Decommissioning cost modelling for offshore wind farms: A bottom-up approach

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Abstract:
The lifespan for offshore wind farms (OWFs) is between 20 and 25 years, and with a growing demand for renewable energy, the number of OWFs approaching decommissioning phase will dramatically increase in the coming years. This paper presents a new cost model by adopting a bottom-up approach for the removal and transportation phases of OWF decommissioning projects. Based on the experience in Oil and Gas industry, a project percentage breakdown analysis is also performed to expand the model further and estimate the overall decommissioning costs. To test the efficiency of the proposed cost modelling approach, the cost estimations for four OWF decommissioning case studies with different levels of public information and data are investigated. The numerical results revealed that in addition to the proposed cost model efficiently estimating the removal and transportation costs, it can also be adapted to estimate the overall decommissioning costs, by applying percentage weightages obtained from the percentage breakdown analysis.

Keywords: Offshore wind farm, offshore decommissioning, cost modelling, bottom-up approach.

1. Introduction

Public concern for climate change has resulted in new strategic policies in developed countries for promoting renewable wind energy resources. In the past two decades, offshore wind power technology has witnessed significant growth due to the recent improvements in construction costs and installation techniques [1]. According to the report provided by the International Renewable Energy Agency (IRENA) [2], the global installed offshore wind power capacity increased from 2.13 GW in 2009 to 23.36 GW in 2018. The European Union with a total capacity of 18.52 GW in 2018 was the global leader in offshore wind [2]. To keep the global leadership, the European Union has set an ambitious plan to increase its offshore wind capacity to 150 GW and 460 GW in 2030 and 2050, respectively [3-5]. All these extension plans demand an energy policy implemented based on economic and environmental concerns.

The expected design life for an Offshore Wind Farm (OWF) is estimated to be between 20 and 25 years [6,7] and with the desire for additional renewable energy resources, the number of OWFs approaching or entering decommissioning will dramatically increase in the next decades.

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However, due to extreme weather conditions, the decommissioning of OWFs can be considerably earlier than predicted. In Sweden, Yttre Stengrund OWF [8] decommissioned in 2015 after 15 years of operation and Utgrunden OWF [9] decommissioned in 2018 after 18 years of operations, both are examples of early decommissioning of OWFs. Although the design and technology of OWFs have been improved in recent years and they may last longer or can be partially replaced to extend the design life, the risk of early decommissioning remains a challenge. In recent years, several decommissioning programs (DPs) have been proposed for currently existed OWFs, such as Sheringham Shoal DP [10] and Lincs Limited DP [11]. In some cases, the DP has been prepared before the commissioning of OWF. The DP for the Cape Wind Energy wind farm is an example of such DPs. The economic feasibility and environmental impacts are two important factors that should be considered in evaluating DPs for OWFs. Hence, efficient cost modelling approaches are needed to estimate the decommissioning costs of OWF projects with a sufficient level of accuracy.

The life cycle costs of OWFs are predicted by cost modelling approaches. In recent years, researchers have been tried to provide different cost modelling approaches for cost estimation of OWF installations [12-16]. For example, Gil et al. [17] performed a sensitivity analysis for the cost and efficiency of the OWF components. Kaiser and Snyder [18] presented a cost modelling method based on the bottom-up approach by considering current technologies and expected market conditions for the period 2012–2017 to estimate stage-specific installation costs. The authors estimated the installation costs for three OWFs in the US, including Cape Wind, Bluewater Wind, and Coastal Point Galveston. Gonzalez-Rodrigue [19] reviewed available data in the literature and provided cost estimations for different components of OWF as a function of wind farm size. However, due to limited experience, few types of research have been done in the field of cost modelling for OWF decommissioning operations. Generally speaking, the decommissioning process of OWFs can be considered as the reverse of the installation process. However, the removal durations of different OWF components are expected to be lower than those needed for installation [20, 21]. Hence, the expected decommissioning costs are typically assumed to be less expensive than the installation. In some researches, the OWF decommissioning costs have been estimated by applying given percentage values to the installation costs [13, 22]. However, the wind farm layouts, water depths and site-specific quantities of each OWF field are unique, and although it is feasible to have a list of expected requirements, it is not feasible to have a single decommissioning execution plan [21]. Therefore, efficient cost models with site-specific strategies and information are needed to estimate the OWF decommissioning costs more accurately.

Lack of experience in any project can cause insufficient planning and costs, or likewise, overestimation can cause incorrect focus or wasted effort on minor tasks. OWF decommissioning is still quite new with limited data or experience available, which can lead to many uncertainties, increased assumptions and thus, less accurate estimates. In contrast, the oil and gas (O&G) industry is further developed in decommissioning and has better availability of historical data for costs, duration and equipment. However, even with this advantage, the O&G industry is still in the learning stages. The popular cost modelling approaches in the industry are analogous, parametric, and bottom-up models [23]. The analogous estimation method takes advantage of similarities of actual costs from a similar project, item or system and adjusts the estimate to suit the similar new event [24]. The parametric model is based on historical data and mathematical expressions, in which the cost is estimated based on the probabilistic relations between product features and cost. In parametric models, it is assumed that the same conditions that affected the past estimate will also affect the future estimate [24]. Several parametric models have been developed for OWF investments, installations, and decommissioning [14, 18, 25, 26]. The parametric methods have some limitations [23]. The bottom-up method is based on the detailed engineering analysis and calculation, which estimates the cost by considering all detailed cost components related to different tasks. The application of the bottom-up method demands a deep knowledge of the detailed design and configuration information for the various system components and accounting information for all material, equipment, and labour [27].

In this study, a new cost model is presented by adopting a bottom-up approach for the removal and transportation phases of OWF decommissioning. Based on the experience in the O&G industry, a project percentage breakdown analysis is performed to expand the model further and estimate the overall decommissioning costs. To verify the effectiveness of the proposed cost modelling approach, the costs calculations for a set of four OWF decommissioning case studies with different levels of available or predicted data are investigated and the obtained results are compared to those reported in other references.

The rest of this paper is organised as follows. In Section 2, the proposed cost modelling approach and its formulations for OWF decommissioning are explained in detail. The performance of the proposed cost modelling approach is investigated on a set of four OWF decommissioning case studies in Section 3. In Section 4, general discussions on the decommissioning costs of OWFs are presented. Finally, some concluding remarks and future research directions are presented in Section 5.

2. Proposed cost modelling approach

The main challenges in the development and assessment of the cost models for the OWF decommissioning are the lack of available data and sensitivity of the costs to the applied technology, site-specific information, logistic strategies, weather uncertainties, etc. In this study, a cost model is presented by adopting a bottom-up approach for the removal and transportation phases of OWF decommissioning. The model is flexible enough to enable improvement with additional or more reliable data and can be expanded with new or additional work scopes. The intent is to have strength in the modelling process irrespective of data reliability.

The general framework of the proposed process for developing an efficient cost model for any OWF decommissioning project is shown in Fig. 1. As can be seen from this figure, the proposed process for cost modelling consists of different steps as follows: i) Scope(s) and boundaries definition, ii) Strategy definition, iii) WBS definition, iv) Data collection, v) Cost model definition, vi) Data input, vii) Comparison, and viii) Refinement/expansion. Each of these steps can be explained as follows.

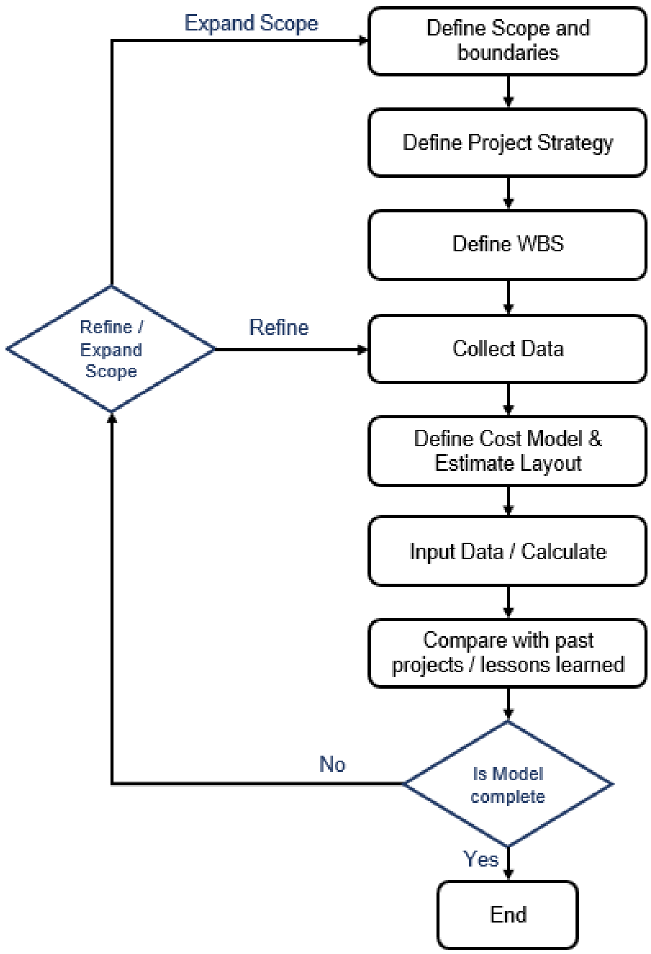

Figure 1. Flowchart of the cost model development for OWF decommissioning

Step 1: *Scope(s) and boundaries definition*

In the first step, the scope(s) of work should be clearly defined including boundary limits. A given scope can include all stages of a complete decommissioning project or part stages such as this study. Scopes of work can be rolled up to suit estimation layout or project requirements. Overall scopes of work considered in this study are shown in Table 1.

Table 1. The scopes of work considered in this study

Scope (S_i)	Removal Operation(s)	Scope (S_i)	Removal Operation(s)
S_1	WTG Topside	S_6	MM Topside
S_2	WTG TP	S_7	MM Foundation
S_3	WTG Monopile	S_8	Cable in Situ
S_4	OS Topside	S_9	Cable Removal
S_5	OS Foundation		

Step 2: *Strategy definition*

A project strategy is developed based on field layout, depth, the number of structures, optimising vessel mobilisation and lifting operations, maximising safety and environmental requirements whilst managing risk assessment mitigations. Cost efficiency should also be maximised based on the selection of vessels, activity durations, contract strategies, and major cost risk exposure stages such as offshore preparation or offshore removal. In this study, the project strategies will be defined for each OWF based on the available information or appropriate estimations.

