



# Cornwall FLOW Accelerator

## FLOW Supply Chains and Installation Analysis

CFA Work Package 6

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## Executive Summary

This report presents an initial analysis of the effect of FLOW supply chains and installation parameters on the timescales for realising FLOW farms in the Celtic Sea. The report uses the installation module of the E<sup>c</sup> Simulator to investigate installation resource availability, weather limitations, task duration, and manufacturing capacity on timescales and costs. Although limited in scope and run for a simplified set of tasks due to time constraints, the results highlight the importance of adopting emerging technologies that can safely and reliably operate in more severe weather, as well as maximising the availability of resources such as cranes and anchor handling tug supply vessels, conditions in order to minimise installation durations.



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## 1 Introduction

### 1.1 Project introduction

Cornwall FLOW Accelerator (CFA) is a collaborative project between research institutes and industry partners. The project aim is to accelerate the development of the floating offshore wind (FLOW) industry in Cornwall and the Celtic Sea by facilitating stakeholder cooperation and providing consultation. The Celtic Sea presents a large opportunity for FLOW projects, having been previously overlooked for fixed offshore deployment due to its water depths. Following the Crown Estate's latest leasing proposal, the Celtic Sea is now set to provide up to 4GW of new floating offshore wind capacity by 2035. Since FLOW projects can take between eight and ten years to develop, there is a clear need for urgent action from local authorities and industry to develop the required manufacturing, logistical, and network infrastructure.

### 1.2 Work package introduction

To support this, WP6 of the CFA project aims to explore how manufacturing supply chains and installation task requirements influence FLOW development timescales. The main factors of interest for this report are:

- The effect of upstream manufacturing capacity and duration on port storage requirements and project timescales;
- The effect of installation vessel availability and task duration on storage requirements and project timescales;
- The influence of metocean conditions on the timescales required for installation and assembly tasks, and the subsequent knock-on impact on port storage requirements;

The main objectives are to:

- Study the factors of interest to provide an initial indication of how supply chain and installation requirements influence the feasibility of FLOW in the Celtic Sea, including potential bottlenecks for project development;
- Provide representative case studies summarising project timescales and storage requirements for 3 sites in the Celtic Sea;

## 2 Methodology

The E<sup>c</sup> simulator (developed by the University of Exeter as part of the CFA project) and its installation module have been used to investigate these factors of interest. This tool uses discrete event simulation, breaking down the installation and decommissioning of a FLOW farm into a series of inter-dependent tasks. This enables it predict costs, emissions, timescales, and utilisation of facilities (such as storage) and equipment (such as vessels). The installation module sits between the design and operation modules within the E<sup>c</sup> simulator, enabling holistic predictions of key performance indicators for wind farm economics and sustainability. A more detailed overview of how these tools function has previously been provided in the E<sup>c</sup> Simulator Impact Case Study report.

### 2.1 Supply chain and installation analysis

To investigate how the factors of interest influence the feasibility of FLOW in the Celtic Sea, multiple simulation runs were conducted with the installation module. In each of these runs, parameters were varied to explore their effect on project timescales and port storage requirements. Given the potentially vast scope of such an analysis, it was necessary to limit focus to three areas (manufacturing capacity, equipment availability, and the sensitivity of assembly and installation work to metocean conditions), without considering the potential for interaction effects between them.

The investigation into manufacturing capacity focussed on the distances between manufacturing locations and the main staging port used for installation, as well as component production rates. The study into equipment availability focussed on the available number of cranes, vessels, and other machinery necessary for the installation of a floating offshore farm. Lastly, the study into sensitivity of work to metocean conditions focussed on adjusting the maximum allowable weather conditions for tasks to progress between high and low values, increasing and decreasing the available weather windows and thus influencing installation timescales.

### 2.2 Cases

The analysis in this report was planned to be conducted within two case frameworks, the first was baseline WP6\_BASE, where assembly of wind turbines and installations tasks are inputted into the installation module and ultimately the E<sup>c</sup> simulator. The second framework was the upstream logistics WP6\_UPSTREAM' this aimed to simulate a given supply chain of the floating wind farm, the manufacturing capacities of components and the storage requirements needed to facilitate assembly and installation. The upstream scenario can be seen as an expanded frame from the baseline, it simulates the upstream and midstream (baseline) together and demonstrates the impact of the two phases of development with each other. Due to time constraints with the event of the CFA project, the run times of the models required, and the late definition of some of these tasks, it was not possible to fully run this study. It is included here instead as a potential reference for future work.

#### 2.2.1 WP6\_BASE parameters

The baseline scenario consists of the installation tasks as well as assembly of the wind turbine at the main installation port. The main tasks are installation of the anchors and mooring system, assembling



the wind turbine on the substructure (floater), connecting the finished turbine to the mooring system in place, laying dynamic interarray cables, and commissioning the turbines. These parameters are summarised in Table 1. Tasks marked with an asterisk were redefined at the very end of the project and therefore run in the simulator only (Section 3.3). Simplified definitions used in the analysis to Sections 3.1 to 3.2

Table 1: Summary of baseline tasks run in E<sup>c</sup> simulator.

