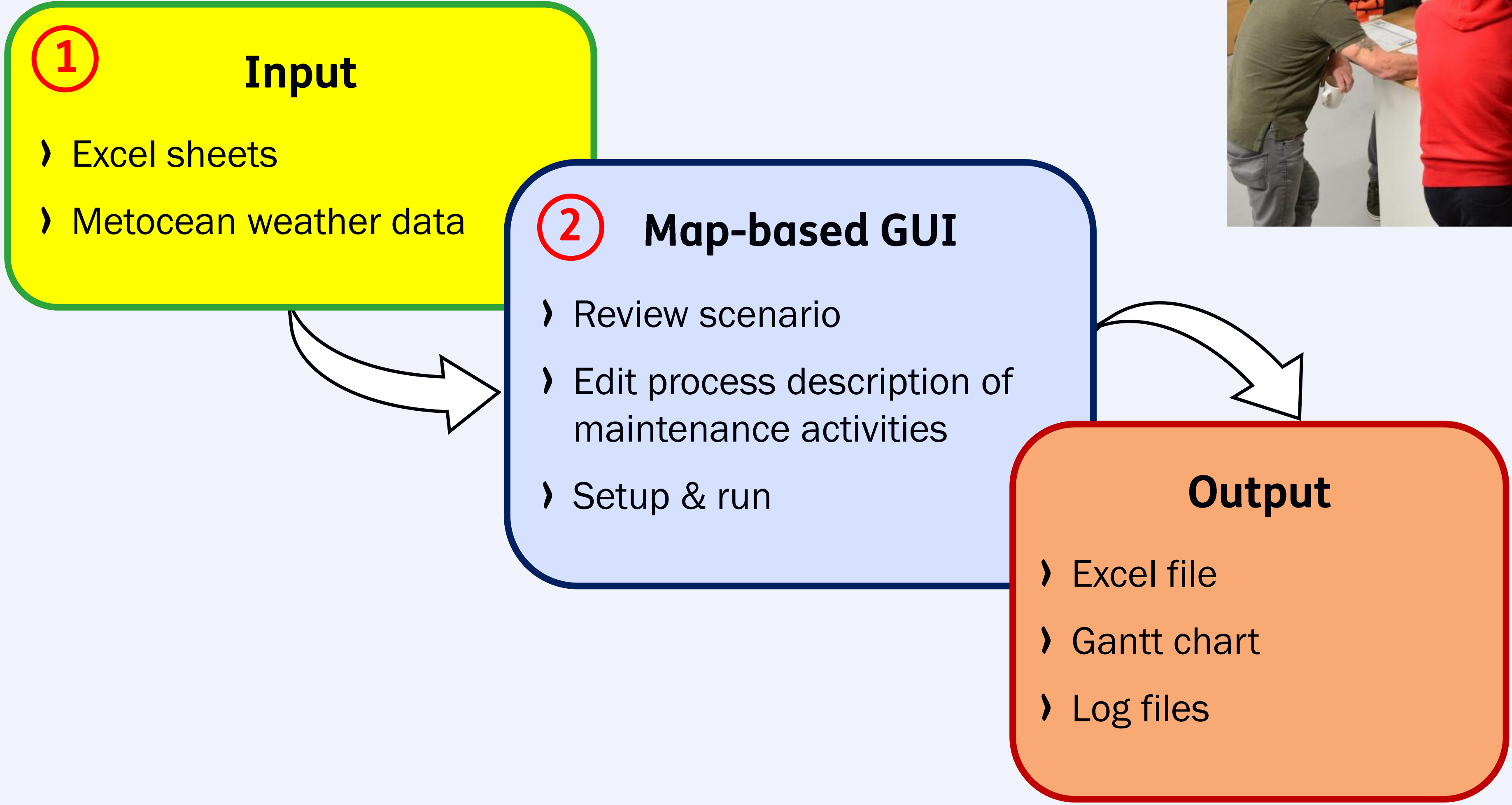
Scheduled mantenance activity

Maintenance action	Replacement
Frequency	8760.00 days
Start	2017-05-01
End	2020-08-31
Number of stages	3
Priority	2

4. Output detail

- Excel-based cost breakdown and KPIs including statistics (μ, σ, P50, P95)
- Detailed Gantt chart
- Complete log files

Modelling process overview



① **Input**

- Excel sheets
- Metocean weather data

② **Map-based GUI**

- Review scenario
- Edit process description of maintenance activities
- Setup & run

Output

- Excel file
- Gantt chart
- Log files

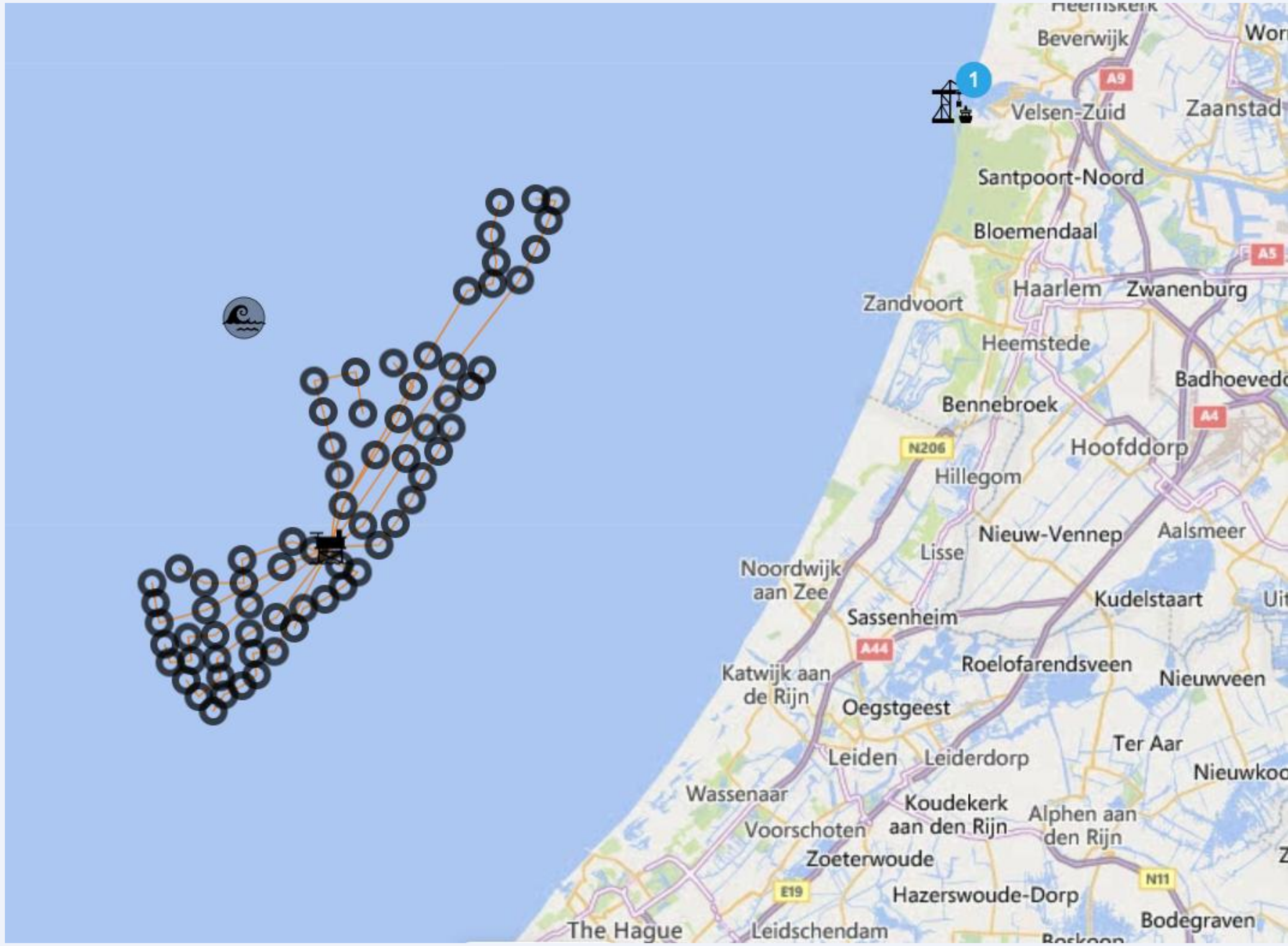
INPUT

TNO

Wind farm specification

Hollandse Kust Zuid (HKZ)