Step 3: *WBS definition*

One of the important parts of any decommissioning project is the definition of WBS. A WBS has several functions during the lifetime of a project and can be used to:

- Define boundaries of the scope of work, including the primary level of interest.
- Allocate and monitor costs for the development of budget or cost control during the project, such as monitoring the estimated costs versus actual costs.
- Schedule layout – development and use of schedules that will use levels defined within the WBS to define schedule levels, also linked to identifying cost levels.

O&G UK has developed a WBS for decommissioning stages [28], which is used to identify each stage of decommissioning for offshore O&G projects. Marine Scotland has also suggested a WBS for OWF decommissioning [29]. In this study, the WBSs provided by mentioned references were reviewed and modified to provide a new WBS for a complete OWF decommissioning project. Fig. 2 shows the proposed general WBS alongside the codes for each phase of the OWF decommissioning project. As it can be seen from Fig. 2, the OWF decommissioning activities can be categorised into 10 phases as follows: i) Project management, ii) Project preparation, iii) Offshore preparation, iv) WTG removal, v) OS removal, vi) MM removal, vii) Cable removal/leave in situ., viii) Seabed clearance, ix) Recycle and waste management and x) Monitoring. In the current study, the cost modelling for phases iv up to vii (i.e., codes 4-7) will be developed. However, the costs for other phases will also be estimated based on a percentage breakdown analysis which will be discussed later in Section 4.2.

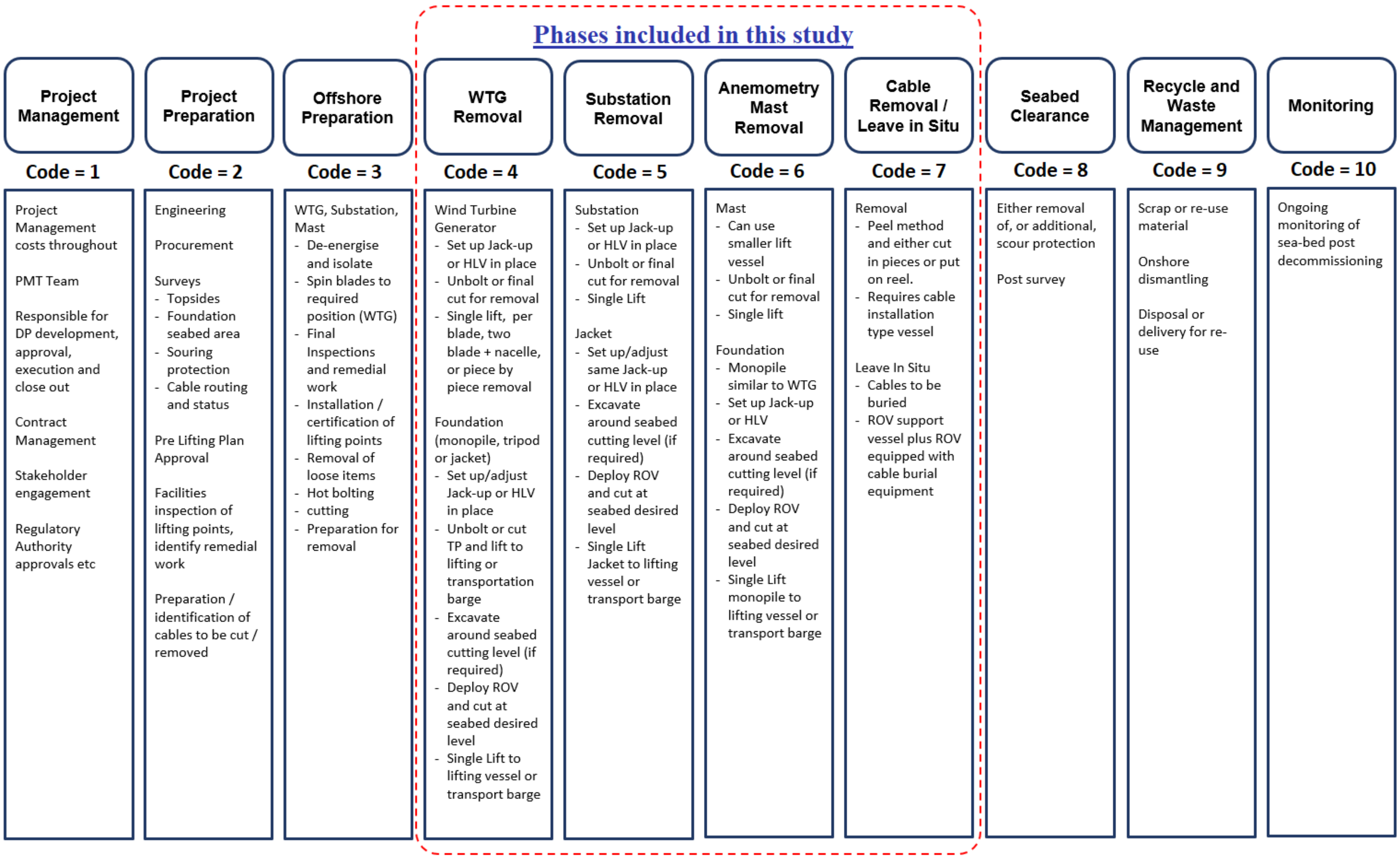

Figure 2. General WBS for OWF decommissioning proposed based on WBSs in O&G UK [28] and Marine Scotland [29]

In the third step, the WBS for the OWF decommissioning project is defined. The proposed detailed WBS for OWF removal stages is shown in Table 2, in which each removal phase has consisted of several levels and sublevels (or activities) identified by their codes. The codes in the WBS are defined to facilitate the project cost management in practice and they will be used to represent the cost items in this study. For different OWF projects, the main drivers will determine the best layout of WBS at the highest levels. The WBS can also be amended to identify a given contract, field or structure.

Step 4: *Data collection*
Data collections play an important role in the accuracy of cost estimations [33]. In this study, the data related to each OWF decommissioning project will be collected from available resources and historic data. In the absence of reliable data, appropriate assumptions will be developed and applied in the numerical tests.

Step 5: *Cost model definition*
Generally speaking, the cost model should be selected based on available data, application of calculations, presentation of the cost estimate, the experience of the user, and available time to produce the model. In this study, the cost model will be developed based on the bottom-up process due to the high dependency on the WBS and lack of reliable or range of available data. The model will also provide flexibility to improve when more data becomes available and will also allow expansion if more stages of the project are applied, or a new scope is added. The cost model formulations will be presented in Section 2.1.

Step 6: *Data input*
In this step, the data received or estimated will be input to the cost model developed in Step 5 to calculate specific or rolled up estimates.

Step 7: *Comparison*
In this step, the estimated costs will be compared to those reported in other references. There is limited data and history available for OWF decommissioning projects. A detailed estimate was provided by Cape Wind Energy [30], but others were either vague or even differed depending on the intent of the data provided. Vessel day rates varied, which will be estimated in this study if they are not available. In cases where data is limited or only given as an overall value, the best estimate will be provided and the results will be compared to those reported in DPs.

Table 2. The WBS considered in this study.

Level	Code	Task title	Level	Code	Task title
1	**4**	**Removal of WTG**	**1**	**6**	**Removal of MM**
2	4.1	WTG (topsides)	2	6.1	MM (topsides)
3	4.1.1	Lifting vessels (e.g., JUV)	3	6.1.1	Lifting vessels
3	4.1.2	Transportation (e.g., BV)	3	6.1.2	Transportation
3	4.1.3	Marine support (e.g., TBs)	3	6.1.3	Marine support
2	4.2	Foundation (e.g., monopile)	2	6.2	Foundation (e.g., monopile)
3	4.2.1	Lifting vessels	3	6.2.1	Lifting vessels
3	4.2.2	Transportation	3	6.2.2	Transportation
3	4.2.3	Marine support	3	6.2.3	Marine support
3	4.2.4	ROV support	3	6.2.4	ROV support
1	**5**	**Removal of OS**	**1**	**7**	**Cable decommissioning activities**
2	5.1	Topside	2	7.1	Cable removal
3	5.1.1	Lifting vessel	3	7.1.1	Array cables
3	5.1.2	Transportation	3	7.1.2	Export cables
3	5.1.3	Marine support	2	7.2	Leave in situ
2	5.2	Foundation (e.g., jacket)	3	7.2.1	Array cables
3	5.2.1	Lifting vessels	3	7.2.2	Export cables
3	5.2.2	Transportation			
3	5.2.3	Marine support			
3	5.2.4	ROV support			

Note: The codes were assigned based on the overall layout of WBS proposed in Fig. 2.

Step 8: *Refinement/expansion*

The cost model will be refined/expanded as follows:

- **Refinement:** Any additional or up to date information that can increase accuracy can be recalculated in the model. This should have no impact on the initial steps of the model process or change the model, where only collected data would be amended. For the model refinement, Steps 4-7 should be repeated to achieve the required accuracy.
- **Scope expansion:** Should the model be expanded to amend from partial to full scope, or include additional scope(s), then each step would be increased and amended accordingly. In this case, the initial estimate can remain under the same WBS, which would become part of an expanded WBS. Any new scope can follow the same process from Step 1 to Step 6.

2.1. Decommissioning cost model

In this subsection, the mathematical formulations for the cost estimation of different work scopes listed in Table 1 will be presented. It is assumed that each scope consists of several activities. The total decommissioning cost C_{total} for all scopes of work can be mathematically expressed as follows:

$$C_{\text{total}} = \alpha_c \sum_{i=1}^{W} C_{S_i} \tag{1}$$

where, C_{S_i} represents the ith scope of work, $\alpha_c > 1$ is the contingency parameter, and W is the number of scopes. According to the work scopes considered in Table 1, the total cost C_{total} can be alternatively written as follows:

$$C_{\text{total}} = C_{\text{WTG}} + C_{\text{OS}} + C_{\text{MM}} + C_{\text{c}} \qquad (2)$$

where, C_{WTG} is the cost for all of WTG scopes, C_{OS} is the cost for all OS scopes, C_{MM} is the cost for all MM scopes, and C_{c} is the cost for all cable scopes.

As the first up to third scopes are related to the WTG removal, the cost for all of the WTG scope C_{WTG} can be obtained as:

$$C_{\text{WTG}} = C_{S_1} + C_{S_2} + C_{S_3} \qquad (3)$$

where, C_{S_1} represents the cost for all removal activities performed on WTG topsides, C_{S_2} indicates the cost for TP removal of WTG, and C_{S_3} is the cost for the removal of the WTG foundations.