<b>Task</b>	<b>Set</b>	<b>Units in group</b>	<b>Duration</b>
<i>install drag anchor &amp; chain mooring</i>	WTG	1	1.25
<i>assemble WTG in staging port - tower positioning</i>	WTG	1	0.67
<i>assemble WTG in staging port - nacelle</i>	WTG	1	0.21
<i>assemble WTG in staging port - blade (1)</i>	WTG	1	0.13
<i>assemble WTG in staging port - blade (2)</i>	WTG	1	0.13
<i>assemble WTG in staging port - blade (3)</i>	WTG	1	0.13
<i>transit WTG to site and connect to moorings</i>	WTG	1	0.63
<i>load CLV with cables &amp; transit to staging port*</i>	Cabling	1	0
<i>load ancillaries &amp; transit to location*</i>	Cabling	1	0
<i>install dynamic interarray cable</i>	Cabling	15	0.25
<i>return to install_cable port*</i>	Cabling	1	0
<i>load CLV with cables &amp; transit to staging port _z*</i>	Cabling_z	1	0
<i>load ancillaries &amp; transit to location _z*</i>	Cabling_z	1	0
<i>install dynamic interarray cable _z*</i>	Cabling_z	7	0.25
<i>return to install_cable port _z*</i>	Cabling_z	1	0
<i>transit to first group of turbines*</i>	commission	1	0
<i>turbine commissioning including transfer &amp; transit to next WTG*</i>	commission	17	0.375
<i>transit back to port*</i>	commission	1	0
<i>transit to last group of turbines*</i>	commission_z	1	0
<i>commissionings including transfer &amp; transit to next WTG*</i>	commission_z	16	0.375



*final transit back to port\**

commission_z	1	0
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Table 2: Summary of installation sets.

Installation set	Number in a set	Unit
WTG	67	15MW turbines
Cabling	4	Groups of 15 turbines ready to connect
Cabling_z	1	Group of 7 turbines ready to connect
Commissioning	3	Groups of 17 turbines ready to commission
Commissioning_z	1	Group of 16 turbines ready to commission

### 2.2.2 WP6\_UPSTREAM parameters

Upstream includes ordering, manufacturing capacity and duration of each component see table below, transportation of the parts to assembly and installation ports, storage at ports whether wet or dry storage depending on the component. Due to time constraints it was ultimately not possible to run the upstream scenarios. This framework should instead be considered in future work.

Table 3: Summary of parameters for upstream scenario.

Type subs	Task name	Install set	No. group	Operation time, port time (day)
Anchor	Manufacturing, anchor	WTG	3	2, -
Anchor	Transport anchors	Transport	0	0, 1
Mooring	Manufacturing, mooring	WTG	3	2, -
Mooring	Transport mooring	Transport	0	0, 1
Tower	Manufacturing, tower	WTG	1	7, -
Tower	Transport tower	Transport	0	0, -
Blade	Manufacturing blades	WTG	3	3, -
Blade	Transport blades	Transport	0	0, 1
Nacelle	Manufacturing nacelle	WTG	1	25, -
Nacelle	Transport nacelle	Transport	0	0, -
Floater	Manufacturing floater	WTG	1	30, -
Floater	Transfer to water	WTG	1	1, -
Cable	Manufacturing cable	WTG	1	7, -
Cable	Transport cable	Transport	0	0, 3
Cable	Manufacturing cable ancillaries	WTG	1	7, -
Cable	Transport ancillaries	Transport	0	0, 1



### 3 Analysis of supply chain and installation process

#### 3.1 Assembly and installation tasks and resources

This section summarises the analysis of how the tasks and available resources for assembly and installation influence the wind farm installation processes. The primary factors within this analysis include the available infrastructure and resources (i.e. the number of available vessels) and the duration and operational requirements of installation tasks. To provide an overview of how these factors influence development progress, the analysis was conducted using the baseline case study in the installation module. The parameters of this case study are summarised in Section 2.2.1. All of the runs presented in this section varied parameters from the settings used for this case. With standard settings and the minimal level of available resources, it was predicted that such an installation process would take nearly 465 days, as shown in Figure 1.

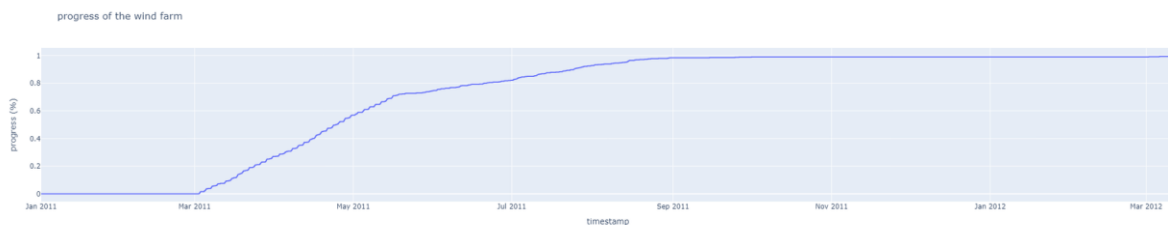


Figure 1: Progress of windfarm installation for baseline case.

##### 3.1.1 Resource availability analysis

To get a greater understanding of the impact of resource availability on installation rate, the number of available resources during installation was increased from the minimum necessary to a much larger number over 5 different runs. The quantities of available resources for installation activities used during each run are summarised in Table 4.

Table 4: Summary of different resource capacity runs, including the maximum number of available vessels.

Resource capacity	1	2	3	4	5
Onshore crane	1	2	3	4	5
AHTS	2	3	4	5	4
CLV	1	2	3	4	5
SOV	1	2	3	4	5

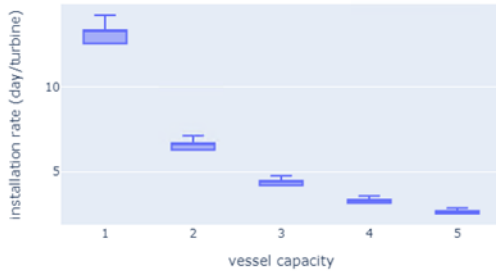
Increasing the available resources for turbine assembly and installation naturally increases the potential installation rate, since more turbines can be assembled and installed in parallel. This is summarised in Table 5 and Figure 2, with Figure 2 also highlighting the variation in vessel utilisation for each level of resource capacity.