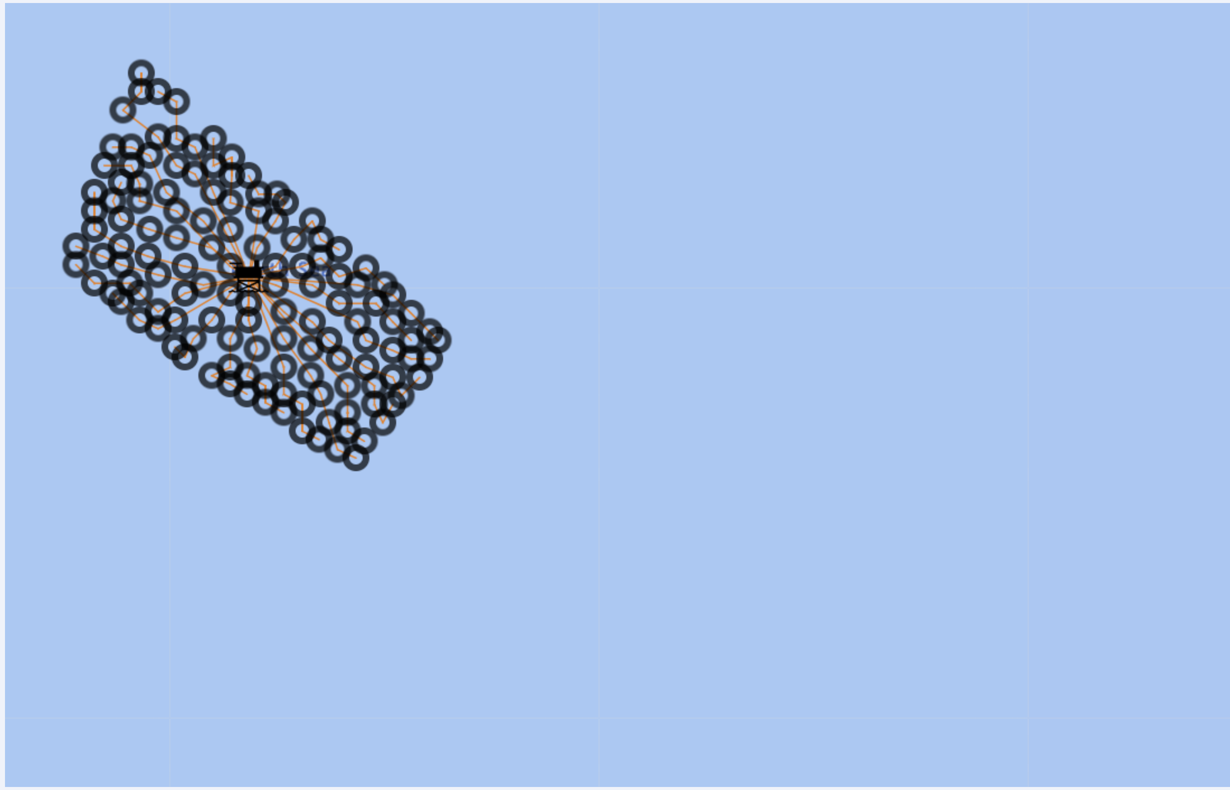
Wind farm specifics	
Wind farm	HKZ III-IV
Capacity	760 MW
Turbine	10 MW (76 WT's)
Distance port → Offshore substation	40 km
Port location	Ijmuiden
Substation	Bravo



Wind farm specification

Zeevonk / IjmuidenVer

Wind farm specifics	
Wind farm	Zeevonk
Capacity	2000 MW
Turbine	15 MW (134 WT’s)
Distance port → Offshore substation	83 km
Port location	Ijmuiden
Substation	OSS Beta



Metocean data

- Data retrieved from metocean-on-demand.com
- Hourly time-series data

- Each scenario is executed 10 times, and each execution has different weather starting year

Metocean			
DateTime	Significant Wave Height (m)	Current Speed (m/s)	Wind speed at 10m (m/s)
2023-06-01 00:00:00	1,21	0,46	7,88
2023-06-01 01:00:00	1,21	0,51	7,84
2023-06-01 02:00:00	1,19	0,42	7,59
2023-06-01 03:00:00	1,18	0,25	7,75
2023-06-01 04:00:00	1,13	0,22	6,48
2023-06-01 05:00:00	1,1	0,43	6,66

Example of time-series metocean data

Vessel Specification

Traditional ROV Inspection Vessel

Vessel specification	
Type	Traditional survey vessel
Use case	Subsea ROV inspection
Transit speed	*Process dependent (see process overview)*
Weather limits	*Process dependent (see process overview)*
Day rate*	35000 €
Mobilization / demobilization costs	25000 €
Fuel type / Consumption	MDO 1500 l/day

** Day rate includes fuel, technician and equipment cost*

Vessel Specification

Traditional MBES Vessel

Vessel specification	
Type	Traditional survey vessel
Use case	MBES survey
Transit speed	*Process dependent (see process overview)*
Weather limits	*Process dependent (see process overview)*
Day rate*	25000 €
Mobilization / demobilization costs	65000 €
Fuel type / Consumption	MDO 1500 l/day

** Day rate includes fuel, technician and equipment cost*

Vessel Specification

Unmanned surface vessel (Blue Essence)

Vessel specification		
Type	Blue Essence ROV	Blue Essence geophysics
Use case	Subsea ROV inspection	MBES survey
Transit speed	*Process dependent (see process overview)*	*Process dependent (see process overview)*
Weather limits	*Process dependent (see process overview)*	*Process dependent (see process overview)*
Day rate*	35000 €	28000 €
Mobilization / demobilization costs	130000 €	130000 €
Fuel type / Consumption	MDO 170 l/day	MDO 170 l/day

** Day rate includes fuel, technician and equipment cost*

PROCESS

TNO

Subsea ROV inspection

The following main inspection activities have been considered for subsea ROV inspections using both traditional and Uncrewed surface vessels.

Inspection activity	Inspection description
Inspection of rock bags, monopile, and cable protection structure	ROV inspects structures for defects such as damage, cracking, and corrosion using a camera. The inspection encompasses jackets, monopiles, rock bags, bolted connections, and other critical points.
Cathodic protection	CP data is acquired where required, displaying a continuous proximity measurement on the video overlay, and contact CP readings are taken where access is possible. An effective strategy combines CP proximity readings and stabbing with the Jacket GVI. The stand-off distance for the proximity reading is between 0.5m and 1m to ensure visibility of the structure in expected turbid waters.

The table below shows the detailed method statement for subsea ROV inspections that has been used for the simulations in this project. The method statement has been derived together with Fugro and Vattenfall.

Step No.	Description	Traditional vessel		Uncrewed surface vessel	
		Duration (hours)	**Operational limits**	**Duration (hours)**	**Operational limits**
1	**Transit to first WTG**	*Distance dependent (10 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m	*Distance dependent (5 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m
2	**Positioning at WTG**	0.5 h	$U_{wind@10m}$= 14 m/s H_s= 1.2 m	0.25 h	$U_{wind@10m}$= 14 m/s H_s= 1.75 m
3	**Deployment of ROV**	0.5 h	$U_{wind@10m}$= 14 m/s H_s= 1.2 m $U_{current}$= 0.6 m/s	0.25 h	$U_{wind@10m}$= 14 m/s H_s= 1.75 m $U_{current}$= 0.6 m/s
4	**ROV inspections**	3 h	$U_{wind@10m}$= 14 m/s H_s= 1.2 m $U_{current}$= 0.6 m/s	3 h	$U_{wind@10m}$= 14 m/s H_s= 1.75 m $U_{current}$= 0.6 m/s
5	**Lift ROV off water**	0.5 h	$U_{wind@10m}$= 14 m/s H_s= 1.2 m $U_{current}$= 0.6 m/s	0.1667 h	$U_{wind@10m}$= 14 m/s H_s= 1.75 m $U_{current}$= 0.6 m/s
6	**Transit to next WTG**	*Distance dependent (5 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m	*Distance dependent (5 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m
Steps 2 to 6 are repeated for all WTGs in the farm					
7	**Transit back to port**	*Distance dependent (10 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m	*Distance dependent (5 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m
8	**Port activities after port call**	12 h		12 h	

MBES Survey

The following main inspection activities have been considered for MBES survey using both traditional and Uncrewed surface vessels.

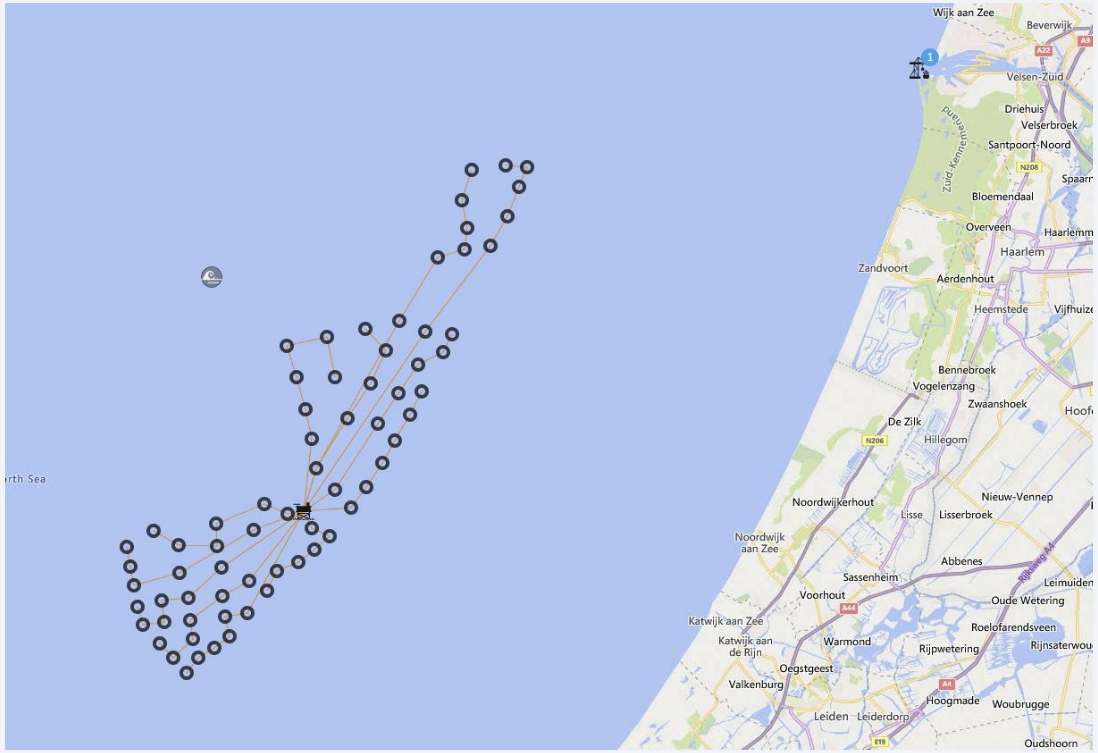
Inspection activity	Inspection description
Jack up area (400 m x 400 m)	The MBES system on the USV is single head (most survey vessels have dual head) and the SVP data is acquired using the eROV. Traditional survey vessels with dual heads could do the survey in 5 lines. Using a hull-mounted system, the USV can survey the area in approximately 6 survey lines (also based on the developer requirements and in-field conditions)
Survey cable route	Generally, the route can be surveyed in a single pass using a USV equipped with a hull-mounted single-head MBES with a survey speed of 4 knots. Depending on the resolution required. The eROV is also able to perform a MBES survey cable route in one pass.