Cost for all of OS activities C_{OS}, which includes the fourth and fifth scopes, is expressed by:

$$C_{\text{OS}} = C_{S_4} + C_{S_5} \qquad (4)$$

where, C_{S_4} is the cost for all removal activities performed on OS topsides and C_{S_5} is the cost for the removal of OS foundations.

Cost for all MM scope C_{MM}, which includes the sixth and seventh scopes, can be obtained via:

$$C_{\text{MM}} = C_{S_6} + C_{S_7} \qquad (5)$$

where, C_{S_6} is the cost for all removal activities performed on MM topsides and C_{S_7} is the cost for the removal of MM foundations.

Cost for cable scope, if a mixture of removal and retain, C_{c}, which includes eighth and ninth scopes, is calculated as follows:

$$C_{\text{c}} = C_{S_8} + C_{S_9} \qquad (6)$$

where, C_{S_8} is the cost for retention of cable, such as burial, and C_{S_9} is the cost for cable removal activities. The cost for cable retention, C_{S_8}, is calculated by:

$$C_{S_8} = C_{S_8,C_1} + C_{S_8,C_2} \tag{7}$$

where, C_{S_8,C_1} is the cost for retention of inter-array cables, such as burial, and C_{S_8,C_2} is the cost for retention of export cable.

The cost for cable removal, C_{S_9}, is written as:

$$C_{S_9} = C_{S_9,C_1} + C_{S_9,C_2} \tag{8}$$

where, C_{S_9,C_1} is the cost for removal of inter-array cable and C_{S_9,C_2} is the cost for the removal of the export cable.

In decommissioning operations, a given scope S_i includes different activities performed by different types of equipment/vessels. Hence, the cost of a given scope (C_{S_i}) can be expressed in terms of the costs of its activities as follows:

$$C_{S_i} = \sum_{n=1}^{Q} C_{S_i,V_n} \tag{9}$$

where, C_{S_i,V_n} represents the cost for multiple activities performed per the ith scope of work (S_i) by vessel V_n, and Q is the number of vessels required to perform the ith scope of work (S_i). The total cost for a given vessel/equipment V_n per ith scope of work (S_i), C_{S_i,V_n}, is given as follows:

$$C_{S_i,V_n} = C_{\mathrm{MB},V_n} + C_{A_i,V_n} \tag{10}$$

where, C_{MB,V_n} represents the mobilisation/demobilisation costs for a given vessel/equipment V_n (one-time charge), C_{A_i,V_n} is the cost for multiple activities performed per scope of work S_i by V_n, and i is the designated scope of work number. The cost of a given vessel/equipment V_n activities within the ith scope (S_i), which is represented by C_{A_i,V_n}, is calculated as follows:

$$C_{A_i,V_n} = C_{\mathrm{DR},V_n} T_{A_i,V_n} F_{A_i,V_n} \tag{11}$$

where, C_{DR,V_n} indicates the day rate of the selected vessel/equipment V_n, T_{A_i,V_n} is the estimated duration for V_n performance per facility within the ith scope (S_i), and F_{A_i,V_n} is the amount of facilities/trips/rotations relevant to the scope S_i and vessel/equipment V_n. For example, the lifting and movement costs for lifting vessel 1 activities within the first scope (S_1) can be expressed by using Equation (11) as follows:

$$C_{A_1,V_1} = C_{\mathrm{DR},V_1} T_{A_1,V_1} F_{A_1,V_1} \tag{12}$$

where, C_{DR,V_1} represents the lifting vessel V_1 day rate, T_{A_1,V_1} is the estimated duration for lifting vessel V_1 performance per facility within the scope S_1, and F_{A_1,V_1} is the amount of facilities relative to the scope S_1 and vessel V_1.

The cost for manpower P_n to perform activities on vessel/equipment V_n within scope S_i, C_{A_i,P_n}, is written as follows:

$$C_{A_i,P_n} = C_{\mathrm{DR},P_n} T_{A_i,P_n} F_{A_i,P_n} \tag{13}$$

where, C_{DR,P_n} represents the day rate for manpower, T_{A_i,P_n} is the estimated duration for activities within the scope S_i on vessel/equipment V_n, and F_{A_i,P_n} is the amount of manpower to perform the activities within the scope S_i on vessel/equipment V_n. It should be noted that the manpower costs are included in overall costs and are not identified separately.

In the investigated decommissioning examples, the duration for vessel transport from field to port, T_{V_n}, is calculated as follows:

$$T_{V_n} = \frac{D_{A_i}}{K_{V_n}} \tag{14}$$

where, D_{A_i} is the distance from the ith facility to the port and K_{V_n} is the transit speed of the vessel/equipment V_n. It is worth mentioning that the unloading time at the port will also be added to the transport time.

By using the above-mentioned formulations, the total decommissioning cost can be calculated for the different scopes of works considered in this study (i.e., Table 1). As the different currencies in different decommissioning sources were used for the cost estimations, the costs in this study will be in £ GBP, NOK and $ US Dollars to compare with original sources. However, final comparisons between the different decommissioning case studies will be given in £ GBP. In addition, all durations will be assumed in days.

2.2. Main Drivers

The main drivers need to be identified to enable the model to provide the best possible estimate. The model will be affected by high-cost items, durations and sequence of events. OWFs have numerous offshore activities at different locations, utilising high-cost vessels and equipment, where the impact of inefficient planning, sequence or work performed will result in higher costs. Identifying the main drivers will also allow optimising all operations and thus save costs. Typical main drivers for OWF decommissioning are as follows:

- Availability and range of selection of vessels, which give a range of day rates, including mobilisation/demobilisation costs
- Quantity of WTGs to be removed, which will define the vessel selection, and also project and contract strategy suitable to maximise cost-effectiveness
- Depth, weight and type of foundation, which may limit the range of vessel types and thus higher rates
- Marine support, port fees and fuel can be underestimated
- Schedule, specifically offshore durations per location for preparation and removal stages
- Market rates will vary and can increase or decrease based on supply and demand requirements
- Safety and environmental requirements need to be assessed, which may limit certain activities or parallel operations

2.3. Proposed Day Rates

Vessel rates are subject to change due to market conditions, availability of vessels, or typical supply and demand changes. For the vessel day rates, the proposed model will apply any available rates in relevant DP, which are limited, or will predict the best estimate. Different sources of day rates were reviewed and the best estimates were selected to use in this study as listed in Table 3. In the numerical tests, the day rates in Tables 3 will be used, if they are not available in the relevant sources.

Table 3. Proposed vessel day rates for cost calculation of decommissioning projects.

Item	Typical vessel	Day rate	Mobilisation/demobilisation	Comments
1	WTIV	£200,000	N/A	Adapted from Ref. [29]. Mobilisation/ demobilisation costs require estimation
2	JUV	£112,600	£405,000	Adopted from Ref. [31].
3	HLV	£135,000	£500,000	Adopted from Ref. [31].
4	CBV	£71,429	N/A	Adapted from Ref. [30]. Mobilisation/demobilisation costs require estimation.
5	CLV1- intra	£80,000	£360,000	Adapted from Ref. [31]. Assumed same installation vessel used for burial or removal.
6	CLV2- export	£100,000	£360,000	Adapted from Ref. [31]. Assumed same installation vessel used for burial or removal.
7	BV	£15,000	£200,000	Adapted from Ref. [32]. The mobilisation rate appears high. Euro value used in £GBP (1€≃1£).
8	TB	£10,000	N/A	Adapted from Ref. [32]. Euro value used in £GBP. No exchange rate applied (1€≃1£).
9	ROV	£3,500	£35,000	Adapted from Ref. [32]. The mobilisation rate appears high. Euro value used in £GBP (1€≃1£).

2.4. Contingency

Contingency is used to cover against unknowns or expected high-risk exposure cost that cannot be fully predicted. Contingency can be applied per cost item, specific items or as a general percentage applied to the final cost. Contingency, which depends on each company policy, should be monitored and managed throughout the project. In this study, contingency will be applied based on available data, or if not available, a 10% weather contingency (i.e., $\alpha_c = 1.10$) will be applied. Weather will affect offshore preparation, offshore removals and transportation.

3. Numerical examples

To test the efficiency of the proposed cost modelling approach, four cost modelling case studies of OWFs with different levels of available or predicted data will be investigated in this section as follows:

1. **Cape Wind Energy [30]:** The DP [30] provided a detailed breakdown estimate for durations and day rates per stage. All data will be used in this case study to verify the proposed model.
2. **Sheringham Shoal [10]:** The available DP [10] for this OWF provided the overall duration and costs. However, a detailed breakdown was not provided. Therefore, the decommissioning cost for this OWF will be estimated based on the best-estimated durations and vessel day rates in Table 3.
3. **Lincs Limited [11]:** In the DP [11] of Lincs OWF, detailed durations for WTG removal were provided only. However, Ref. [11] does not provide the vessel day rates. The decommissioning cost for this OWF will be estimated based on the day rates proposed in Table 3.
4. **Example OWF:** This is a benchmark OWF with a capacity of 140x3.6 MW. The layout and size of this OWF are assumed based on Ref. [31]. The removal durations and costs will be calculated based on the best estimates.

The overall information about the investigated OWFs is summarised in Table 4. Moreover, the detailed information on applied vessels/equipment for each OWF case study are presented in Table 5 to keep the paper to a manageable size. It is worth mentioning that some of the information in Table 5 were gathered from the DPs published in the literature, while others are assumed in this study to provide the best cost estimate. In the investigated case studies, readers will be referred to Table 5 for the detailed assumptions required for the cost calculations. Each OWF case study will be provided with an estimate of the removal stages and full project costs.

3.1. Case study 1: Cape Wind Energy

Cape Wind Energy was a proposed OWF on Horseshoe Shoal in Nantucket Sound off Cape Cod, Massachusetts, US. After years of seeking approval, the project was not sanctioned. The case study is the most compatible case for the proposed cost model due to the level of available details. This OWF consists of 101×3.6 MW WTGs and one OS. In the cost calculations, the removal of WTG topsides is identified as the first scope S_1, TP and monopile removal costs are rolled up to S_2, OS scopes are identified separately as S_4 and S_5, and cable removal scope is identified as S_9.

Table 4. Information of OWF case studies investigated in this study.

