# Resource and Information Sharing for the Installation Process of the Offshore Wind Energy

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**Abstract.** The costs of the installation phase of the production system offshore wind energy plant have a considerable influence on the electricity production costs. For this reason, there are efforts undertaken to reduce the installation costs. The resources (e.g. installation vessels) and information (e.g. weather forecasts) play a vital role in the logistics installation network. This paper investigates the potential of a shared use of resources and the sharing of different information in the installation phase of the offshore wind energy by means of an event discrete, agent-based simulation. This is motivated by the large number of wind parks still to be installed in the future. To this end, simultaneously installed wind farm projects are examined and the effects of exchange of different information are investigated. The impact of weather restrictions on the processes of loading, transport and installation is taken into consideration. By means of the resource and information sharing approaches, significant savings potential was identified for the offshore wind energy installation.

**Keywords:** Resource sharing, Information sharing, Offshore wind energy, Installation phase, Logistics, Simulation study.

## 1 Introduction

The reduction of greenhouse gas emissions caused by fossil fuel fired energy generation has been urged by various initiatives worldwide [1]. In the context of the German energy transition, offshore wind energy (OWE) is a key technology [8]. This shift is mainly motivated by the high potential availability of wind, the resulting high number of full load hours and the good power plant characteristics of OWE [6]. Due to the planned exit from nuclear energy in Germany, OWE, as a form of energy generation that is able to provide base load, is an important component of the future energy mix. Both the specific challenges of OWE and the competition with conventional and other renewable energy sources lead to a need for optimization and the lowering of costs in all areas of the value chain of this young industry [8].

The logistics network for the installation of an offshore wind farm (OWF) is initially determined by the specific OWF project. Thereby, the number of wind energy turbines, the components to be installed and the characteristics of the construction site are defined [4]. The most important challenge of OWE logistics is the need to manage dynamic influences, especially the weather and sea conditions. Since logistics serve as a connecting element in SC, this requires that the optimization of logistics is considered as a cross-system matter [5]. In the context of the OWE installation phase, this does not only include considering the SC of one OWF but also taking into account OWFs that are to be installed at the same time. Thus, a consideration that extends across different SCs and projects is necessary due to the SC structure of an OWF as well as due to its project-based nature. The starting points for examining the network are the suppliers of semi-finished products and partial systems, which supply the majority of component and system manufacturers directly or via the ports of the network. Subsequently, the manufacturers deliver the components to the different ports from where the components are transported to the corresponding OWFs where they are installed [3]. The most critical processes for an economic OWF installation are the operations conducted by the installation vessel (IV). These vessels are cost intensive (up to 200,000 € per day) and affected by weather conditions. Furthermore, there are a limited number of installation vessels available on the market. For the case of a simultaneous installation of different OWFs, this resource has to be shared between different OWF projects. Therefore, all SC partners should have the same information base and align the processes for an optimal supply of the IV [4].

In this paper the authors examine the benefits of the application of the resource sharing (RS) and the information sharing (IS) approach to the installation-logistics of OWE. A presentation of previous scientific studies in the area of the planning and control of OWE installations, IS in supply chains (SC) as well as RS in logistics is presented in Chapter 2. Afterwards, in Chapter 3 the impact of IS in the RS logistics network for OWFs installation is evaluated by a discrete event simulation study. After discussing the simulation results (also in Chapter 3), a conclusion and outlook in Chapter 4 concludes this contribution.

## 2 Research Objectives – a Literature Review

The dynamic influences of weather and sea conditions make the transfer of planning and control concepts from other areas to the OWE a challenging task. Therefore, efficient planning and control of the logistics chain are expected to be an important contribution to reducing costs [13]. In scientific literature various works can be identified in this context. [10] describes the determination of an optimal installation schedule for OWFs based on a mathematical model using mixed integer linear programming. The approach involves different weather conditions, installation methods and layouts for the loading of the vessel. Due to the NP hard mathematical problem, the authors conclude that the approach is only usable for small scenarios. Based on the results of this contribution [11] presents a heuristic for the solution of larger problems. Several vessels, longer periods and a larger variety of weather conditions can be integrated in the heuristic. [2] presents another mathematical model for aggregated installation planning of OWFs. The model includes different operating conditions, such as weather conditions and vessel availability. [9] present a discrete event simulation for the transport and the installation of OWE turbines. The simulation model incorporates historical wind speeds and wave heights as well as a probabilistic approach to the analysis of the logistics chain. [5] discuss the scope and conditions of transferring the RS approach to the field of OWE logistics. As a result, the authors considered the needs of standardizing objects and processes as well as making supply and demand transparent as the basis for transferring RS into OWE logistics. [3] present a first simulation study to determine the benefits of RS in the OWE installation phase. The authors consider three simultaneously installed OWFs and include the transport and installation processes as well as the process times and the weather and seaway limits of the processes. The study considers the two approaches "OWF-specific resource allocation" and "resource pool for all OWFs". By means of the RS approach, significant savings potential was identified for the OWE installation.