The table below shows the detailed method statement for subsea ROV inspections that has been used for the simulations in this project. The method statement has been derived together with Fugro and Vattenfall.

Step No.	Description	Traditional vessel		Unmanned surface vessel	
		Duration (hours)	**Operational limits**	**Duration (hours)**	**Operational limits**
1	**Transit to first WTG**	*Distance dependent (10 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m	*Distance dependent (5 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m
2	**Jack up area survey**	3 h	$U_{wind@10m}$= 14 m/s H_s= 1.5 m	2.5 h	$U_{wind@10m}$= 14 m/s H_s= 1.25 m
3	**Cable survey**	*Distance dependent (5 knots)*	$U_{wind@10m}$= 14 m/s H_s= 1.5 m	*Distance dependent (3.5 knots)*	$U_{wind@10m}$= 14 m/s H_s= 1.25 m
Steps 1 to 3 are repeated for all WTGs in the farm					
4	**Transit back to port**	*Distance dependent (10 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m	*Distance dependent (5 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m
5	**Port activities after port call**	12 h		12 h	

Vessel routing

The assumed routes differ for ROV and MBES campaigns. However, the routes are assumed to be the same for each vessel type.



ROV

- The vessels only need to go to each **turbine location** for the inspection of the rock bags, monopile, cable protection structure and cathodic protection.
- The shortest path to go past each turbine is a sensible route.

MBES

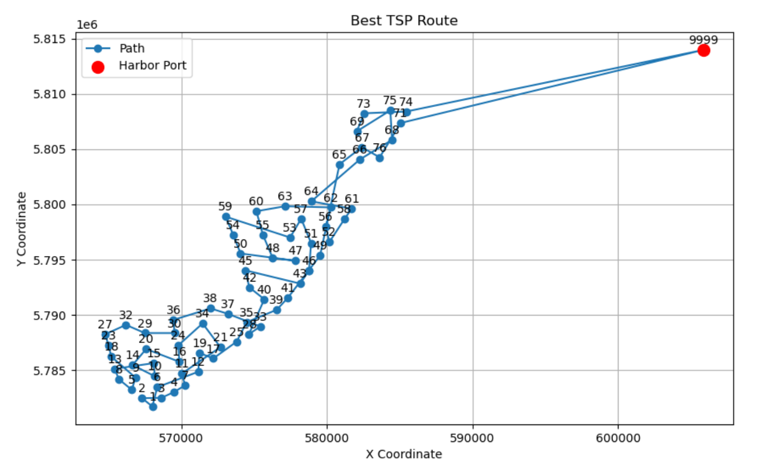
- Has to go to each **turbine location** for the 400x400 jack-up survey and additionally has to **transit over each cable** for the cable inspection
- Shortest path is not sufficient anymore, because it is not guaranteed to pass over all cables.

ROV shortest route

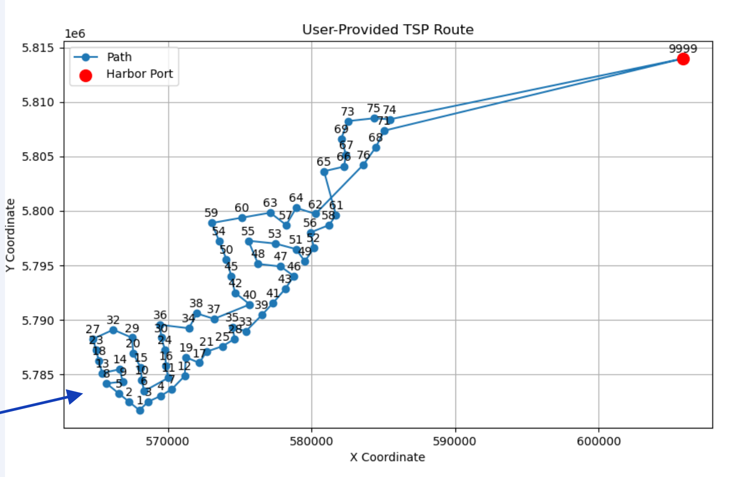
There are multiple ways to find the shortest route using algorithms. Finding the exact shortest path is notoriously difficult and computationally expensive if you have a lot of turbine locations. Therefore, we use an algorithm to get a good approximation of the shortest path instead.

- This problem is similar to the **traveling salesman problem**, a well-known shortest-path problem.
- The problem is defined as finding the shortest path while passing through all nodes. In our case, the nodes are wind turbine locations.
- We can get a good estimation very quickly with a **genetic algorithm**.

- The two figures depict the best solution after 5 seconds of progress (top figure) and the best solution found after a couple of runs of 100+ seconds each. This is the path we use.
- A similar method is used for Ijmuiden Ver.



Solution after running for ~5 seconds for HKZ



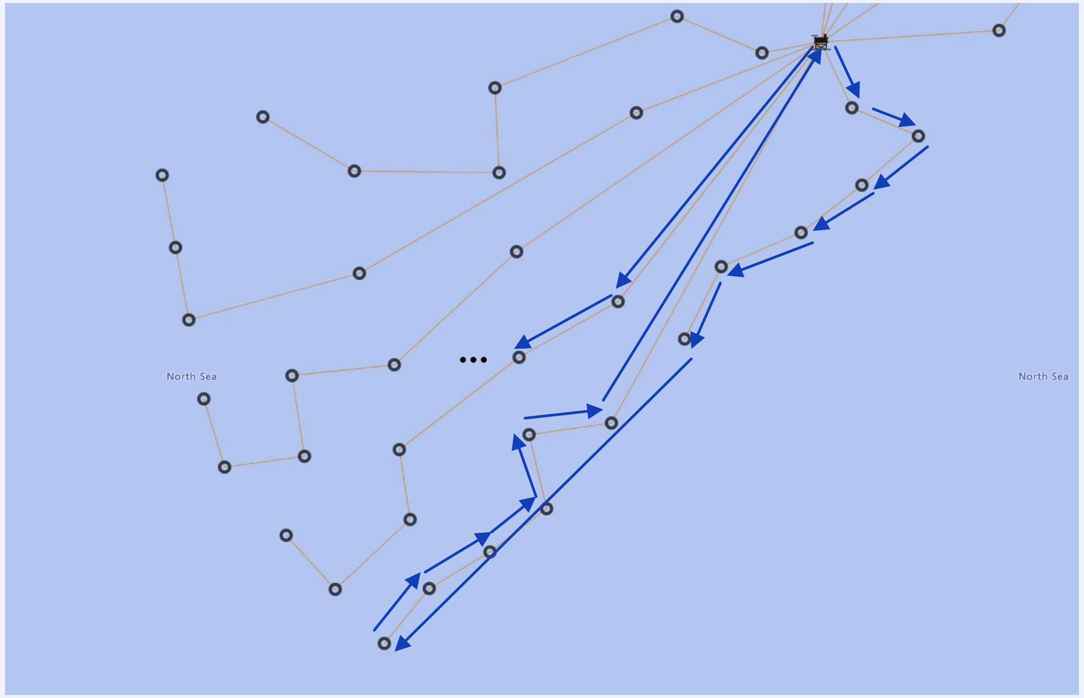
The best solution found of multiple runs for 100+ seconds for HKZ

Our path!