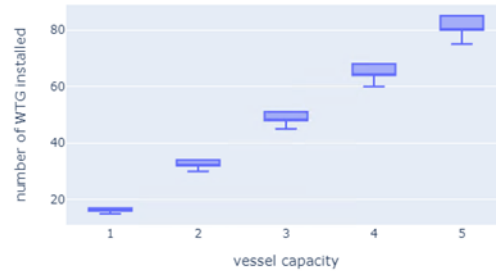
Table 5: Effect of increased resource capacity on median turbine installation rate.

Resource capacity	1	2	3	4	5
Installation rate (day/turbine)	13.4	6.7	4.5	3.3	2.7
Turbine installed per year (turbine/year)	16	32	48	64	80

installation rate vs. vessel capacity



number of turbine installed per year vs. vessel capacity



vessel capacity vs vessel utilisation

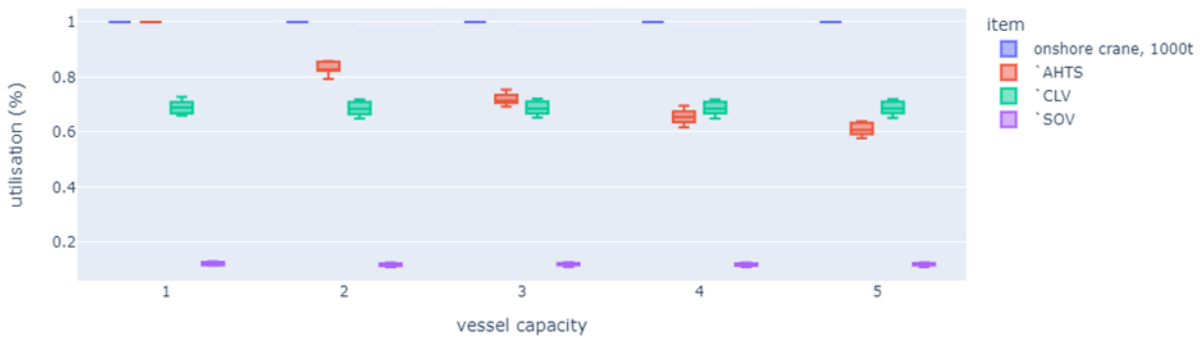


Figure 2: Summary of how available resource capacity influences turbine installation rate (top left), the annual number of turbines installed (top right), and annual resource utilisation (bottom). Resources are assumed to be utilised even during poor weather, since the equipment will be paid for and on standby awaiting better conditions.

The bottom image in Figure 2 highlights how the onshore crane used for assembly work at the port are heavily utilised resource during installation, even when crane numbers dramatically increase. This indicates that the availability of cranes for assembly work could potentially present one of the largest bottlenecks for a farm installation process, although it should be noted that this baseline run does not include the effect of upstream manufacturing. As a result, it assumes a constant supply of components that are ready for assembly with no waiting for manufactured components to arrive, which will influence crane utilisation. Anchor handling tug supply vessels are also heavily utilised, , representing another potential bottleneck, particularly when only the bare minimum are available, Service operation vessels and cable laying vessels are utilised more sparingly, with increasing numbers not resulting in significant changes in overall utilisation.

### 3.1.2 Installation task analysis

To get a greater understanding of how installation rate was influenced by factors relating to installation tasks, runs were conducted where task duration, task weather limit, and annual installation period (i.e. the number of months throughout the year that installation tasks are conducted at site) were varied.

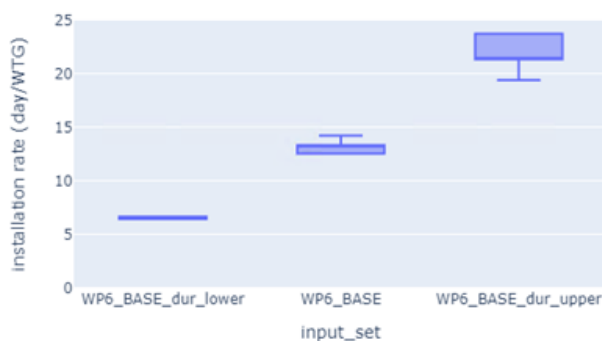


Results for the effect of task duration on the installation rate of the baseline case are summarised in Figure 3: Variation in turbine installation rate with task duration. Task duration was varied between low, baseline, and high conditions, which are summarised in Table 6.

Table 6: Time requirements of installation tasks.

Task	Time requirement (days)		
	Low	Median (baseline)	High
<i>install drag anchor &amp; chain mooring</i>	1	1.25	1.5
<i>assemble WTG in staging port - tower positioning</i>	0.67	0.67	2
<i>assemble WTG in staging port - nacelle</i>	0.21	0.21	2
<i>assemble WTG in staging port - blade (1)</i>	0.13	0.13	2
<i>assemble WTG in staging port - blade (2)</i>	0.13	0.13	2
<i>assemble WTG in staging port - blade (3)</i>	0.13	0.13	2
<i>transit WTG to site and connect to moorings</i>	0.63	0.63	1.5
<i>install dynamic interarray cable</i>	0.25	0.25	1
<i>transit to first group of turbines</i>	0	0	0
<i>turbine commissioning including transfer &amp; transit to next WTG</i>	0.3	0.38	0.3
<i>transit back to port</i>	0	0	0
<i>transit to last group of turbines</i>	0	0	0
<i>commissioning, including transfer &amp; transit to next WTG</i>	0.3	0.38	0.3
<i>final transit back to port</i>	0	0	0

installation rate vs. task duration



WTG installed per year vs. task duration



Figure 3: Variation in turbine installation rate with task duration.