	Description	Unit	Cape Wind Energy [30]	Sheringham Shoal[10]	Lincs Limited [11]	Example OWF [31]
General	Commissioned	Year	N/A	2012	2012	N/A
	Farm capacity	MW	364	316.8	270	504
	Depth	m	17-44	15-23	8-18	15-30
Turbines	WTGs	Quantity×MW	101×3.6	88×3.6	75×3.6	140×3.6
	Topside weight	tonnes	337	475	435	N/A
	Foundation type	Structure	Monopile	Monopile	Monopile	**Monopile***
	Foundation weight	tonnes	285-650	200	515-610	N/A
	Removal duration	Days	333	300 [10]	171 [11]	**448***
MM	Mast	Quantity	1	**2***	1	**1***
	Foundation	Structure	N/A	N/A	Monopile	Monopile
OS	Substation(s)	Quantity	1	2	1	**1***
	Topside weight	tonnes	2672	875	2250	N/A
	Foundation type	Structure	Jacket	Monopile	Jacket	**Jacket***
	Foundation weight	tonnes	304	N/A	970	N/A
	Removal duration	Days	6	**8***	**4***	**6***
Estimates	Total duration	Days	339	308 [10]	175	**454***
	Duration per WTG	Days	3.30	3.41	2.28	**3.20***

*All entries are assumed/estimated in this study.

The Cape Wind Energy DP [30] provided a detailed breakdown of durations and final costs, that were fully used in the present model. It should be noted that the details of MM are not available in the Cape Wind Energy DP [30]. In this study, the removal cost of MM will not be considered and it is assumed that it was included in the overall cost. In this study, it is assumed that a single JUV will be used for the removal of WTG topsides, and all of OS. It should also be noted that the Cape Wind Energy DP [30] mentioned that a float over would be used, but JUV showed in their estimate. Hence JUV rates will be applied in this study. It is assumed that two BVs with the transportation capacity of 2 WTG topsides or TPs+foundations units per trip will be used for transport. TBs are also required for various support activities. Detailed vessel day rates and overall estimates were also provided in the mentioned DP. Estimates are in $ US Dollars. In this study, the cost estimates for this OWF will be changed to £ GBP, if required for comparison purposes. The exchange rate will be used based on average monthly rates at the time of writing this study. In Cape Wind Energy DP [30], the ROV or cutting services were also not identified, which will be excluded in this study for comparison purposes. The cable removal values were provided, but a single estimate was provided only for both inter-array and export cables. Pile removal scope and fuel costs were provided but will be excluded in this study to enable equal comparison with other estimates, and ease of locating referenced values. The overall decommissioning strategy for Cape Wind Energy OWF can be found in Table 5.

Table 5. Applied vessels/equipment for different OWF case studies investigated in this study.

	Cape Wind Energy			Sheringham Shoal			Lincs Limited			Example OWF		
Main actions	Vessel	Quantity	Comment(s)	Vessel	Quantity	Comment(s)	Vessel	Quantity	Comment(s)	Vessel	Quantity	Comment(s)
Removal of all WTG	JUV	1	Requires TBs and anchor handling. The Cape Wind Energy DP [30] shows TBs only.	JUV	2	Use 2 JUVs in parallel [10]	JUV 1	1	Removal durations are available from Ref. [11] for the cycle of 9 turbines.	JUV 1	1	Self-propelled
Removal of WTG foundations + TPs	DBV	1	Cape Wind Energy DP [30] suggests a DBV				JUV 2	1	Removal durations are available from Ref. [11] for a cycle of 8 foundations+TPs.	JUV 2	1	Self-propelled
Transport of WTG topsides	BV	2	2×BVs are required: 1 in transit, 1 in field	JUV	2	It is assumed that five WTGs with foundations can be loaded on the deck space of JUV [10]	BV	1	One BV is assumed.	BV	2	2×BVs are assumed, 1 in transit, 1 in field
Removal of OS topsides Removal of OS foundation	JUV	1	Requires TBs and anchor handling. The Cape Wind Energy DP [30] shows TBs only.	HLV	1	A single lift will require BVs.	HLV	1	It is assumed in this study.	HLV	1	It is assumed in this study.
Transport of OS topside	BV	1	One BV is assumed.	BV	1	One BV is assumed.	BV	1	One BV is assumed.	BV	1	One BV is assumed in this study.
Transport of OS foundation	BV	2	2×BVs are assumed.	BV	1	One BV is assumed.	BV	1	One BV is assumed.	BV	1	One BV is assumed in this study.
Marine support (TBs, crew boat and anchor support)	-	Var	As required per lifting vessel	TB	Var	As required per lifting vessel	-	Var	It will not be included in the estimate.	TB	Var	As required per lifting vessel
Removal of MM topside	-	-		-	-		-	-		CBV	1	The same vessel will be used for transportation.
Removal of MM foundation	-	-		-	-	Not stated, it is assumed that rolled up in estimated costs.	-	-	Not stated in Lincs DP [11]. It is assumed that rolled up in estimated costs.	JUV	1	
Transport of MM topside	-	-	Not stated, it is assumed that rolled up in estimated costs.	-	-		-	-		-	-	-
Transport of MM foundation	-	-		-	-		-	-		BV	1	One BV is assumed in this study.
ROV activities	-	-		ROV	Var	Assumed in this study to support foundation excavation, lifting gear fitting and cutting. ROV has not been stated in the Sheringham DP estimate [10].	ROV	Var	It is assumed in this study to support foundation excavation, lifting gear fitting and cutting. ROV has not been stated in Lincs DP estimate [11].	ROV	Var	Assumed in this study to support foundation excavation, lifting gear fitting and cutting.
Suitable vessel for cable removal	CLV	1	One cost is given for all cable scope.	CLV	1	Assumed in this study for leave in situ. activities. It has not been stated in the Sheringham DP estimate [10].	CLV	1	It is assumed in this study for leave in situ. activities. It has not been stated in Lincs DP estimate [11].	CLV	1	It is assumed for cable inspection and burial activities

Table A.1 shows the estimated durations for the lifting and transportation of WTGs and OS of the Cape Wind Energy OWF. As it can be seen from Table A.1, it is expected that the WTG topsides removal using JUV would take 181 days plus 101 days for their transportation using two BVs. The TPs+foundations removals are predicted to take 152 using JUV, while two BVs will transport them to the port in 101 days. In addition, based on Cape Wind Energy DP [30], the cable removal process in S_9 will take 208 days using CLV. Based on these durations, Table B.1 presents the detailed cost estimations for different scopes of work in the Cape Wind Energy OWF. From Table B.1, it is observable that the removal costs of the WTGs and OS are about \$36.7M and \$0.65M, respectively. The total removal cost of the project is about \$46.5M, which includes the cable activities costs and removal cost of the WTGs and OS. It is worth mentioning that the Cape Wind Energy DP [30] was assumed that the contingency is included in the day rates of the vessel/equipment.

3.2. Case study 2: Sheringham Shoal

Sheringham Shoal OWF consists of 88×3.6 MW WTGs, two OSs, 80 km inter-array cables, and 82 km export cables. The details for the MM are not available in Sheringham Shoal DP [10], which will not be considered in this study. Similarly, ROV activities have not been reported by Ref. [10], which may be included in overall costs. However, in this study, the ROV activities will be included in the cost estimations. The Sheringham Shoal DP [10] suggests utilising two JUVs in parallel for WTG and TP+foundation removals, subject to risk assessments. The transportation of removed components will be performed by the same non-propelled JUVs with the capacity of 5 WTG or TP+foundation units per trip. The removal process for OS topsides and their jackets will be performed by HLV, while a BV is assumed for the transportation. Regarding the cables, no specific values were given. Sheringham Shoal DP [10] stated that they will be left in situ. According to the mentioned points, the overall decommissioning strategy for Sheringham Shoal OWF can be summarised as shown in Table 5. In this case study, all WTG topsides and foundations estimations will be rolled up under the work scope S_1. Similarly, all OS scope will be rolled as S_4, and the cabling scope will be identified as S_8.

Sheringham Shoal DP [10] provided a breakdown of the final cost, and a total duration of 308 days. There were some gaps in detailed data for costs and duration between stages that were estimated for purpose of this model. Duration and overall cost data were collected from Sheringham Shoal DP [10] with the following notes and assumptions:

- In Ref. [10], no vessel/equipment day rates were provided. In this case study, the proposed day rates for vessels/equipment in Table 3 will be applied.
- Estimates have been done in NOK and changed to £ GBP. For comparison purposes, the exchange rate will be used based on Ref. [10].

- The overall duration of 308 days was applied with durations estimated between WTG and OS scopes [10]. Transport duration of 1.25 days is applied due to allowing time for offloading 5 WTGs from a JUV.
- There is no information available on the type of cable retention scope or vessel used. However, it is assumed that a full inspection and burial is required with a CLV and using day rates proposed in Table 3.

The estimated durations for the removal and inspection of different components of the Sheringham Shoal OWF are presented in Tables A.2 and A.3. As it can be seen from Table A.2, the total removal duration for 88 WTGs is assumed as 300 days, considering 3.41 days for each WTG. The assumption of 1.25 days per trip for transportation has resulted in 44 days of transportation for WTGs and TP+foundations. As it can be seen from Table A.3, the total duration for cables left in situ. activity using CLV is expected to be about 111 days. Table B.2 presents the detailed cost calculations based on the estimated durations for different work scopes of the Sheringham Shoal OWF. Observing this table, the costs excluding contingency for cables left in situ. activities and removal of WTGs and OS are estimated to be about £10.5M, £54.2M, and £3.06M, respectively. From Table B.2, it is observable that the total removal cost for these work scopes including the 30% contingency adopted from Ref. [10] is estimated to be about £88.1M.

3.3. Case study 3: Lincs Limited

Lincs Limited OWF located on the east coast of England is the third investigated case study. This OWF consists of 75×3.6 MW WTGs and one OS. The details for the ROV and MM activities are not available in the DP of this OWF [11]. In this case study, the ROV activities will be assumed for the WTG and OS foundations removals. However, the removal cost of MM will not be considered. The removal durations for WTGs were taken from Lincs DP [11]. However, all other durations will be estimated in this case study. The Lincs Limited DP [11] assumed a JUV for WTGs and OS lifting operations, while the removed components will be transported by a BV with the capacity of 9 WTG topsides per trip or 8 TPs+foundations per trip. It is also assumed that required TBs will be used to support different operations. The assumptions on the applied vessels/equipment for the Lincs Limited OWF are shown in Table 5. In this case study, all WTG topsides and foundations costs will be rolled up under the first scope of work S_1. Similarly, OS removal operations will be rolled as the fourth scope of work S_4. Cable scope is identified as the eighth scope of work S_8. Durations and overall cost data were collected from Lincs Limited DP [11] with the following note and assumptions:

- The Lincs estimate in Ref. [11] is focused mainly on the removal of WTG removals [11]. However, the cost estimation in this case study will be based on a mixture of Lincs values for WTG removals and the best estimates for the remainder of removal phases.
- The Lincs Limited DP [11] assumed 12% contingency which will also be applied in this study.