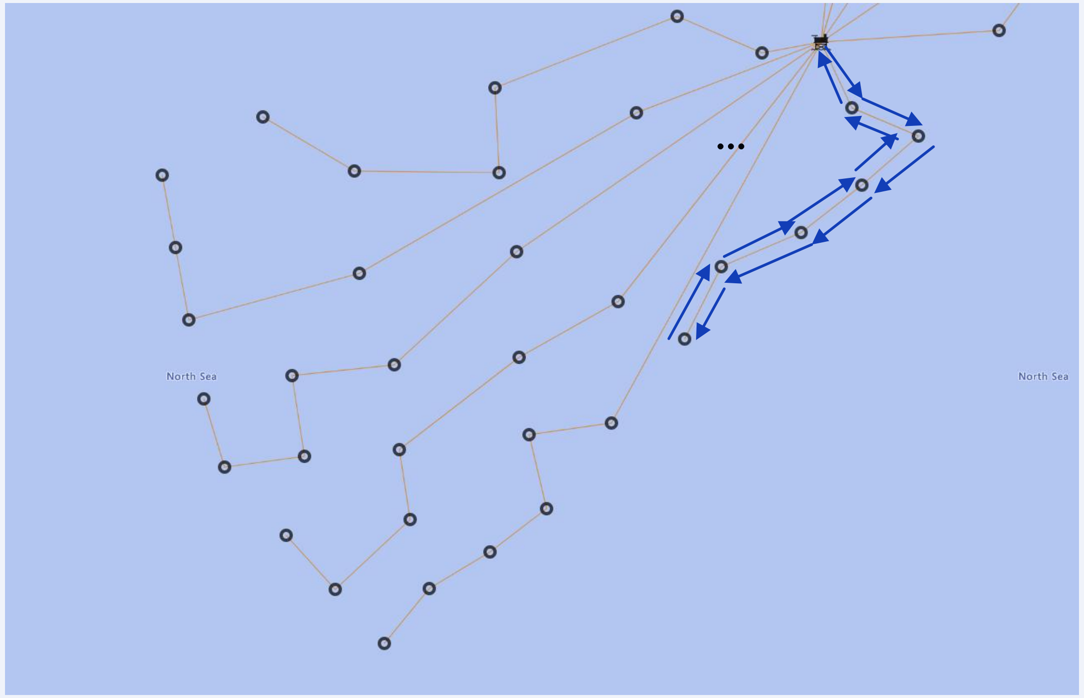
MBES route

Since the MBES campaigns have to pass each turbine and each cable, we assumed the route to pass each "string" of inter-array, similarly as depicted in Option 1. The decision was made to go for a single-pass MBES scan instead of a double pass (Option 2).

Option 1: single pass



Option 2: double pass



Combined Subsea ROV + MBES inspection

This operational scenario looks at performing both the ROV inspections and MBES survey combined, in one single set of operations

Using traditional vessels: When conducting this scenario using traditional vessels , 2 separate vessels are required for ROV inspections and MBES survey respectively. Hence the simulation results from ROV inspections and MBES survey are added together.

Using Uncrewed surface vessel: Fugro's Blue Essence can conduct both ROV inspections and MBES surveys

The detailed method statement can be seen as below:

GROW PRIMA-USV

Step No.	Description	Uncrewed surface vessel	
		Duration (hours)	**Operational limits**
1	**Transit to first WTG**	*Distance dependent (10 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m
2	**Positioning at WTG**	0.25 h	$U_{wind@10m}$= 14 m/s H_s= 1.75 m
3	**Jack up area survey**	2.5 h	$U_{wind@10m}$= 14 m/s H_s= 1.25 m
4	**Deployment of ROV**	0.25 h	$U_{wind@10m}$= 14 m/s H_s= 1.75 m $U_{current}$= 0.6 m/s
5	**ROV inspections**	3 h	$U_{wind@10m}$= 14 m/s H_s= 1.75 m $U_{current}$= 0.6 m/s
6	**ROV Retrieval**	0.1667 h	$U_{wind@10m}$= 14 m/s H_s= 1.75 m $U_{current}$= 0.6 m/s
7	**Cable survey**	*Distance dependent (3.5 knots)*	$U_{wind@10m}$= 14 m/s H_s= 1.25 m
Steps 2 to 7 are repeated for all WTGs in the farm			
8	**Transit back to port**	*Distance dependent (10 knots)*	$U_{wind@10m}$= 14 m/s H_s= 2.5 m
9	**Port activities after port call**	12 h	

Key assumptions

Costs

- Only the vessel day rates and mob/demob costs are considered.
- The crew, equipment and fuel costs are included in the vessel day rate.
- The same day rate is applied when the vessel is working as well as waiting

Activities

- It is assumed both vessels can operate 24/7 (with the exception of weather limits)
- It is considered that there will be no power generation loss during the inspection and survey

Key assumptions

Port calls

Port calls have to occur after a vessel stays offshore for X amount of time to replenish resources such as fuel. Port calls are currently **not** a modeling function within UWiSE.

To incorporate the effects of port calls into this study, the durations of port calls can be added to the results after the simulations. Below follows an example on how this is done:

Example
Vessel A can remain offshore for 1 week before requiring a port call. After running an MBES simulation in UWiSE, the total amount of time spent offshore is 24 days (3,43 weeks). Normally this would require 3 port calls:

1. First after 7 days
2. Second after 14 days
3. Third after 21 days

In case each port call takes approximately 12 hours, we now add 12 [hours/port call] * 3 [port calls] = 36 [hours] = 1.5 [days] to the campaign duration. The average travel time between the wind farm to the port is accounted for in the port call modeling as well (this is different for HKZ and Zeevonk).

RESULTS

TNO

Definitions

Perfect Weather Cost: This is the average cost of conducting the particular operation over the full simulation period considering perfect weather conditions i.e.no weather delays are taken in to account.

Average Cost: This is the average cost of conducting the particular operation over the full simulation period. Here the workability of the vessel plays a deciding factor and the weather limits are taken into account.

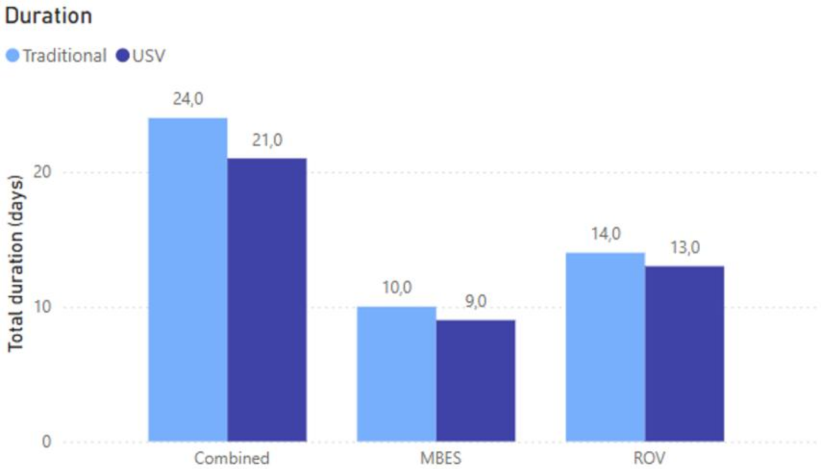
Weather Delays: These are average delays in the operation in hours occurring during the entire simulation period. During this period, the vessel will be in waiting status.

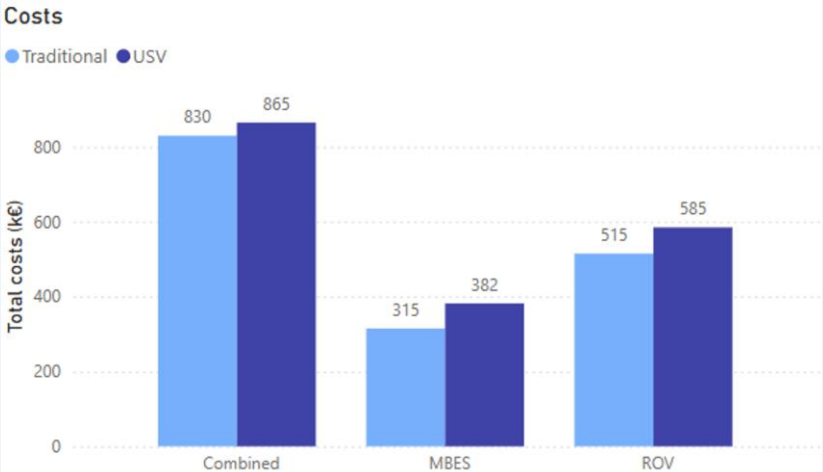
Average duration: This is the average duration of operation in days taking in to considering the total time required to complete the particular offshore operation including any weather delays.

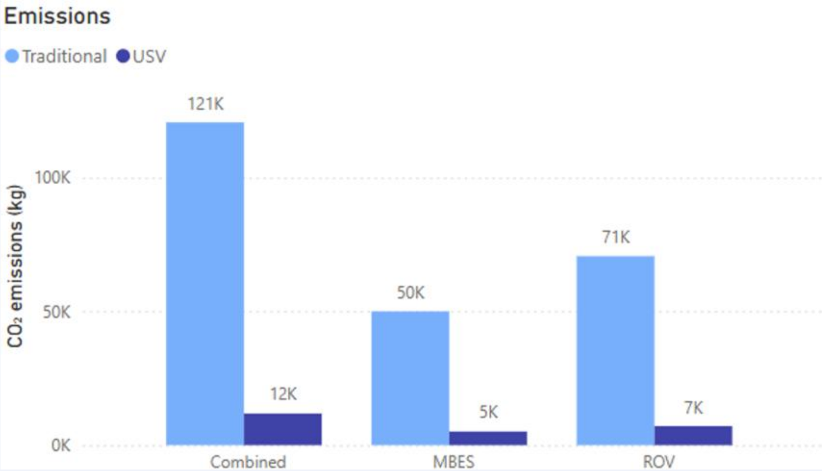
CO2 eqvt. Emission: This is the average CO2 equivalent emissions discharged by the vessel during the particular offshore operation.