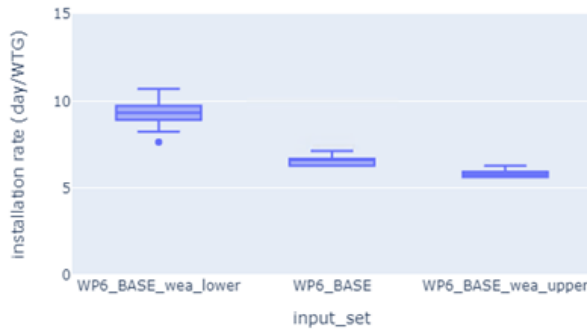
As would be expected, reducing the time required to complete individual tasks significantly reduces the installation rate of floating offshore wind turbines, enabling more turbines to be installed per year. This is not only due to the fact that more tasks can be completed in a given amount of time, but also because it enables the utilisation of shorter weather windows.

Results for the effect of weather limits on overall installation rate for a 7 month installation period (March to end of September) are shown in Figure 4. This highlights how more stringent weather limits



will negatively impact the installation rate, while installation rate increases with more relaxed weather limit up to a point where the weather limits are so relaxed they no longer influence when the task can be conducted. This highlights the importance of taking advantage of technical innovations that can allow tasks to be conducted safely and reliably in poor weather conditions, as doing so will accelerate the rate of turbine installation.

Installation rate vs. weather limits



WTG installed per year vs. weather limits

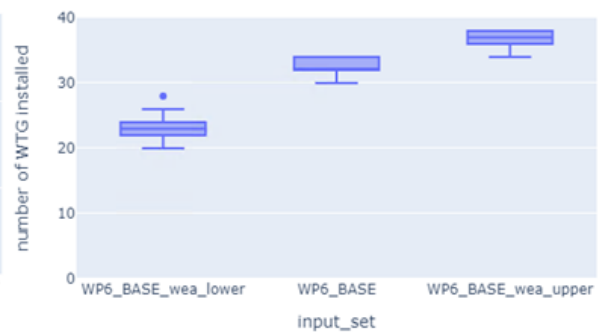


Figure 4: Effect of weather limits on installation rate. Note that lower limits mean the task is limited to less severe conditions.

### 3.2 Weather window availability

This section summarises the analysis of metocean data and task weather limits on the wind farm installation processes. The installation module was used to run a set of baseline tasks (summarised in Section 5), with the weather (wind and wave) limits of these tasks varied to assess their sensitivity to metocean conditions. Prior to initialising a new task, the installation module first checks whether the weather conditions are within the given task limits. If they are, it then checks whether the conditions remain suitable for the time required to complete the task prior to starting it. The installation module also summarises this data, provide a time history of available weather windows for each task.

Table 7: Summary of installation tasks used for metocean condition analysis.

Task	Duration at port (hours)	Duration at offshore site (hours)	Vessel	Weather limit: wind speed (m/s)	Weather limit: wave height (m)
Install drag anchor & mooring (3 sets)	24 (24 / 36)	6 (6 / 72)	AHTS: 1	20 (18 / 22)	2.5 (2.0 / 3.0)
Assembly – tower positioning	48 (24 / 72)	-	Onshore crane, 1000t: 1	10 (8 / 12)	-
Assembly – nacelle	48 (24 / 72)	-	Onshore crane, 1000t: 1	10 (8 / 12)	-
Assembly – three blades	48 (24 / 72)	-	Onshore crane, 1000t: 1	10 (8 / 12)	-
Transit WTG to site and connect to mooring	0 (0 / 12)	24 (12 / 36)	AHTS: 2	20 (18 / 22)	2.0 (1.8 / 2.2)
Install dynamic inter array cables	96 (48 / 96)	4 (4 / 24)	CLV: 1	20 (18 / 22)	2.5 (2.0 / 3.0)



<i>Commission turbine</i>	0 (0 / 12)	24 (12 / 36)	SOV: 1	20 (18 / 22)	3.5 (3.0 / 4.0)
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The analysis used metocean conditions representative of the 3 CFA sites and Port Talbot, which was assumed to be the main installation port for this analysis. The metocean data used was gathered between 2011 and 2020 from the ERA-5 database (Hersbach, et al., 2023) at the locations shown in Figure 5 (note that these locations do not exactly correspond to the locations of the sites or port, but are rather the closest available measurement sites). All wind speeds were measured at height of 10 m, while wave data is reported via significant wave height.

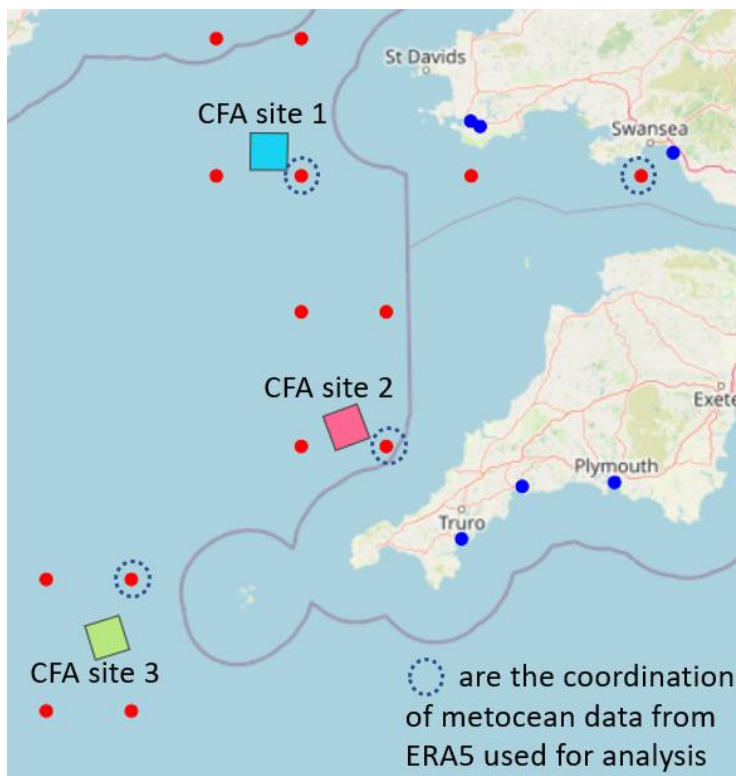


Figure 5: Location of metocean data coordinates relative to the CFA sites.