- Vessel rates were provided by Lincs [11], but they are combined with other costs which makes it difficult to identify the vessel rates specifically. In this study, the vessel rates proposed in Table 3 will be used.
- Estimates will be done in £ GBP.
- It has been assumed that the cables will be left in situ, with durations based on expected overall cable length and durations on other sources. For purpose of this scope, it will be assumed a full inspection and burial is required for inter-array cables around the foundations as well as export cables with a CLV, using the day rates in Table 3.

The estimated durations for the removal and transportation of different components in the Lincs Limited OWF are presented in Tables A.4 and A.5. From Table A.4, it can be seen that the total lifting duration of 171 days is estimated for the WTGs removal including their TPs and foundations, while the transportation phase of WTG units is expected to take 74 days. The ROV will be required during the foundation removals, which is expected to operate for 70 and 4 days for WTG and OS foundations, respectively. It is observable from Table A.5 that the inspection/burial duration for the cables around the foundations is estimated to be about 56 days, while the left in situ activities for export cables will take 30 days. The detailed cost estimations for different activities as well as some notes on key assumptions are presented in Table B.3. From this table, it can be observed that the estimated costs for the removal of WTGs and OS excluding the contingency are about £21M and £1.64M, respectively. The cost of the left in situ. activities for inter-array and export cables excluding the contingency is estimated to be about £7.22M. The total estimated cost including 12% contingency is estimated to be about £33M.

3.4. Case study 4: Example OWF

In this study, a given example of an OWF was taken from Ref. [31]. This OWF consists of 140x3.6 MW WTGs, one MM, and one OS. There are no details or durations available for removal operations in this case study and therefore all costs will be calculated by the proposed model based on the best estimates. It is assumed that a JUV will be employed for the removal of WTGs, and another JUV will be used for TP+foundation removal in a single crane operation (or two JUVs can be employed in parallel). Two BVs will be used for the transportation of WTG components– one in the field and one in transit. It is also assumed that each trip of BV will include two units, e.g. two TP + foundations, or one topside plus TP + foundation. The same JUV mobilised for WTG removal will also be used for the removal of the MM foundation, while the MM topside will be lifted by a CBV. In addition, the removal operations for the OS topside and jacket structure will be performed by an HLV due to the heavyweight of the components. The cables will be left in situ, which require inspection and burial operations. The ROV activities are included in different operations for example purposes, this may result in overestimation. The detailed assumptions on the vessel/equipment for the example OWF are presented in Table 5. Vessel day rates were estimated and normalised as far as practical based on sourced rates in Table 3, where some of the rates are also based on the same source [31].

Example OWF data is developed based on best estimate reviewing appropriate sources for the duration. Depending on the site layout and decommissioning technique, removal of WTG can range from 0.7 to 1.7 days per MW [21], giving a range of 2.52 to 6.12 days for a 3.6 MW WTG. WTG removals were also compared to estimates from Sheringham Shoal of 3.41 days (without contingency) [10], Lincs at 2.28 days [11] and Cape Wind Energy at 3.30 days [30]. It is proposed to apply 3.20 days for the example OWF (excluding contingency). The time required for transportation and offloading is also considered as 1 day. For the cost calculations, the scopes of work for this example OWF are identified as follows: S_1= WTG topside, S_2= TP/Monopile, S_4= OS topside, S_5= OS foundation, S_6= MM topside, S_7= MM foundation, and S_8= Cable retention.

Tables A.6 lists the estimated durations for different work scopes in this case study. From Table A.6, it can be seen that the total duration for removal of 140×WTGs topsides is estimated as 251 days, while the removal duration for TP+foundations is taken as 211 days. In both cases, the BVs will be in loading, transit or offloading for 70 days. It can also be expected that the removal process of OS topside and its jacket will take 4 days, in which the BVs will be in loading, transit or offloading for 2 days. The estimated durations for the cable inspection/burial activities are presented in Table A.7. It is observable from this table that the cable inspection/burial activities are expected to take 70 days for the inter-array cables around foundations, while the corresponding duration for the export cables is about 18 days.

The detailed removal cost estimations for different scopes of work in the example OWF are presented in Table B.4. From this table, it is observable that the removal costs excluding contingency for WTGs, OS, and MM are estimated to be about £63.36M, £1.18M, and £344K, respectively. The cost of leave in situ. activities excluding contingency for inter-array and export cables is equal to £6.5M. The total removal cost for the considered work scopes calculated by the proposed cost model after applying 10% weather contingency is estimated to be about £78.5M.

4. General results discussions

In this section, some general discussions on the decommissioning costs of OWFs will be presented. In the first subsection, removal cost comparisons between the proposed model and different sources will be presented to assess the accuracy of the obtained estimations. Then, an overall project percentage breakdown analysis will be performed to review if the cost of each decommissioning stage can be estimated as a percentage weighting per overall cost of the decommissioning project. In literature, the cost of decommissioning is sometimes identified as £/MW, which will also be investigated in the last subsection.

4.1. Cost comparison

Based on the cost estimations obtained in Section 3, a comparison summary between model and source during the offshore removal stages is shown in Table 6. The maximum difference between model and source estimates is within 10%, but the estimates have several assumptions that could change the percentage difference either way. The DP of the Cape Wind Energy OWF [30] provided the most detailed data and was most suited to the model thus had the same estimated value. The DPs of Sheringham Shoal [10] and Lincs Limited [11] OWFs provided only limited data, where the model relied on estimates for vessel rates from Table 3, and durations from Table 4. A process of estimation was done but would need more study to refine. Adjustments of these values would have an obvious effect on the final cost.

Table 6. Comparison of removal costs obtained in this study with those provided by the different DPs.

	Cape Wind Energy[1] 101×3.6MW	Sheringham Shoal[2] 88×3.6MW	Lincs Limited[2] 75×3.6MW	Example OWF[1] 140×3.6MW
Model	$46,466,000	£67,774,688	£20,986,021	£78,520,695
Source	$46,466,000 [30]	£73,276,638	£19,682,000	N/A
Difference	0.0%	7.5%	6.6%	N/A

[1]All of offshore removal stages
[2]WTG removal only

4.2. Project percentage breakdown analysis

As shown in Fig. 2, the OWF decommissioning consists of different stages. In this study, the cost estimations were provided for the removal activities. To provide the overall decommissioning cost estimates for different OWFs investigated in this study, the cost of other stages should be estimated as well. The highest cost of an OWF decommissioning project is expected to be during WBSs 4 to 7 due to high vessel day rates, over 50% of total project costs. If the cost of each stage can be estimated as a percentage weighting per overall decommissioning project, it would be feasible to provide an overall cost estimate. The accuracy would vary but can give an order of magnitude estimate, where accuracy can be defined based on data and the method used. In this subsection, the costs of other stages will be estimated based on a project percentage breakdown analysis.

The proposed percentage breakdown analysis considers all stages of the overall WBS and compares them to each source breakdown. Some similarities are depending on the WBS level, but the intent or method of estimate per source was not always feasible to compare. O&G UK [28] breakdown was also reviewed in this study, where a large number of costs are placed in Plug & Abandonment (P&A), which does not apply to OWF decommissioning projects. In the current study, a process is used to normalise the percentage weightage comparison. The sources, findings, comparison and proposed weightages are shown in Table 7 with the following additional information:

- Project management cost is expected to be between 3% and 7% of the overall cost. In this study, 5% is selected for project management.
- Onshore project preparation includes surveys, engineering and procurement, which could be between 8% to 12%. In this study, 10% is selected for onshore preparation.

- Offshore preparation appears to be low for Sheringham [10]. Vessel plus manpower and several weeks of work assume 15% to 20%. In this study, 17% is selected for offshore preparation.
- Removals and transportation stage ranges from 50.5% [21], 54% [30] to 67% [10]. In this study, 58% is selected for this stage.
- Seabed clearance will vary and may be minimal. 5% is selected for seabed clearance.
- Recycle/waste management will vary depending on the recoverable funds from reuse, recycle, or scrap, (6% for disassembly [21], Sheringham Shoal [10] states 0.4% expecting to recover costs, Cape Wind Energy [30] assumes 42% expecting large disposal costs, O&G [28] expect 2%, but is normalised to 4% for comparison, refer to Table 8. In this study, 5% is proposed for recycling/waste management but could increase or decrease depending on recycling and income recovery opportunities.
- Monitoring for OWF is considered small, but still part of WBS. In this study, it is considered negligible and not included in the overall decommissioning cost estimate.

The proposed percentage breakdown distribution is shown in Fig. 3. This is an additional finding and not the main focus of this study and will therefore require further study to confirm the proposed percentage breakdown.

Table 7. Proposed OWF decommissioning project percentages breakdown.

OWF WBS Activity	Cape Wind Energy [30]		Sheringham Shoal [10]		Lincs [11]	Example OWF (estimates)		O&G UK [28]
	$M	% Weight	MNOK	% Weight	% Weight	£M	% Weight	Normalised %
Project Management	N/A	N/A	61.6	5.7%	5%	6.8	5%	7%
Onshore Preparation	N/A	N/A	88.0	8.2%	N/A	13.5	10%	10%
Offshore Preparation	N/A	N/A	108.6	10.1%	N/A	23.0	17%	17%
Offshore Removal	52.1	50%	758.4	70.4%	N/A	78.5	58%	56%
Seabed Clearance	7.9	8%	57.6	5.3	N/A	6.8	5%	3%
Recycle/Waste	43.3	42%	3.9	0.4%	7%	6.8	5%	4%
Monitoring	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2%
Totals	103.3	100%	1078	100%	N/A	135	100%	100%

Table 8. Comparison with O&G UK WBS percentage weightage.