Result summary – HKZ

Perfect Weather Conditions

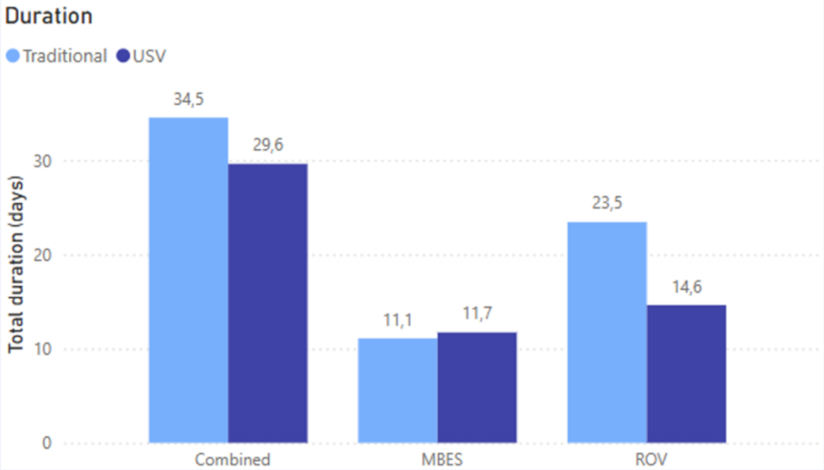


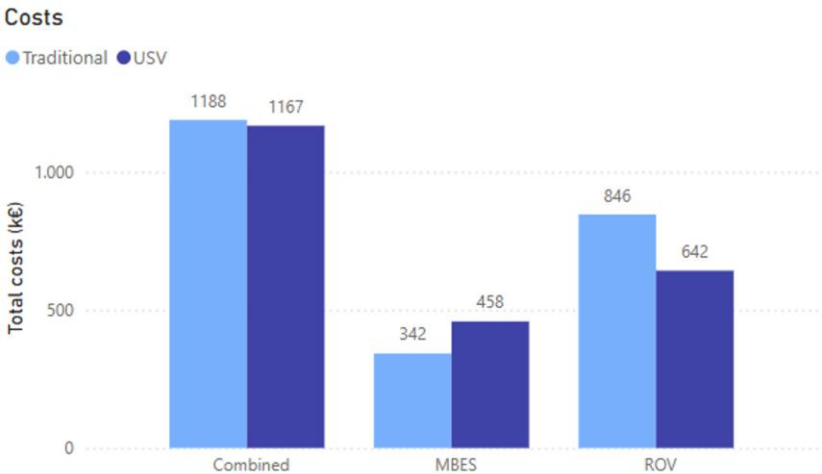


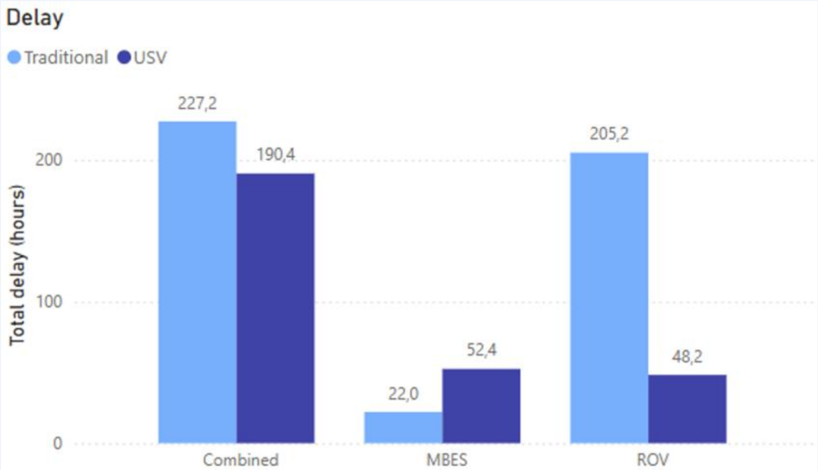


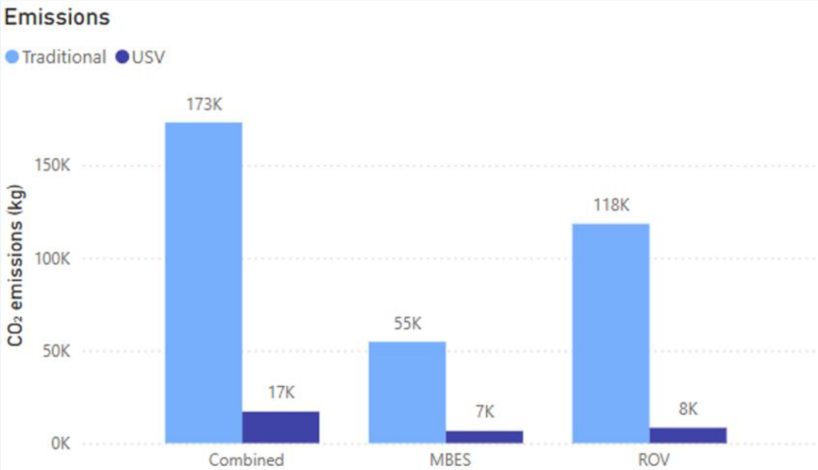
Result summary – HKZ

Average Simulations



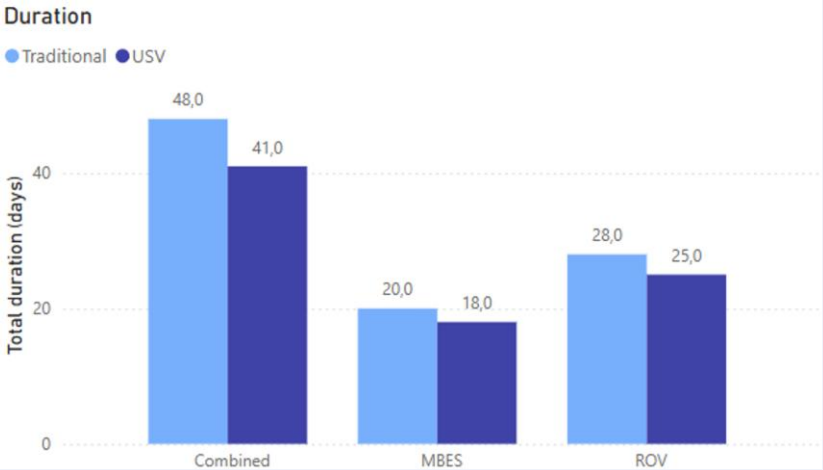


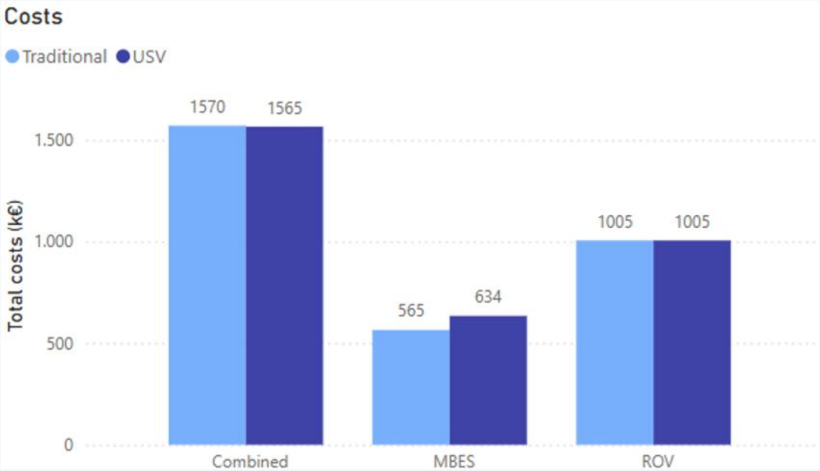


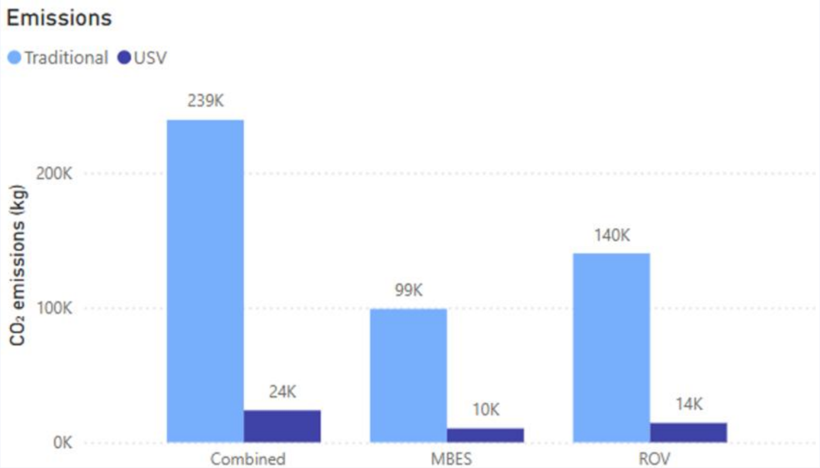


Result summary – Zeevonk

Perfect Weather Conditions

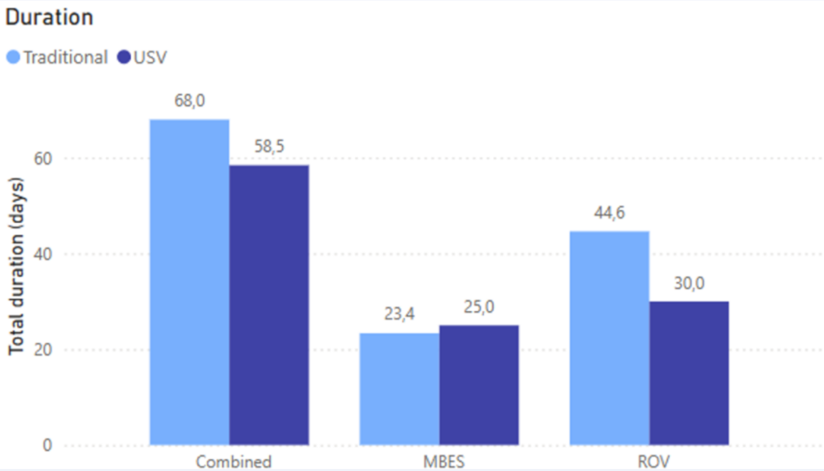


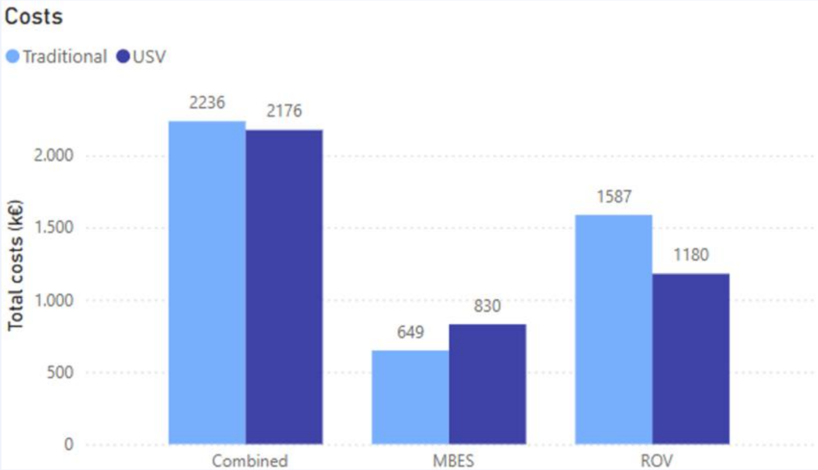


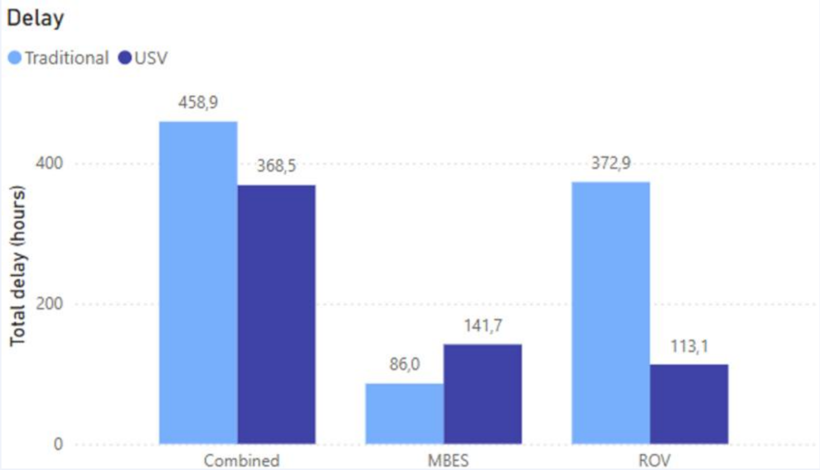


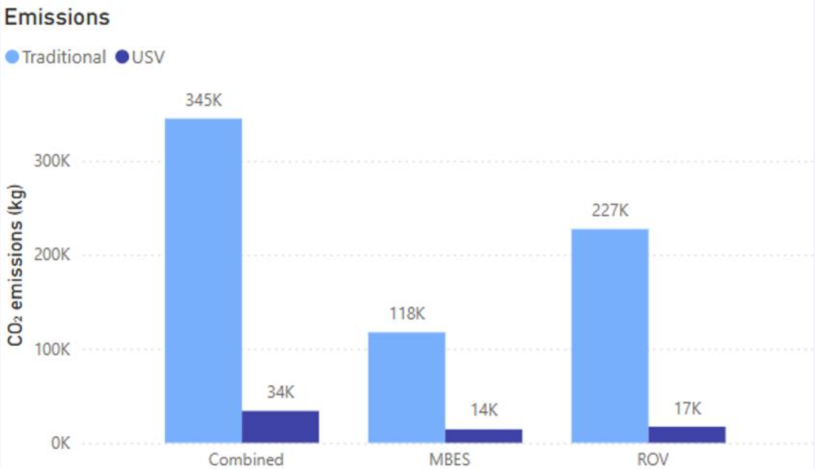
Result summary – Zeevonk

Average Simulations


Duration


Costs


Delay


Emissions

Subsea ROV Inspection

- Wind farm site – HKZ

	Traditional	Fugro USV
Perfect Weather Cost	515 k€	585 k€
Average Cost	846 k€	642 k€
Weather Delays	205.2 hours	48.2 hours
Average duration	23.5 days	14.6 days
CO2 eqvt. emissions	118 tonne	8 tonne

- Wind farm site – Zeevonk

	Traditional	Fugro USV
Perfect Weather Cost	1005 k€	1005 k€
Average Cost	1587 k€	1180 k€
Weather Delays	372.9 hours	113.1 hours
Average duration	44.6 days	30.0 days
CO2 eqvt. emissions	227 tonne	17 tonne

MBES Survey

Wind farm site – HKZ

	Traditional	Fugro USV
Perfect Weather Cost	315 k€	382 k€
Average Cost	342 k€	458 k€
Weather Delays	22.0 hours	52.4 hours
Average duration	11.1 days	11.7 days
CO2 eqvt. emissions	55 tonne	7 tonne

Wind farm site – Zeevonk

	Traditional	Fugro USV
Perfect Weather Cost	565 k€	634 k€
Average Cost	649 k€	830 k€