The average available sufficiently good weather at each of the 3 CFA sites under different weather limit scenarios is shown in Figure 6 for the following tasks:

- Commissioning a turbine (assumed duration: 24 hr, wind speed limit: 20 m/s, wave: 3.5 m, purple lines)
- Installing a dynamic Inter-array cable (assumed duration: 4 hr, wind speed: 20, wave 2.5 m, green lines)
- Installing a complete drag anchor & mooring system for one turbine (assumed duration: 6 hr, wind speed: 20 m/s, wave: 2.5 m, blue line)
- Transiting a WTG from port to site and connect it to the mooring (assumed duration: 24 hr, wind speed: 20 m/s, wave: 2.0 m, red line)



The monthly average weather availability is the average value for the 10 years of metocean data that was used during this analysis. For each task and site, it is naturally significantly greater in summer than it is in winter. For the tasks that can be conducted when the significant wave height is up to 2.5 m (every task apart from turbine commissioning), the monthly availability in summer (around 60 to 90 % depending on time requirements and location) is much higher than it is in the winter period (where it is typically around 20 to 40 %). Available weather windows for the commissioning turbine task are lower, since the stricter weather limit naturally reduces the time available to complete this task.



Figure 6: Comparison of the available weather windows for installation tasks at each CFA site. The legend shows the limits for the tasks simulated (see bullet points on Page 14).

Close inspection of Figure 6 suggests that Site 3 has slightly lower weather availability than the other two sites. This can be seen more easily in Figure 7, which a separate graph for each task to compare its weather windows for each site. This clearly shows that the more energetic metocean conditions at Site 3 (green) result in a fewer available weather windows throughout the year

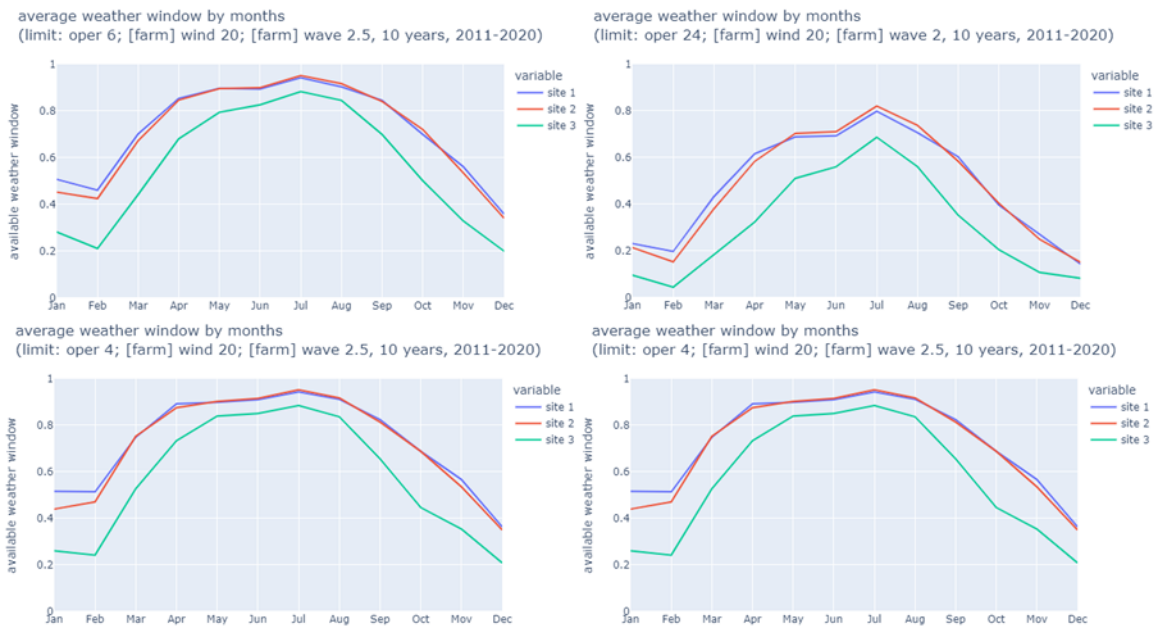


Figure 7: Comparison of the available weather windows at each site for the 4 different installation tasks.

Rather than presenting an average value taken from the 10 year period, Figure 8 summarises the distribution in available weather windows across that period. This highlights the potential risks involved in using data from a single year, or from averaging data over multiple years, when calculating installation duration. The variation in metocean conditions from one year to the next can result in significant differences between extremes, with availability for some tasks ranging from a minimum of 20 % to a maximum of 80 % in a given month depending on the year. Even within the middle of the distribution, variation can still remain relatively high depending on the tasks and the month.