O&G UK WBS activity	O&G UK[1] % Weight	Estimate for Normalisation[2] (£M)	Factor[3]	Adjusted Normalised Estimate[4] (£M)	Normalised % estimate to compare with OWF	OWF WBS Activity
Project Management	6.9%	17.3	75%	4.3	7%	Project Management
Remaining Running Costs	9.8%	24.5	75%	6.1	10%	Onshore Preparation
Well P&A	49.0%	122.5	Excluded	N/A	-	-
Make Safe	3.1%	7.8	75%	1.9	17%	Offshore Preparation
Preparation	3.1%	7.8	N/A	7.8	N/A	N/A
Topside Removal	6.6%	16.5	N/A	16.5	56%	Offshore Removal
Substructure Removal	6.6%	16.5	N/A	16.5	N/A	N/A
Recycle/Waste	2.1%	5.3	50%	2.6	4%	Recycle/Waste
Subsea Removal	11.3%	28.3	Excluded	N/A	N/A	N/A
Site Remediation	1.2%	3.0	50%	1.5	3%	Seabed Clearance
Post Monitoring	0.5%	1.3	N/A	1.3	2%	Monitoring
Totals	100%	250	N/A	59	100%	N/A

[1]O&G UK percentage breakdown taken from Oil& Gas UK Decommissioning Insight 2018 [28]
[2]£250M estimate for O&G decommissioning project, taken as order of magnitude for normalising purposes.
[3]Factor applied based on the impact of excluding Well P&A and subsea which is 61.3% of WBS breakdown. Factor also adjusted due to difference with O&G and OWF.
[4]Adjusted Normalised Estimate used to assist in calculating Normalised % estimate- used for final comparison.

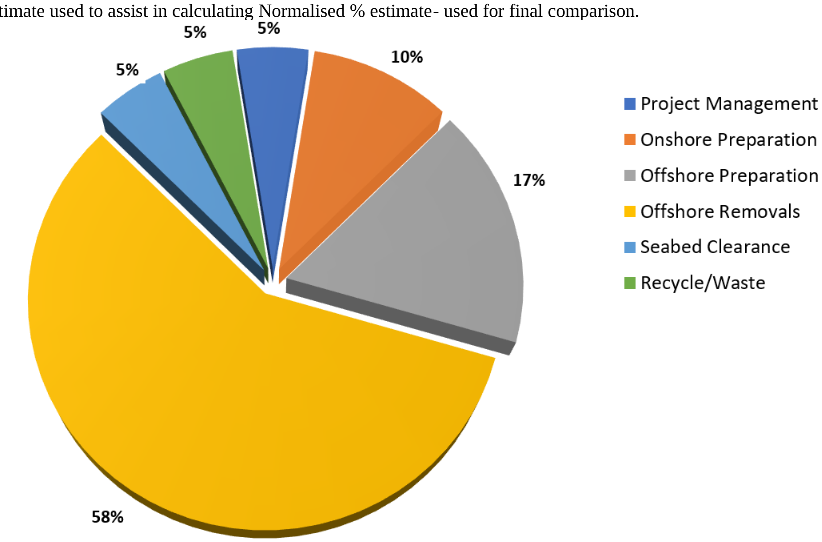

Fig. 3. Proposed percentage breakdown distribution

4.2.1. Overall cost estimation

In addition to estimating the removal costs, the model was also used to estimate the overall project costs, based on applying percentage weightages obtained in the previous subsection. The comparison for full project costs between model and source is shown in Table 9. From Table 9, it can be seen that the estimate yielded by the proposed cost model for the example OWF is substantially higher than the source [31]. The difference can be for several reasons such as that decommissioning was not the real focal point of Ref. [31], or different data or intent were used for estimation. It does appear that the estimate provided by Ref. [31] is low, or potentially not applicable to compare with this model. The model example OWF may also be overestimated for including MM and ROV activities, instead of including them as roll-ups in other costs. It can also be seen from Table 9 that the overall cost obtained from the proposed model are relatively close to those stated by Cape Wind Energy [30] and Sheringham Shoal [10] DPs.

Table 9. Comparison of overall decommissioning costs obtained by the proposed model and other sources.

	Cape Wind Energy	Sheringham Shoal	Lincs	Example OWF
Size	101×3.6 MW	88×3.6 MW	75×3.6 MW	140×3.6 MW
Model	$80,113,836	£151,908,783	£57,633,695	£135,380,509
Source	$97,502,684 [30]	£142,400,809 [10]	WTG only [11]	£20,500,000 [31]

4.2.2. Decommissioning cost analysis per MW

Several sources have been discussed the costs comparisons based on £/MW of installed capacity for the installation and decommissioning projects [21, 22]. Each OWF is different and no one field is the same, hence it does not appear to be feasible to estimate the overall costs in terms of £/MW [21]. Ref. [21] stated a range of percentage estimates from lowest at £31,000/MW for 88 WTGs in Sheringham Shoal (but also stated that the overall estimate is 1,415,515 kNOK for 317 MW – approximately £449,214/W). The highest estimate stated was £111,000/MW for 160 WTG at Gywnty Móe. Table 10 lists the overall decommissioning costs per MW of installed capacity obtained from the proposed model and other resources for different case studies. From Table 10, it is observable that the model offers a potential to calculate £/MW but does not offer any additional information to back up the theory of a £/MW method as a suitable estimate for OWF decommissioning projects.

Table 10. Comparison of the decommissioning costs per unit of energy (£/MW) obtained by the proposed model and different sources.

	Cape Wind Energy	Sheringham Shoal	Lincs	Example OWF
Size	101×3.6 MW	88×3.6 MW	75×3.6 MW	140×3.6 MW
Model	174,677	479,208	213,458	268,612
Source	WTG only	449,214 [10]	449,214 [11]	N/A

5. Concluding remarks and future research directions

In this study, a new cost model was developed based on the bottom-up approach for the removal and transportation phases of OWF decommissioning projects, relying on the WBS. The detailed formulations for cost calculation were derived by adopting the bottom-up approach for different scopes of work in WBS. The model can deal with the data challenges and provides enough flexibility to enable improvement with additional reliable data and can be easily expanded with new scopes of work. Based on the experience in the O&G industry, a project percentage breakdown analysis was performed to include the cost components of all project phases and calculate the overall decommissioning costs. The results of percentage breakdown analysis revealed that offshore removal and offshore preparation are the major contributors to the total decommissioning cost, representing about 58% and 17% of overall cost, respectively. In order to show the efficiency of the proposed approach, four OWF case studies with different levels of available or predicted data were investigated and the results obtained from the model were compared to those reported in other references. The case studies have proven that the proposed model can estimate the costs with relatively good accuracy. The numerical comparisons suggested that the proposed cost model can estimate the removal and transportation costs within 10% of compared OWF sourced estimates. A brief analysis on the decommissioning costs per unit of energy (£/MW) was also performed, in which the results showed that the proposed cost model offers a potential to calculate £/MW in comparison to the available values in literature. Based on this analysis, the overall decommissioning costs are expected to be in the range of 175K£/MW to 480K£/MW. However, each OWF is unique and it may not be feasible to provide a general estimate to suit all projects, there was also no consistency available when comparing £/MW estimates.

The proposed cost model can be easily expanded with new or additional scopes, with the intent of no or minimal impact on the initial scopes. Hence, the user of the model (industry and researchers) can refine and feed their data to the model once it becomes known/available. Since bottom-up cost models can include detailed cost components, the model can be used for cost sensitivity analysis, another potential benefit for the industry in making decisions towards reducing cost. Further improvements can be conducted to enhance the applicability of the model by confirming scope boundaries, vessel selections, project and installation strategies, replacing assumptions with appropriate updated data, and adding recycling costs to the model for a full lifecycle cost analysis.

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Nomenclature

AWJC	Abrasive Water Jet Cutting
BV	Barge Vessel
CBV	Crane Barge Vessel
CLV	Cable Laying Vessel
DBV	Derrick Barge Vessel
DP	Decommissioning Program

DWC	Diamond Wire Cutting
HLV	Heavy Lift Vessel
JUV	Jack-Up Vessel
MM	Meteorological Mast
O&G	Oil and Gas
OS	Offshore Substation
OWF	Offshore Wind Farm
P&A	Plug and Abandonment
ROV	Remote Operated Vehicle
SB	Supply Boat
TB	Tugboat
WBS	Work Breakdown Structure
WTG	Wind Turbine Generator
WTIV	Wind Turbine Installation Vessel

Appendix A. Estimated lifting and transport durations

Table A.1. Estimated lifting and transport durations for the WTGs and OS removals of the Cape Wind Energy OWF[1]

		WTG (101×3.6MW)			OS	
Structure	Scope No.	S_1	S_2		S_4	S_5
	Description	Topside	TP	Monopile	Topside	Jacket
	No. of Facilities	101	101		1	1
Lifts	Vessel type	JUV L1	DBV L2		JUV L1	JUV L1
	No. of Lifts	3	Single lift		Single lift	Single lift
	Duration per structure (days)	1.79	1.50		2	4
	Total duration (days)	181	152		2	4
Transport	Method	BVs*	BVs*		BV	BV
	Qty per trip	2	2		1	1
	Duration per trip (days)	6	2.5		1	1
	No. of trips	101	101		1	1
	Total duration per BV (days)	101	101		1	1
Marine Support	No. of TBs	3	3		3	2

* One in site, one in transit

[1] All entries are taken from Cape Wind Energy DP [30]

Table A.2. Estimated lifting and transport durations for the WTGs and OSs removals in the Sheringham Shoal OWF

		WTG (88×3.6MW)			OS	
Structure	Scope No.	S_1			S_4	
	Description	Topside	TP	Monopile	Topside	Jacket
	No. of Facilities	88	88	88	2	2
Lifts	Vessel type	JUV L1 & JUV L2			HLV L3	HLV L3
	No of Lifts	3	Single lift		2	
	Duration per structure (days)	3.41			4	
	Total duration (days)	300			4	
Transport	Method	2×JUV			BV	
	Qty per trip	5	5		1	
	Duration per trip (days)	**1.25***	**1.25***		**2***	
	No. of trips	18	18		2	
	Total duration (days)	**22***	**22***		**4***	
Marine Support	No. of TBs	**2***	**2***		**2***	
Cuts	Method	DWC	DWC	AWJC	DWC	AWJC
ROV	Duration (excavate, lifting gear, cuts)	**300***			**8***	

* The entries in bold are assumed/estimated in this study.