Weather Delays	86.0 hours	141.7 hours
Average duration	23.4 days	25.0 days
CO2 eqvt. emissions	118 tonne	14 tonne

Subsea ROV Inspection + MBES Survey

Wind farm site – HKZ

	Traditional	Fugro USV
Perfect Weather Cost	830 k€	865 k€
Average Cost	1188 k€	1167 k€
Weather Delays	227.2 hours	190.4 hours
Average duration	34.5 days	29.6 days
CO2 eqvt. emissions	173 tonne	17 tonne

Wind farm site – Zeevonk

	Traditional	Fugro USV
Perfect Weather Cost	1570 k€	1565 k€
Average Cost	2236 k€	2176 k€
Weather Delays	458.9 hours	368.5 hours
Average duration	68 days	58.5 days
CO2 eqvt. emissions	345 tonne	34 tonne

DISCUSSION

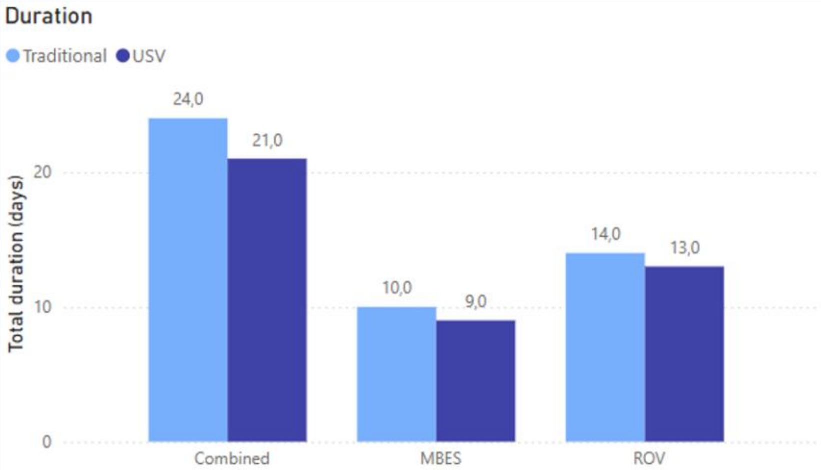
Main Findings: Perfect weather durations – HKZ

Difference in the duration of operations in perfect weather conditions:

- In perfect weather conditions for subsea ROV inspections – it can be seen that the time taken by USV is slightly lower than traditional vessels for subsea ROV inspections. The slower transit speed gives the USV a disadvantage, however, this is compensated by the positioning at the WTG, deployment of ROV, and lifting of the ROV out of the water.
- In perfect weather conditions for MBES surveys– it can be seen that the time taken by USV is also slightly lower than using the traditional vessel. Once again, the USV is slower during the transit and also during the cable survey. However, the jack-up area survey process step is faster for the USV, making it the overall faster vessel without the effects of weather.