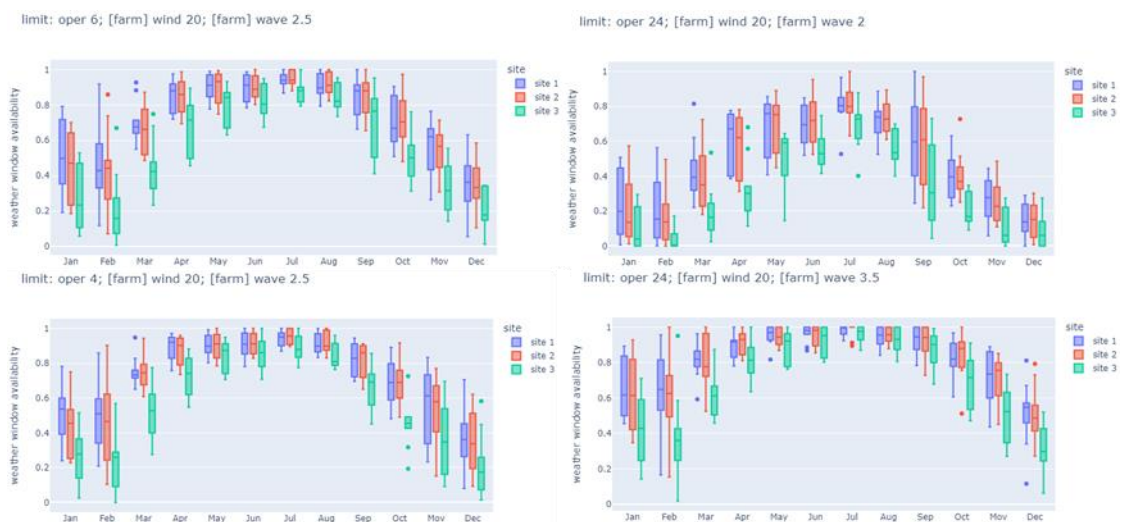


Figure 8: Comparison showing the distribution of available weather windows over the 10 year metocean data period at each site for the 4 different installation tasks.

The impact of operation duration on the average available weather windows is summarised in Figure 9. This shows that longer task durations result in lower available weather windows, with the effect most obvious when the task has relatively strict weather limits, particularly in winter. For tasks with



relatively relaxed weather limits (such as 20 m/s waves with a 3.5 m H<sub>s</sub> swell), the variation in available weather windows can be relatively low, particularly in summer.

Although a comparison of averages (meaning there will likely be significant variation from one year to the next), this suggests that planning installation around maximising productivity during the summer months will likely result in the fastest timescales for installation. Similarly, making use of installation equipment and processes capable of operating in more severe weather conditions (such as robustly engineered specialist equipment for safely transferring personnel from vessels to wind turbines, rather than harnesses and rope ladders) will also be necessary for maximising installation rate. This latter point can clearly be seen in Figure 10, which directly compares the effect of task weather limits on average available weather windows.

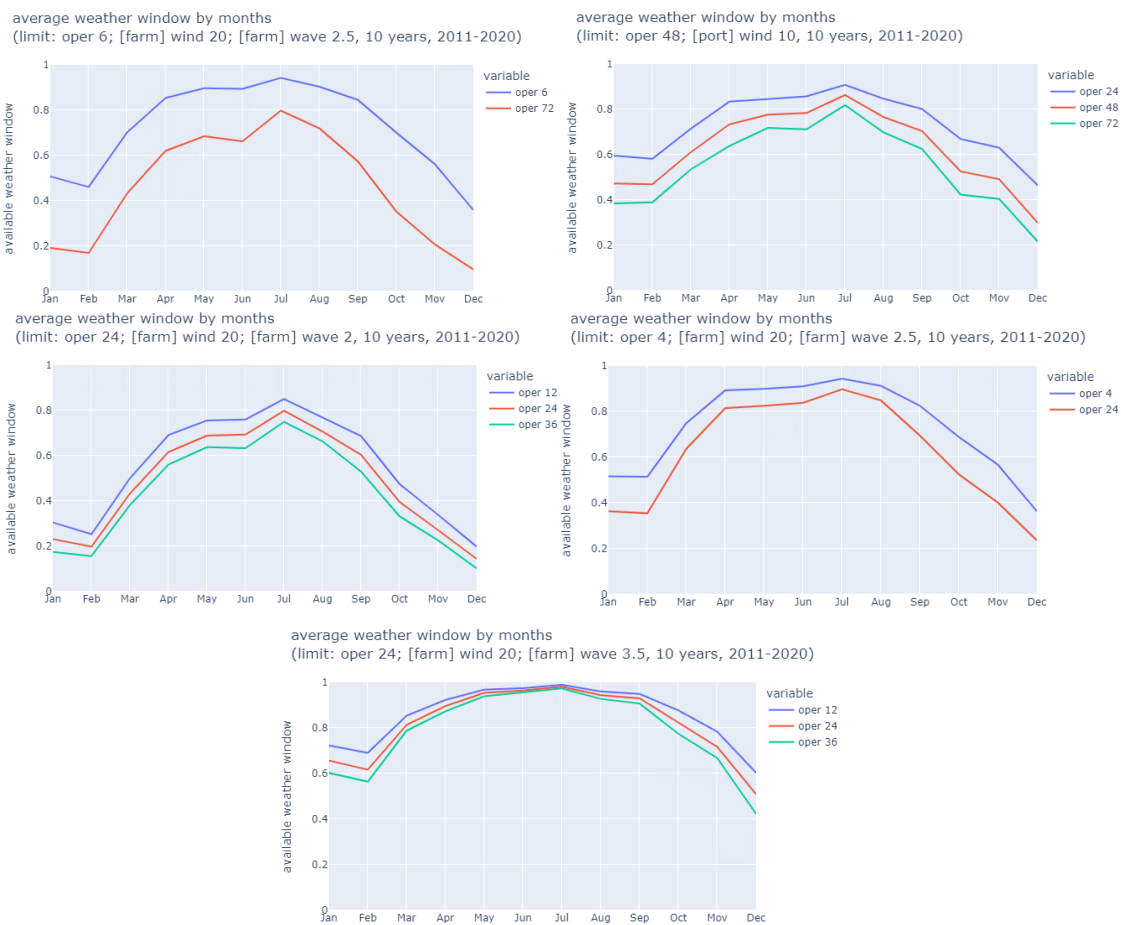


Figure 9: Effect of task duration on weather window availability. Longer task durations can be seen to result in lower available weather windows, with the effect most obvious when the task has relatively strict weather limits.