Table A.3. Estimated left in situ. operations for inter-array and export cables of the Sheringham Shoal OWF

	Scope	Description	Length (km)	Qty	Time (days)	Vessel type	Method
Cable- remain in situ	S_8	Export 1	25	1	15	CLV	Inspect/burial
	S_8	Export 2	57	1	30	CLV	Inspect/burial
	S_8	Intra	80	88	66	CLV	Inspect/burial

Table A.4. Estimated lifting and transport durations for the WTGs and OS removals in the Lincs Limited OWF

		WTG (75×3.6MW)			OS	
Structure	Scope No.	S_1			S_4	
	Description	Topside	TP	Monopile	Topside	Jacket
	No. of Facilities	75	75		2	
Lifts	Vessel type	JUV L1			HLV L2	
	No of Lifts	3	1		2	
	Duration per structure (days)	1.34	0.94		**2***	
	Total duration (days)	100.83	70.31		**4***	
Transport	Method	BV	BV		BV	
	Qty per trip	9	8		1	
	Duration per trip (days)	6	2.5		2	
	No. of trips	9	8		2	
	Total duration per BV (days)	54	20		4	
Marine Support	No. of TBs	2	2		2	
Cuts	Method	DWC	DWC	AWJC	DWC	AWJC
ROV	Duration (all scopes)	**70***			**4***	

* The entries in bold are assumed/estimated in this study.

Table A.5. Estimated left in situ. operations for inter-array and export cables of the Lincs Limited OWF.

	Scope	Description	Length (km)	Qty	Time (days)	Vessel type	Method
Cable- left in situ	S_8	Export 1	48	2	**30***	CLV	Inspect/burial
	S_8	Intra	1.17	75	**56.25***	CLV	Inspect/burial

* The entries in bold are assumed/estimated in this study.

Table A.6. Estimated lifting and transport durations for the WTGs, OS, and MM removals in the example OWF.

		WTG (140×3.6MW)		OS		MM	
Structure	Scope No.	S_1	S_2	S_4	S_5	S_6	S_7
	Description	Topside	TP/Monopile	Topside	Jacket	Topside	Foundation
	No. of Facilities	140	140	1	1	1	1
Lifts	Vessel type	JUV L1	JUV L2	HLV L3	HLV L3	CBV L4	JUV L1
	No of Lifts	3	Single Lift	1	1	1	1
	Duration per structure (days)	1.79	1.50	2	2	1	1.5
	Total duration (days)	251	211	2	2	1	1.5
Transport	Method	BVs, one at site, one in transit	BVs, one at site, one in transit	BV	BV	CBV L4	BV
	Qty per trip	2	2	1	1	1	1
	Duration per trip (days)	1	1	2	2	1	1
	No. of trips	140	140	2	2	1	1
	Total duration per BV (days)	70	70	2	2	1	1
Marine Support	No. of TBs	2	2				2
Cuts	Method	AWJC	DWC	AWJC	DWC	AWJC	DWC
ROV (all scopes)	Duration (days)		211		2		1.5

Table A.7. Estimated left in situ. operations for intra and export cables of the example OWF.

	Scope	Description	Length (km)	Qty	Time (days)	Vessel type	Method
Cable- remain in situ	S_8	Intra	154	140	70	CLV	Inspect/burial
		Export	36	1	18	CLV	Inspect/burial

Appendix B. Removal cost calculations

Table B.1. Detailed removal cost estimations for different scopes of work in the Cape Wind Energy OWF.

WBS Code	Description	Notation	Mob costs $(C_{\mathrm{MB},V_n})^1$ \$ USD	Day rate $(C_{\mathrm{DR},V_n})^2$ \$ USD	Activity duration $(T_A \times V_n)$ days	No. of trips/locations $(F_A \times V_n)$	Total duration (days)[3,4]	Cost activities $(C_A \times V_n)$ \$ USD	Qty $(Q_A \times V_n)$	Totals \$ USD
4	Removal of WTGs	C_{WTG}						Subtotal $(C_{S_1} + C_{S_2} + C_{S_3})$		36,703,015
4.1	WTG- All scope	C_{S_1}								18,328,361
4.1.1	Lift vessel activities- JB-114	C_{S_1,L_1}	1,828,800	57,150	1.79	101	181	10,344,150	1	12,172,950
4.1.2	Transportation (2×BVs)	C_{S_1,B_1}		8,803	1.79	101	181	1,593,343	2	3,186,686
4.1.3	Marine support (3×TBs)	C_{S_1,M_1}	165,216	5,163	1.79	101	181	934,503	3	2,968,725
4.2	TP- S_2 (included above)	C_{S_2}								18,374,654
4.2.1	Lift Vessel Activities- 1000T Crane	C_{S_2,L_2}	50,000	90,000	1.50	101	152	13,680,000	1	13,730,000
4.2.2	Transportation (2×BVs)	C_{S_2,B_3}		7,500	1.50	101	152	1,140,000	2	2,280,000
4.2.3	Marine support (3×TBs)	C_{S_2,M_1}	10,326	5,163	1.50	101	152	784,776	3	2,364,654
4.2.4	ROV activities[5]	C_{S_3,R_n}								0
4.3	Monopile Foundation- S_3 (included Above)	C_{S_3}								0
5	Removal of OS	C_{OS}						Subtotal $(C_{S_4} + C_{S_5})$		653,442
5.1	OS Topsides	C_{S_4}								222,234
5.1.1	Lift Vessel Activities JB-114	C_{S_4,L_1}		57,150	2.00	1	2	114,300	1	114,300
5.1.2	Transportation (1×BV)	C_{S_4,B_3}		7,500	2.00	1	2	15,000	1	15,000
5.1.3	Marine support (3×TBs)	C_{S_4,M_1}		5,163	2.00	1	2	30,978	3	92,934
5.2	OS Jacket (excludes piles)	C_{S_5}								431,208
5.2.1	Lift Vessel Activities- JB114	C_{S_5,L_1}		57,150	4.00	1	4	228,600	1	228,600
5.2.2	Transportation (2×BVs)	C_{S_5,B_3}		7,500	4.00	1	4	60,000	2	120,000
5.2.3	Marine support (2×TBs)	C_{S_5,M_1}		5,163	4.00	1	4	41,304	2	82,608
5.2.4	ROV activities[5]	C_{S_5,R_3}								0
6	Removal of MM[5]	C_{MM}						Subtotal $(C_{S_6} + C_{S_7})$		0
7	Cable activities	C_{c}						Subtotal $(C_{S_8} + C_{S_9})$		9,109,568
7.1	Leave in situ activities	C_{S_8}								0
7.2	Cable Removal	C_{S_9}								9,109,568
7.2.1	Array cables[6]	C_{S_9,C_1}		43,796	1.00	208	208	9,109,568	1	9,109,568
7.2.2	Export cables	C_{S_9,C_2}								
	Total[7]						(Sum of WBS Level 4 to 7 Sub Totals)			\$46,466,000
	Contingency[8]	α_c								-
	Model estimate	C_{total}								\$46,466,000

[1]Mobilisation rate includes mobilisation and demobilisation, one off cost.
[2]Vessel/equipment rates taken from Cape Wind Energy- expected estimate in \$ US Dollars [30]. ROV and cutting costs are assumed to be included in overall costs.
[3]Total duration to perform an activity per vessel/equipment is used. Costs for all are included in totals.
[4]All durations taken from Cape Energy Reference [30] [5]Not shown [6]Includes DBV, BV, and TB. Only one cable cost provided, assume array plus export cables.
[7]Aligned with Cape Wind Energy estimate (excluding fuel and piles) [30] [8]Contingency included in day rates [30]

Table B.2. Detailed removal cost estimations for different scopes of work in the Sheringham Shoal OWF

WBS Code	Description	Notation	Mob costs (C_{MB,V_n})[1] £ GBP	Day rate (C_{DR,V_n})[2] £ GBP	Activity duration ($T_A \times V_n$) days	No. of trips/locations ($F_A \times V_n$)	Total duration (days)[3,4]	Cost activities ($C_A \times V_n$) £ GBP	Qty ($Q_A \times V_n$)	Totals £ GBP
4	Removal of WTGs	C_{WTG}							Subtotal ($C_{S_1} + C_{S_2} + C_{S_3}$)	54,214,688
4.1	WTG- All scope	C_{S_1}								54,214,688
4.1.1	2 JUVs									
4.1.1.1	JUV 1	C_{S_1,L_1}	405,000	112,600	3.41	44	150	16,894,504	1	17,299,504
4.1.1.2	JUV 2	C_{S_1,L_2}	405,000	112,600	3.41	44	150	16,894,504	1	17,299,504
4.1.2	Transportation (part of JUV)									
4.1.2.1	JUV 1 (part of L1 cost)	C_{S_1,L_1}		112,600	1.25	22	28	3,096,500	1	3,096,500
4.1.2.2	JUV 2 (part of L2 cost)	C_{S_1,L_2}		112,600	1.25	22	28	3,096,500	1	3,096,500
4.1.3	Marine support[9]	C_{S_1,M_1}		10,000	4.66	66	308	3,075,600	4	12,302,400
4.2.4	ROV activities									
4.2.4.1	ROV activities 1[5]	C_{S_1,R_1}	35,000	3,500	3.41	44	150	525,140	1	560,140
4.2.4.2	ROV activities 2[5]	C_{S_1,R_2}	35,000	3,500	3.41	44	150	525,140	1	560,140
4.2	Transition Piece- S_2 (included above)	C_{S_2}								0
4.3	Monopile Foundation- S_3 (included above)	C_{S_3}								0
5	Removal of OS	C_{OS}							Subtotal ($C_{S_4} + C_{S_5}$)	3,060,000
5.1	OS topsides	C_{S_4}								3,060,000
5.1.1	HLV[4]	C_{S_4,L_3}	500,000	135,000	4.00	2	8	1,080,000	2	2,660,000
5.1.2	Transportation	C_{S_4,B_3}	200,000	15,000	2.00	2	4	60,000	2	320,000
5.1.3	Marine support	C_{S_4,M_3}	0	10,000	2.00	2	4	40,000	2	80,000
5.2.4	ROV activities	C_{S_4,R_3}	35,000	3,500	4.00	1	4	14,000	1	49,000
5.2	OS Jacket (included Above)	C_{S_5}								0
6	Removal of MM[10]	C_{MM}							Subtotal ($C_{S_6} + C_{S_7}$)	0
7	Cable Activities	C_{c}							Subtotal ($C_8 + C_{S_9}$)	10,500,000
7.1	Leave in Situ activities[11]	C_{S_8}								10,500,000
7.1.1	Array cables	C_{S_8,C_1}	360,000	80,000	0.75	88	66	5,280,000	1	5,640,000
7.1.2	Export cables	C_{S_8,C_2}	360,000	100,000	22.50	2	45	4,500,000	1	4,860,000
7.2	Cable Removal	C_{S_9}								0
	Total[6]								(Sum of WBS Level 4 to 7 Sub Totals)	£67,774,688
	Contingency[7]	α_c								1.30
	Model estimate	C_{total}								£88,107,094

[1]Mobilisation rate includes mobilisation and demobilisation, one-off cost.
[2]Vessel rates taken from Table 11 proposed vessel day rates (if source rates unavailable), not provided with Sheringham estimate (overall values only).
[3]Total duration to perform an activity per vessel/equipment used. Costs for all included in totals.
[4]Total duration for Campaign 2 taken as 308 days, spread across WTG and OS. All other data estimated based on available text, reference Sheringham [10]
[5]ROV activities included as an example, the rate may be included in other rates. Duration based on continual location on the vessel.
[6]At this point, the estimate will exclude contingency for comparison purposes with value at Note 12.
[7]Sheringham applied 30% contingency on cost- reference Sheringham [10]. Will only be used to compare overall cost comparison with the model.
[8]Model estimate used for Sheringham comparison, by applying model weightage of 58%. [9]Two TBs [10]Not included [11]Leave in situ only
[12]1 kNOK = 0.1006 GBP used as exchange rate - reference Sheringham [10]

Table B.3. Detailed removal cost estimations for different scopes of work in the Lincs Limited OWF.