Task Description (HKZ)	Perfect weather duration (days)		Duration difference (%)
	Traditional Vessel	Fugro USV	
Subsea ROV inspection	14	13	USV (-)7%
MBES survey	10	9	USV (-)10%

Table with result highlights of HKZ campaign durations with no weather delays.



Plot of the HKZ campaign durations with no weather delays

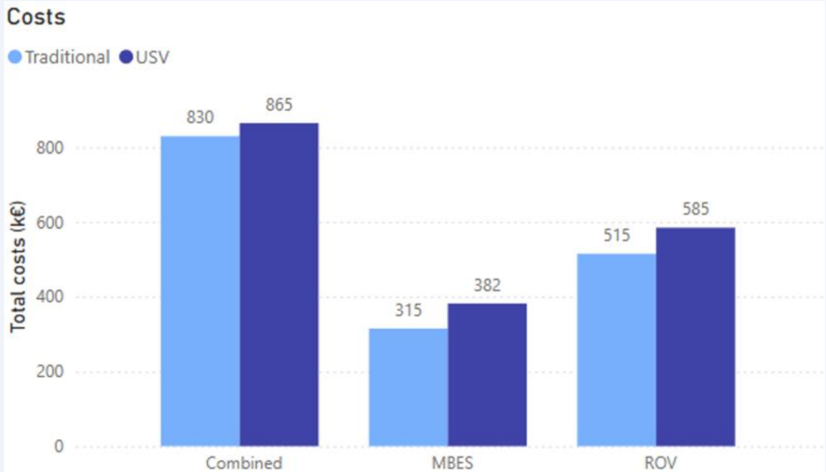
Main Findings: Perfect weather costs – HKZ

Difference in the costs of operations in perfect weather conditions:

- In perfect weather conditions, the USV is the more expensive option over both the ROV and MBES campaigns, despite the shorter campaign durations.
- The main cause of this is the significantly higher mobilization costs. Moreover, there is a slight day rate difference for the MBES campaign

Task Description	Day rate (k€)		Day rate difference (%)	Mob / demob		Mob / demob difference (%)
	Traditional Vessel	**Fugro USV**		**Traditional Vessel**	**Fugro USV**	
Subsea ROV inspection	35000 €	35000 €	-	25000 €	130000 €	+420%
MBES survey	25000 €	28000 €	+12%	65000 €	130000 €	+100%

Table with highlighted day rate and mobilization cost differences between the traditional vessel and USV.

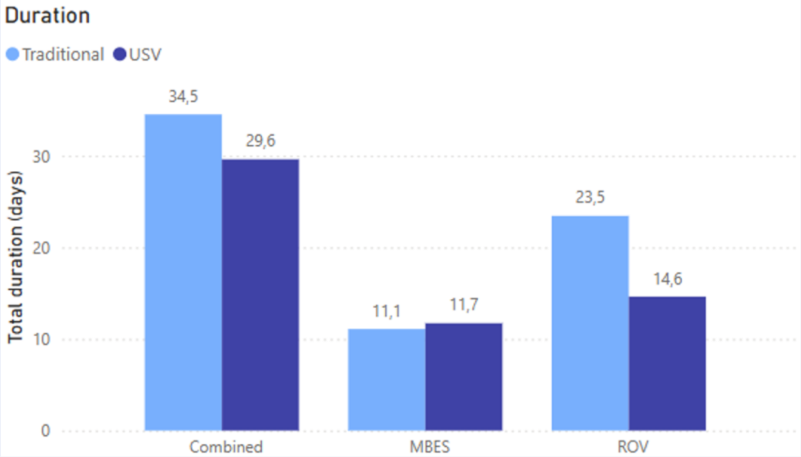


Plot of the HKZ campaign costs with no weather delays

Main Findings: Average duration results - HKZ

Difference in the duration of operations with weather effects included:

- The USV is now significantly faster in the ROV campaign compared to the traditional vessel. Stricter weather limits for the traditional vessel cause an increase in weather delays, which in turn increase campaign durations.
- The USV is slightly slower than the traditional vessel for MBES campaigns, despite its faster campaign completion under perfect weather conditions. Contrary to the ROV campaign, the weather limits for MBES campaigns are slightly more unfavourable for the USV.



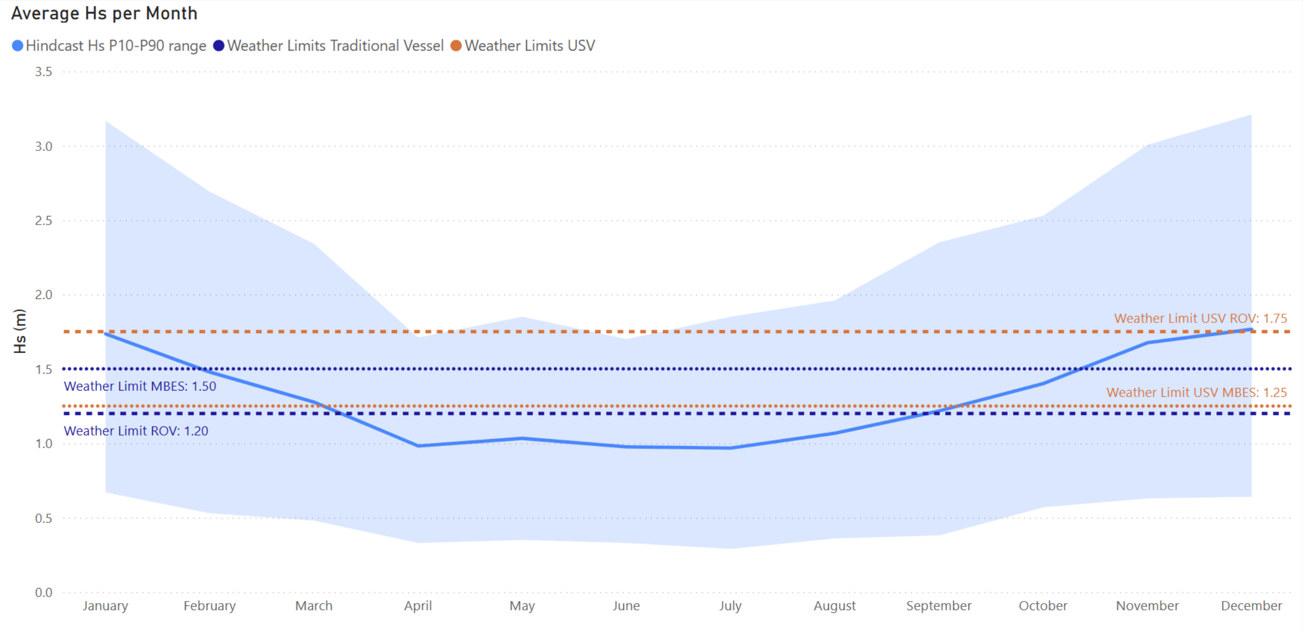
Plot with the average duration per month for HKZ with weather effects.

	Traditional		Fugro USV	
Process	**H_s limit**	**Duration**	**H_s limit**	**Duration**
Positioning at WTG	1.2	0.5	1.75	0.25
Deployment of ROV	1.2	0.5	1.75	0.25
ROV inspections	1.2	3	1.75	3
Lift ROV out water	1.2	0.5	1.75	0.1667

Table with the H_s limits for a selection of processes during the ROV campaign.

	Traditional		Fugro USV	
Process	**H_s limit**	**Vessel speed (knots)**	**H_s limit**	**Vessel speed (knots)**
Jack-up area survey	1.5	-	1.25	-
Cable survey	1.5	5	1.25	3.5

Table with the H_s limits for a selection of processes during the MBES campaign.

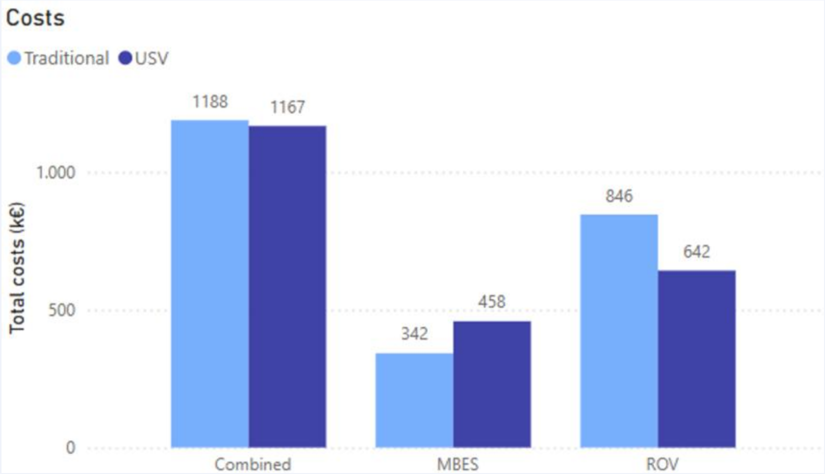


Plot with the average H_s per month (blue line) and the wave height weather constraints as defined for the scenarios.