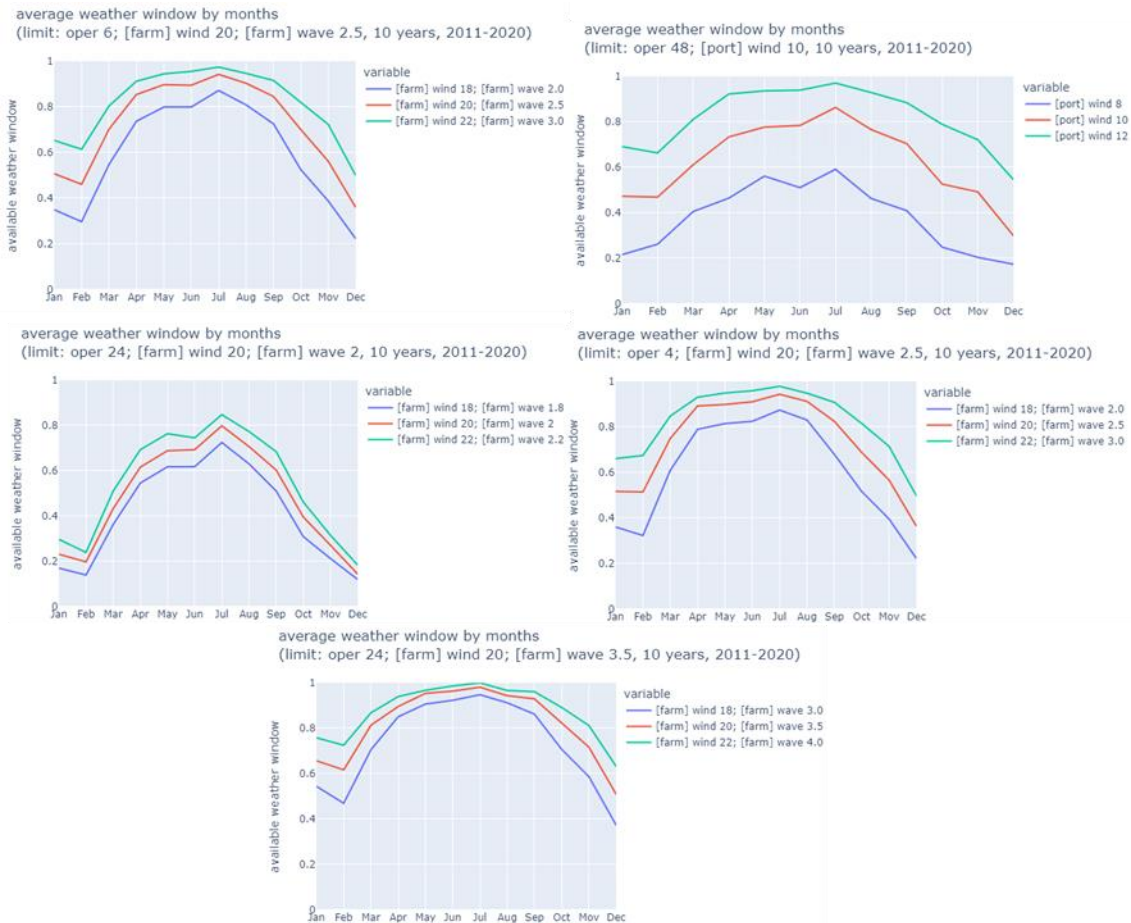


Figure 10: Effect of task weather limit on average weather window availability. Stricter limits naturally reduce the available weather windows for completing a task.

### 3.3 Simulator verification

As part of ongoing verification of the Ec Simulator, the tool was also used to run the baseline case at Site 1. It was also intended to run the upstream cases at Sites 1, 2, and 3 as well to do a comparison of location effects, but due to late changes to task definitions, the run times of these models, and time constraints with the imminent end of the CFA project, it was not possible to complete this analysis. The results of the baseline case are instead included here for reference.

A summary of the KPIs for the baseline case at Site 1 are shown in Figure 11, with LCOE calculated using a discount rate of 7.5 %. Predicted cashflows are summarised in Figure 12. The main output parameters of the installation module are summarised in Table 8.

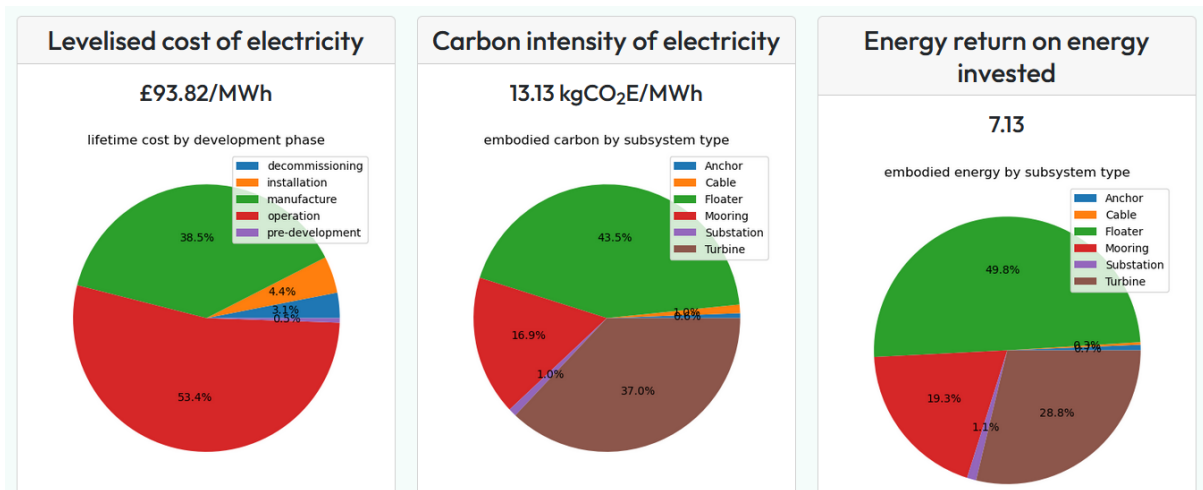


Figure 11: Summary of KPIs for the baseline case.