Uncertainty in the SC is mainly the driver of the IS in SCs. [7] describe that sharing information improves the time and resource efficiency, the service level, and the cycle time in SCs. This leads to the need for the integration of defined information flows into the processes. Uncertainty in the existing literature is primarily named on demand uncertainties of the retailer. The SCs considered are primarily two stages and consider a substitutable consumption product (e.g. [12]). In literature three levels of IS are distinguished. The first level (called decentralised information control) describes the approach of decentralised information storage without the exchange of information between actors in a SC. Level two (named coordinated control) includes the exchange of information with the upstream and downstream actor in the SC. The third level (centrally operating information) provides the full exchange of information within the SC [7]. [2] and [4] present the first studies on IS in the installation phase of OWE. The authors analyse the effects of a limited information exchange. For this, the influences of weather conditions are included. The quality of the weather forecast for the transport and installation process is taken as uncertainty. [2] investigate the influence of the information items weather forecast and port capacity. [4] extend the analysis of [2] and consider a further information item (IV supply) and increase the number of OWT. The results of the two studies show that the high impact of the weather forecast on the processes can be reduced by the exchange of further information. Therefore, more accurate and reliable weather forecasts can help to improve the planning and control of logistics processes for OWF. Furthermore, the information exchange is a fundamental process for the industry to operate more effectively.

# 3 Simulation Study

## 3.1 Structure of the Simulation, Information Items and Simulation Scenarios

In this paper, an agent-based discrete event simulation model is proposed. This simulation model is based on real processes and process times. The partners of the OWE SC are represented as agents, that are able to take decisions based on available information and selected IS scenario. Based on the results of Beinke et al. [4], the information items "weather forecast" and "IV supply" are considered. The weather uncertainty comes essentially from the weather forecast. The decision-making is made based on this forecast in the simulation model and it is taken into account in the modelling of the processes. The objective of the “IV supply” information item is to use the suitable time windows of sufficient weather conditions for the installation processes. In this simulation model, the construction of three OWFs located in different distances from the shore is simulated. Due to the distance of each wind farm from the shore (OWF1 is the farthest, and OWF3 is the closest), the weather conditions of OWF3 are better than OWF2, and those of OWF2 are better than of OWF1. For the construction of each wind farm, the SC structure, the corresponding production ports, and the corresponding base port is determined. However, the resources like transport vessels and IVs are shared between different wind farms. Based on these two information items, there are four scenarios in this simulation study.

**Table 1.** Simulation scenarios.

| Scenario | Weather Forecast | Vessel Availability |
|---|---|---|
| S1 | No share | No share |
| S2 | Share | No share |
| S3 | No share | Share |
| S4 | Share | Share |

In the first scenario (S1), the shipment of the components from the production ports to the corresponding base port is performed as long as the base port still has capacity. In the base port, all incoming installation orders are collected in a pool. According to the FIFO principle, the project planner selects the installation order whose execution does not require a set-up of the IV. Indeed the shift from the top structure to the foundation and vice versa requires a set-up that can take until 7 days. In S2, the shipment of the components from the production ports is performed only if the weather forecast of the next days has an availability of 85%. Regarding the installation of the components, in this scenario, the orders are selected according to avoiding the setting-up of IVs and based on the weather forecast. In this context, the installation order with the best weather availabilities is selected first. In S3, the shipment of the components from the production ports to is performed only if at least one IV will be available in the next two days. The collection and the selection of installation orders is the same as for (S1). In the last scenario (S4), the foundations are shipped to the corresponding base port first. The shipment of top structure components are then performed after the final installation of all foundations. In addition, the decision when to ship a component depends, as in S2, on the weather forecast, and, as in S3, on the IVs availabilities. Regarding the installation of the components, the orders are selected according to the same logic adopted in S2.