Main Findings: Average costs results – HKZ

Difference in the costs of operations with weather effects included

- The USV is more cost-effective option for the ROV campaign. This is caused by the large amount of weather delays for the traditional vessel, which make the campaign duration a lot longer.
- The USV is the more expensive option for the MBES campaign. The slightly higher day rate, higher mobilization costs, longer campaign duration, and unfavourable weather constraints make it overall more expensive compared to the traditional vessel.

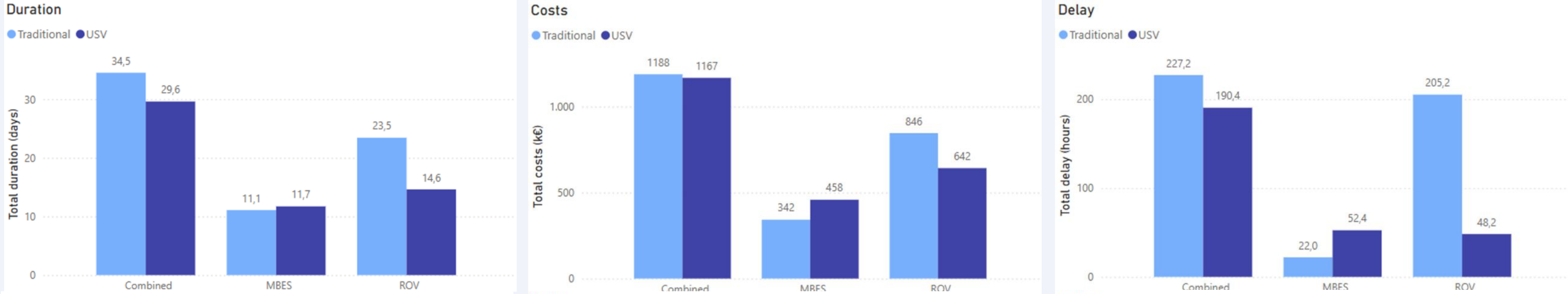


Plot with the average costs per month for HKZ with weather effects.

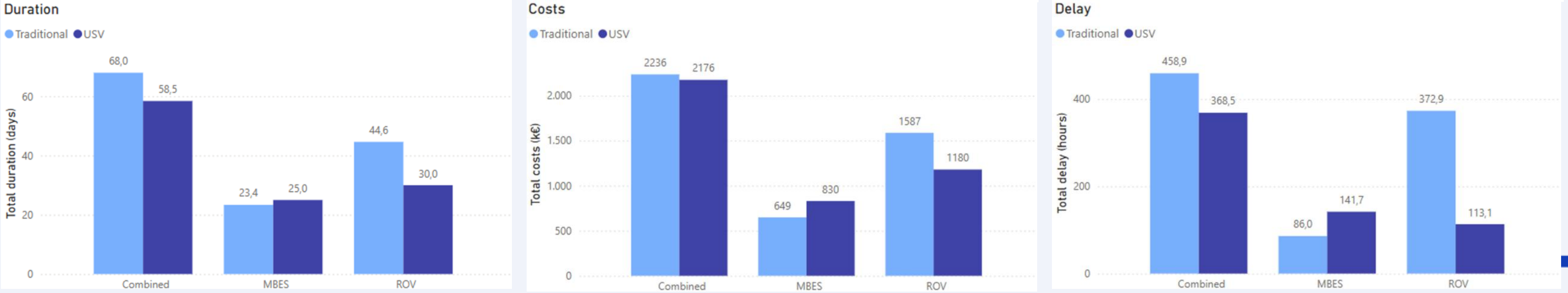
Main Findings: Zeevonk compared to HKZ

Analysis of the Zeevonk results compared to the HKZ results

- The magnitude of the costs and durations increase for the Zeevonk studies because of the larger wind farm and the further distance from shore. As a result, the absolute cost differences are typically higher for the Zeevonk studies.
- The ratios between USV and traditional vessel results are generally the same for all campaigns. This can be observed by the heights of the bars in the graphs that remain approximately the same.
- Small differences can be observed in the ratios of the weather delays. This is likely an effect of the slightly varying metocean conditions at the two different sites.



HKZ results



Zeevonk results

Main Findings: Combined campaign – HKZ

Analysis of the combined campaigns

- The combined campaigns show that the USV completes the campaign faster.
- The costs do not reflect this to the same extend, as both campaigns are nearly identical in costs. This is largely a result of the USV's constant day rate of 35000 € throughout the entire campaign, as it has both the ROV and MBES capabilities at both times. The traditional vessel however has a day rate of 25000 € throughout the MBES campaign and 35000 € throughout the ROV campaign, giving it a lower day rate on average.

	Duration (days)		Duration difference (%)	Costs (k€)		Cost difference (%)
	Traditional Vessel	**Fugro USV**		**Traditional Vessel**	**Fugro USV**	
Combined campaign	34.5	29.6	USV -14%	1188	1167	USV -2%

Main Findings: Combined campaign

Analysis of the combined campaigns

- An interesting observation is that the summed-up campaign durations and costs of the individual USV MBES and ROV campaigns, is lower than the combined campaign.

  Unintuitive result, as the combined campaign only has a single mobilization and passes every single wind turbine only once.
- Best explained by an example:

USV MBES Scenario

- MBES operations are executed in series, significantly impacted by weather due to the $H_s < 1.25$m constraint.
- Example: If the campaign takes 30 days without delays, and weather delays account for 25%, then 7.5 days are lost.

USV ROV Scenario

- ROV operations, executed in series, experience fewer delays due to the $H_s < 1.75$m constraint.
- Example: If the campaign takes 30 days without delays, and weather delays account for 10%, then 3 days are lost.

USV Combined MBES + ROV Scenario

- Work is alternated between MBES and ROV tasks, but the campaign remains limited by MBES constraints.
- Conditions where $H_s = 1.5$m allow ROV work but prevent MBES operations. If ROV tasks at a turbine are completed, the campaign is stalled by the next MBES task, delaying subsequent ROV work.
- Example: If the campaign takes 60 days, and weather delays match MBES constraints (25%), then 15 days are lost. This is 4.5 days longer than the combined delays of the independent campaigns (10.5 days).

Main Findings: Combined campaign

Analysis of the combined campaigns

- This is an unrealistic result and limited by TNO’s UWiSE model. Realistically, ROV work would continue to be executed if MBES work is constrained by the weather (e.g. $H_s = 1.5$).
- It is expected that the case for combined ROV+MBES work becomes better with improved scheduling, or by conducting the ROV work in series with the MBES work.

USV MBES Scenario

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- Example: If the campaign takes 30 days without delays, and weather delays account for 25%, then 7.5 days are lost.

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- Conditions where $H_s = 1.5$m allow ROV work but prevent MBES operations. If ROV tasks at a turbine are completed, the campaign is stalled by the next MBES task, delaying subsequent ROV work.
- Example: If the campaign takes 60 days, and weather delays match MBES constraints (25%), then 15 days are lost. This is 4.5 days longer than the combined delays of the independent campaigns (10.5 days).

Main Findings: Emissions

Analysis of the emissions

- Emission differences between -87% and -93% in favor of the USV can be observed, making USV emissions drastically lower than the traditional vessel. This is caused by the lower emissions per day of operation for the USV.
- The emission variations are largely the same for HKZ and Zeevonk
  - The campaign duration ratios between HKZ and Zeevonk do not change much
  - The emissions are a linear calculation between campaign duration and average emission per unit of time

Task Description (HKZ)	CO2e (tonne)		Emission variation (%)
	Traditional Vessel	Fugro USV	
Subsea ROV inspection	118	8	(-)93%
MBES survey	55	7	(-)87%
Combined ROV + MBES	173	17	(-)90%

Task Description (Ijmuiden Ver)	CO2e (tonne)		Emission variation (%)
	Traditional Vessel	Fugro USV	
Subsea ROV inspection	227	17	(-)93%
MBES survey	118	14	(-)88%
Combined ROV + MBES	345	34	(-)90%

	Fuel consumption (l/day)
Fugro USV	170
Traditional vessel	1500

Main findings: Summary

Summary of the most notable findings in this study.

- The modeling results show that the **USV is faster** than the traditional vessel for **completing the ROV and combined campaign**. Both vessels are approximately **equally fast in completing the MBES** campaign
    - The usefulness of combined campaigns is **largely dependent on planning/scheduling capabilities**.
    - The scenario definition and **UWiSE simulation model limitations could underestimate the full potential** of combined campaigns with the USV.
- The **USV shows a significant reduction in emissions** for all campaigns
- The vessel costs, largely influenced by day rates and mobilization costs, are volatile. Therefore**, it is difficult to make generic conclusions about the costs in this study**.

Future studies

- **Sensitivity analysis, e.g.**
  - Effects of campaign starting month
  - Day rates and mob/demob costs
- **In-depth emission analysis**
  - Beyond direct emissions (scope 2, scope 3)
  - LCA analysis
  - Quantify lower GHG emission during mobilisation phase for USV
- **Other USV models –** study & analyze the workability parameters of improved & later USV models for different wind farm configurations