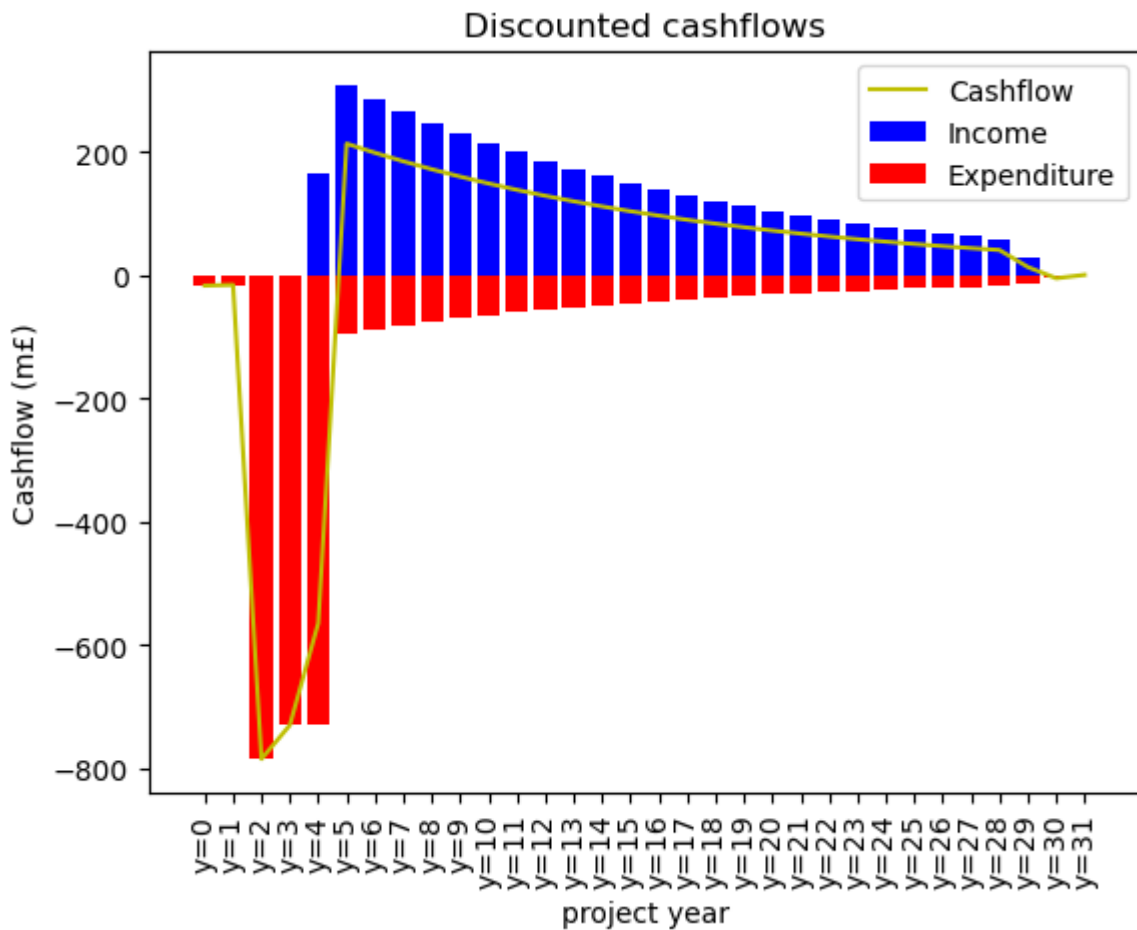


Figure 12: Predicted cashflows for the baseline case at Site 1.





Table 8: Main output of simulator installation module for the baseline case.

<b>Parameter</b>	<b>Value</b>	<b>Unit</b>
<i>Installation duration</i>	435.625	Days
<i>Installation rate</i>	6.5	Days/turbine
<i>No. turbines</i>	67	-
<i>AHTS total hire duration</i>	228	days
<i>AHTS utilisation</i>	0.992874	-
<i>onshore crane, 1000t total hire duration</i>	217	days
<i>onshore crane, 1000t utilisation</i>	1	-
<i>CLV total hire duration</i>	166	days
<i>CLV utilisation</i>	0.222166	-
<i>SOV total hire duration</i>	330	days
<i>SOV utilisation</i>	0.939134	-



## 4 Conclusions

This initial analysis has examined the sensitivity of a FLOW farm installation process to varying installation task requirements, including task durations, weather limits, and resource availability. Although limited in scope and run for a simplified set of tasks due to time constraints, the results highlight the importance of adopting emerging technologies that can safely and reliably operate in more severe weather conditions in order to minimise installation durations. Maximising the availability of resources to avoid bottlenecks will also be crucial, as increasing the availability of equipment such as cranes and anchor handling tug supply vessels was shown to improve installation rates.



## 5 References

Hersbach, H. et al., 2023. *ERA5 hourly data on single levels from 1940 to present*. [Online] Available at: <https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview> [Accessed 30 06 2023].