### 3.2 Simulation Specifications

In order to specify the simulation, the specific parameters, the variables and restrictions as well as the indicators for measuring the performance will be presented in the following.

**Parameter**

| | |
|---|---|
| $WP_i$ | OWF $i$, with $i \in [1, 3]$ |
| $N_i$ | Number of wind turbines of OWF $i, \forall$ i $N_i = 80$ |
| $S$ | set of information sharing scenarios, with $\lvert S \rvert = 4$ |
| $s$ | Index of scenario $s \in [1, 4]$ |
| c | Type of component ($c \in [F, T, N, B]$; foundation, tower, nacelle and sets of rotor blades) |
| $BP_{is}$ | Base port associated to the OWF $i$ under scenario $s$ |
| $HLV_{sci}$ | Set of HLV used in scenario $s$ to transport components from the production ports to base ports $BP_{is}$. |
| $v$ | Index of a IV |
| $vl$ | Index of a HVL |
| $T$ | Planning horizon |
| Δt | time interval unit (1h); $\forall\, t \in T,\ t_{i+1} - t_i = \Delta t = 1$ |
| t | index of the planning period |
| $Start_i$ | Planned start of the construction of OWF $i$ |
| $MAXCap_{ic}$ | Maximal capacity of base port $BP_{is}$ |

For further and detail information about the process times and the process restrictions see [3].

**Variables and Constrains**

| | |
|---|---|
| $EndInst_{is}$ | End date of construction of OWF $i$ in scenario $s$ |
| $Cap_{ict}$ | Actual capacity of base port $BP_{is}$ in time period $t$ |
| $XC_{cit}$ | Number of component of type $c$ installed until planning period $t$ in the OWF $i$ |
| $StartHVL_{vls}$ | Start date of usage of HVL $vl$ used in scenario $s$ |
| $RelHVL_{vls}$ | Release date of HVL $vl$ used in scenario $s$ to transport components from the production ports |
| $StartIV_{vs}$ | Start date of usage of IV $v$ used in scenario $s$ |
| $RelIV_{vs}$ | Release date of IV $v$ used in scenario $s$ |
| $BinHVL_{vlst}$ | Binary variable that indicates if the HVL $vl$ is utilized at planning period $t$ under scenario $s$ |
| $StartBP_{is}$ | Start date of operation at base port $BP_{is}$ |
| $EndBP_{is}$ | End date of operation at base port $BP_{is}$ |

$$\forall\, i \in WP_i,\ \forall c \in [F, T, N, B];\ \forall\, t \in [0, EndInst_i],\ \sum_i XC_{cit} = N_i \quad (1)$$
$$\forall\, t' \in T, \sum_{t=1}^{t'} XC_{Tit} \leq \sum_{t=1}^{t'} XC_{Fit} \quad (2)$$
$$\forall\, t' \in T, \sum_{t=1}^{t'} XC_{Nit} \leq \sum_{t=1}^{t'} XC_{Tit} \quad (3)$$
$$\forall\, t' \in T, \sum_{t=1}^{t'} XC_{Bit} \leq \sum_{t=1}^{t'} XC_{Nit} \quad (4)$$

Constraint 1 restricts the sum of the built components during the planning period to the total number of wind turbines N for each wind farm. Constraint 2 ensures that the sum of installed towers for each wind farm does not exceed the sum of installed foundations. Constraint 3 guarantees that the sum of installed nacelles for each wind farm does not exceed the sum of installed towers. Constraint 4 ensures that the sum of installed sets of rotor blades for each wind farm does not exceed the sum of installed nacelles.

### 3.3 Simulation Results

From economical perspectives, OIT and AUIV are the main important factors and the decision criterion for the SC partners in the context of OWF. For OIT, especially the scenarios S2 to S4 provide improvements to the basic scenario S1. In particular, the improvements of OWF 1 and 3 in scenario 4 have to be named (reduction of 17.08 % and 30.90 %). Generally, IS leads to a shorter OIT. Referring to the logic adopted in S2 and S4, the selection of installation orders in these scenarios is per-formed based on weather availabilities. Since the weather condition of OWF3 is better than other OWFs, the installation orders of OWF3 are always prioritized. This leads to a better planning of the installation orders, and hence, the reduction of the whole installation time, the reduction in the net usage time of the base port and an increased utilization of the installation vessels. As a result, the OIT of OWF3 in S2 and S4 is strongly reduced compared to the S1. The RS of IV slightly improve the OIT, however, the AUIV is increased due to the fact that the supply of components is based on the installation vessel availability. In addition, the OIT each OWF is identical due to not prioritizing the installation orders of OWFs. The importance of AUIV is due to high charter rates of IVs. The higher utilization is also due to the reduction of OIT. The sharing of weather data and availability of the installation vessel affects the supply of components from production ports to the base ports as well. Accordingly, the usage of HVLs is optimized. This explains the decrease of the AUHLV in contrast to S1. The fact that the supply of top structure components is only performed after the installation of foundations, leads to significant reduction of AUBP and ABPUT, without affecting the OIT. The following Table 2 summarizes the average values of the simulation results in relation to the performance indicators per OWF and in total or as an average, respectively.