WBS Code	Description	Notation	Mob costs $(C_{\mathrm{MB},V_n})^1$ £ GBP	Day rate $(C_{\mathrm{DR},V_n})^2$ £ GBP	Activity duration $(T_A \times V_n)$ days	No. of trips/locations $(F_A \times V_n)$	Total duration (days)[3,4]	Cost activities $(C_A \times V_n)$ £ GBP	Qty $(Q_A \times V_n)$	Totals £ GBP
4	Removal of WTGs	C_{WTG}						Subtotal $(C_{S_1} + C_{S_2} + C_{S_3})$		20,986,021[5]
4.1	WTG- All scope	C_{S_1}								12,768,833
4.1.1	Lift vessel[6] activities	C_{S_1,L_1}	405,000	112,600	1.34	75	101	11,353,833	1	11,758,833
4.1.2	Transportation	C_{S_1,B_1}	200,000	15,000	6.00	9	54	810,000	1	1,010,000
4.1.3	Marine support[7]	C_{S_1,M_1}								
4.2	Transition Piece- S_2 (included above)	C_{S_2}								8,217,188
4.2.1	Lift Vessel Activities[8]	C_{S_2,L_1}		112,600	0.94	75	70	7,917,188	1	7,917,188
4.2.2	Transportation	C_{S_2,B_1}		15,000	2.50	8	20	300,000	1	300,000
4.2.3	Marine support[7]	C_{S_1,M_1}								
4.2.4	ROV activities[9]	C_{S_2,R_1}	35,000	3,500	0.94	75	70	246,094	1	281,094
4.3	Monopile Foundation- S_3 (included Above)	C_{S_3}								
5	Removal of OS	C_{OS}						Subtotal $(C_{S_4} + C_{S_5})$		1,640,000
5.1	OS Topsides	C_{S_4}								1,640,000
5.1.1	HLV[10]	C_{S_4,L_3}	500,000	135,000	4.00	1	4	540,000	2	1,580,000
5.1.2	Transportation	C_{S_4,B_1}		15,000	2.00	1	2	30,000	2	60,000
5.1.3	Marine support[11]	C_{S_4,M_1}								
5.1.4	ROV activities[9]	C_{S_4,R_2}	35,000	3,500	2.00	1	4	14,000	1	49,000
5.2	OS Jacket (included Above)	C_{S_5}								0
6	Removal of MM[12]	C_{MM}						Subtotal $(C_{S_6} + C_{S_7})$		0
7	Cable Activities	C_{c}						Subtotal $(C_{S_8} + C_{S_9})$		7,220,000
7.1	Leave in Situ activities[13]	C_{S_8}								7,220,000
7.1.1	Array Cables[2]	C_{S_8,C_1}	360,000	80,000	0.75	75	56	4,500,000	1	4,860,000
7.1.2	Export Cables	C_{S_8,C_2}	360,000	100,000	10.00	2	20	2,000,000	1	2,360,000
7.2	Cable Removal	C_{S_9}								0
	Total							(Sum of WBS Level 4 to 7 Sub Totals)		29,846,000
	Contingency[14]	α_c								1.12
	Model estimate	C_{total}								£33,428,000

[1]Mobilisation rate includes mobilisation and demobilisation, one-off cost
[2]Vessel rates taken from proposed vessel day rates to use for decommissioning (were not provided).
[3]Total duration to perform an activity per vessel/equipment used. Costs for all included in totals.
[4]WTG durations taken from Lincs DP.
[5]WTG model total will be used for comparison with Lincs estimate (WTG only)
[6]Based on Lincs DP [11]. The topside durations used are (0.1 + 9) +3 days weather delay, in 9 cycle times, thus 1.33 days per WTG topside. The remainder was used for BV estimated days.
[7]Assumed included in costs
[8]Based on Lincs DP. Foundation durations are (0.5 + 5) + 2 days weather delay, in 8 cycle times, thus 0.94 days per WTG foundation. The remainder was used for BV estimated days.
[9]ROV activities included as an example. [10]Topsides assumed to require HLV, durations estimated. [11]Assumed rolled up [12]Not included
[13]Leave in situ only [14]Contingency based on Lincs DP [11] estimate.

Table B.4. Detailed removal cost estimations for different scopes of work in the example OWF.

WBS Code	Description	Notation	Mob costs (C_{MB,V_n})[1] £ GBP	Day rate (C_{DR,V_n})[2] £ GBP	Activity duration $(T_A \times V_n)$ days	No. of trips/locations $(F_A \times V_n)$	Total duration (days)[3]	Cost activities $(C_A \times V_n)$ £ GBP	Qty $(Q_A \times V_n)$	Totals £ GBP
4	Removal of WTGs	C_{WTG}						Subtotal $(C_{S_1} + C_{S_2} + C_{S_3})$		63,356,802
4.1	WTG (topsides)- S_1	C_{S_1}								33,555,337
4.1.1	JUV 1[4]	C_{S_1,L_1}	405,000	112,600	1.79	140	251	28,250,337	1	28,655,337
4.1.2	Transportation[5]	C_{S_1,B_1}		15,000	1.00	70	70	1,050,000	2	2,100,000
4.1.3	Marine support	C_{S_1,M_1}		10,000	1.00	140	140	1,400,000	2	2,800,000
4.2	TP- S_2 (includes foundation)	C_{S_2}								29,801,465
4.2.1	JUV 2	C_{S_2,L_2}	405,000	112,600	1.50	140	211	23,724,040	1	24,129,040
4.2.2	Transportation	C_{S_2,B_2}	0	15,000	1.00	70	70	1,050,000	2	2,100,000
4.2.3	Marine support	C_{S_2,M_2}	0	10,000	1.00	140	140	1,400,000	2	2,800,000
4.2.4	ROV activities[6]	C_{S_2,R_1}	35,000	3,500	1.50	140	211	737,426	1	772,426
4.3	Monopile Foundation- S_3 (included Above)	C_{S_3}								0
5	Removal of OS	C_{OS}						Subtotal $(C_{S_4} + C_{S_5})$		1,182,000
5.1	OS Topsides	C_{S_4}								820,000
5.1.1	HLV	C_{S_4,L_3}	500,000	135,000	2.00	1	2	270,000	1	770,000
5.1.2	Transportation	C_{S_4,B_3}	0	15,000	2.00	1	2	30,000	1	30,000
5.1.3	Marine support	C_{S_4,M_3}	0	5,000	2.00	1	2	10,000	2	20,000
5.2	OS Jacket	C_{S_5}								362,000
5.2.1	HLV	C_{S_5,L_3}		135,000	2.00	1	2	270,000	1	270,000
5.2.2	Transportation	C_{S_5,B_3}	0	15,000	2.00	1	2	30,000	1	30,000
5.2.3	Marine support	C_{S_5,M_3}		5,000	2.00	1	2	10,000	2	20,000
5.2.4	ROV activities	C_{S_5,R_2}	35,000	3,500	2.00	1	2	7,000	1	42,000
6	Removal of MM	C_{MM}						Subtotal $(C_{S_6} + C_{S_7})$		343,648
6.1	MM (topsides)[7]	C_{S_6}								152,498
6.1.1	CBV	C_{S_6,L_4}		71,249	1.00	1	1	71,249	1	71,249
6.1.2	Transportation (included in CBV)			71,249	1.00	1	1	71,249	1	71,249
6.1.3	Marine support	C_{S_6,M_4}		5,000	2.00	1	2	10,000	1	10,000
6.2	Monopile Foundation (included above)	C_{S_7}								191,150
6.2.1	JUV 2	C_{S_7,L_2}		112,600	1.50	1	2	168,900	1	168,900
6.2.2	Transportation	C_{S_7,B_2}		15,000	1.00	1	1	15,000	1	15,000
6.2.3	Marine support	C_{S_7,M_2}		1,000	1.00	1	1	1,000	2	2,000
6.2.4	ROV activities	C_{S_7,R_1}		3,500	1.50	1	2	5,250	1	5,250
7	Cable activities	C_c						Subtotal $(C_{S_8} + C_{S_9})$		6,500,000
7.1	Leave in Situ activities	C_{S_8}								6,500,000
7.1.1	Array Cables	C_{S_8,C_1}	360,000	80,000	0.50	140	70	5,600,000	1	5,960,000
7.1.2	Export Cables	C_{S_8,C_2}	360,000	10,000	18.00	1	18	180,000	1	540,000
7.2	Cable Removal	C_{S_9}								0
	Total							(Sum of WBS Level 4 to 7 Sub Totals)		£71,382,450
	Contingency[8]	α_c							Weather	1.10
	Model estimate	C_{total}								£78,520,695

[1]Mobilisation rate includes mobilisation and demobilisation, one-off cost
[2]Vessel rates taken from proposed vessel day rates to use for decommissioning (were not provided)
[3]Durations based on best estimates gained from normalising sources.
[4]2×JUVs proposed. [5]Assumes 2 BVs used in the field, one in transit. Will take full WTG structure or 2×structure, or 2×TP+foundation (depending on final strategy)
[6]ROV included for example- may be an additional cost. Either included in costs or excluded from other estimates.
[7]MM included for example- may be an additional cost. Either included in costs or excluded from other estimates.
[8]Weather applied for example purposes, will vary depending on location.

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