**Table 2**. Simulation results

| | | Simulation results | | | | Comparing of scenarios [%] | | |
|---|---|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 | S2 to S1 | S3 to S1 | S4 to S1 |
| OIT [d] | OWF 1 | 542.60 | 471.28 | 527.16 | 449.91 | -13.14 | -2.85 | -17.08 |
| | OWF 2 | 545.16 | 526.98 | 524.47 | 513.67 | -3.33 | -3.80 | -5.78 |
| | OWF 3 | 548.38 | 409.29 | 527.92 | 378.93 | -25.36 | -3.73 | -30.90 |
| | **Total** | **1636.14** | **1407.55** | **1579.54** | **1342.51** | **-13.97** | **-3.46** | **-17.95** |
| AUIV [%] | OWF 1 | 91.38 | 94.86 | 93.54 | 97.65 | 3.81 | 2.36 | 6.86 |
| | OWF 2 | 91.48 | 94.24 | 93.60 | 94.54 | 3.01 | 2.31 | 3.34 |
| | OWF 3 | 91.47 | 94.24 | 93.62 | 97.74 | 3.04 | 2.35 | 6.86 |
| | **Average** | **91.44** | **94.45** | **93.58** | **96.64** | **3.29** | **2.34** | **5.69** |
| AUHLV [%] | OWF 1 | 55.06 | 48.41 | 52.19 | 48.38 | -12.08 | -5.21 | -12.12 |
| | OWF 2 | 55.11 | 44.63 | 52.39 | 43.78 | -19.02 | -4.93 | -20.56 |
| | OWF 3 | 55.06 | 51.59 | 52.13 | 51.90 | -6.29 | -5.33 | -5.74 |
| | **Average** | **55.07** | **48.21** | **52.24** | **48.02** | **-12.47** | **-5.15** | **-12.81** |
| ABPUT [d] | OWF 1 | 551.30 | 482.42 | 538.60 | 460.64 | -12.49 | -2.30 | -16.44 |
| | OWF 2 | 552.72 | 537.34 | 536.28 | 514.38 | -2.78 | -2.97 | -6.94 |
| | OWF 3 | 554.74 | 417.46 | 538.54 | 384.96 | -24.75 | -2.92 | -30.61 |
| | **Total** | **1658.76** | **1437.22** | **1613.42** | **1359.98** | **-13.36** | **-2.73** | **-18.01** |
| AUBP [%] | OWF 1 | 56.25 | 59.48 | 61.05 | 41.48 | 5.75 | 8.53 | -26.26 |
| | OWF 2 | 56.43 | 60.10 | 63.87 | 40.31 | 6.50 | 13.18 | -28.57 |
| | OWF 3 | 56.67 | 57.42 | 60.48 | 40.53 | 1.32 | 6.72 | -28.48 |
| | **Average** | **56.45** | **59.00** | **61.80** | **40.77** | **4.52** | **9.47** | **-27.77** |

# 4 Conclusion and Outlook

In this contribution, based on the theoretical background of planning of OWE installation logistics as well as the approaches of IS and RS, a simulation study was presented. The study examines the benefits of IS in a RS logistics network for the simultaneous installation of three OWFs. The simulation was able to prove that the impact of IS of different information items has a significant effect on the installation times and the usage times of the resources and ports as well as on their degree of utilization. By means of the IS and RS approach, significant savings potential was identified for the OWE installation. Summarizing the influences of the performance measures clarifies that sharing information has a positive effect on the logistics network for the installation of the OWE. Limited resources and infrastructures can be better used by the presented approach. This allows the installation of more OWFs with existing resources in a defined period of time and a reduction of installation costs. Furthermore, the results of this contribution could be transferred to other fields and domains like maintenance of OWF.

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