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Comparative Levelized Cost of Energy Analysis

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Abstract

To estimate the economic feasibility of floating and bottom-fixed substructures at various offshore sites, a generally applicable calculation tool has been developed. With this “LCOE calculation tool” it is possible to optimize the design and reduce the costs of deep offshore wind farms, by analyzing key aspects already during the planning and pre-design phase. Hereby the conducted breakdown of the several cost categories assists identifying main cost-drivers prior a final investment decision. Whereas the influence of varying site specific, technological and financial parameters on the cost-effectiveness is investigated in a sensitivity analysis. To validate and enlarge the tool’s dataset, the tool was applied to a real floating concept with the aim to compare the cost-effectiveness of floating solutions with their bottom-fixed counterparts.

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Keywords: Offshore wind; Floating wind turbines; Wind farm planning; AFOSP; Levelized Cost of Energy; Economics; Life Circle Assessment; Sensitivity analysis; Concrete substructure

1. Introduction

The global market for floating offshore wind turbines (FOWTs) shows a great potential [1]. Technical feasibility of FOWTs has been demonstrated in various simulations and prototypes. On the pathway to commercialization, economic feasibility seems to be the key challenge which has to be mastered.

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Promoters and engineering companies strongly rely on having tools, judging the cost-effectiveness of wind farms in different locations, to support their planning and decision making process. Currently there is a tendency in the offshore industry to move into greater water depths further away from shore and to install turbines with a higher rated power [2][3]. This trend leads to more complex infrastructures which makes the planning, installation and operation process even more challenging. Due to the fact that the deep offshore wind industry and the floating wind sector in particular are still in its infancies, there is a lack of this kind of tools. To address these existing shortcomings, a so called "Levelized Cost of Energy (LCOE) calculation tool" based on an extensive database compiled from publicly available sources has been developed and through a sensitivity analysis, parameters offering cost reduction potential were identified.

1.1. Objectives

The main objective of the LCOE calculation tool is to optimize the design and reduce the costs of deep offshore wind farms, by analyzing key aspects already during the planning and pre-design phase. As a case study, the competitiveness of a new FOWT concept is judged and compared to other floating concepts and bottom-fixed systems.

The conceptual design of this new solution, which results from a joint research project named "Alternative floating offshore substructures for offshore wind farms" (AFOSP) carried out by KIC InnoEnergy, Gas Natural Fenosa, the University of Stuttgart and Universitat Politècnica de Catalunya. The main differentiating aspect with respect to other FOWT concepts is the monolithic nature of the whole structure, including both, platform and tower, as well as the utilization of post tensioned concrete as main material.

2. The LCOE calculation tool

The developed tool analyzes and compares different offshore wind solutions in deep waters from a techno-economic perspective.

2.1. Methodology

Offshore wind farms are capital-intensive projects which will accumulate revenues over a long period of time, before reaching their break-even points. When evaluating long term investment projects, quantification of expenses in different phases of the project becomes important due to capital costs and risk placement. Therefore a Life Cycle Cost Analysis (LCCA) is conducted for each of the regarded substructure types. Hence all costs occurring through different life cycle phases of a wind farm are considered; from wind farm development, manufacturing, acquisition and installation of components to operation and maintenance of the wind farm and finally decommissioning. Total costs are discounted to values at equal points of time and assigned to expected wind farm energy production, to find costs per produced unit of energy, so called Levelized Cost of Energy (LCOE). The LCOE calculation tool includes all capital-, operational- and decommissioning expenditure (CAPEX, OPEX and DECEX) incurred over the lifetime of a project. The result is a constant unit cost per kWh of a payment stream that has the same present value as the total cost of a generating plant over its lifetime. Simplified the presented calculation tool is based on the following, general approach [4]:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}} \tag{1}$$

$LCOE$:	Levelized cost of electricity in €ct/kWh	i:	Weighted average cost of capital (WACC) in %
I_0:	Capital expenditure (CAPEX) in €ct	n:	Operational lifetime in years
A_t:	Annual operating costs (OPEX) in year t	t:	Individual year of lifetime (1,2,…n)
M_{el}:	Produced electricity in the corresponding year in kWh		

The economic assessment of a wind turbine projects starts by determining input parameters for the calculation. Herby energetic parameters like the capacity factor, the wind farm availability and the different kinds of losses have to be defined. Besides theses parameters, financial specifications like the WACC and other aspects like the lifetime of the substructure types have to be considered. In a next step, the tool selects the respective CAPEX-, OPEX- and DECEX values connected to the chosen main parameters from the data sheet. Based on the product of the basic costs, which are a function of water depth and the two scaling parameters considering the distance to shore respectively turbine size, specific costs can be generated for every cost category. In combination with other parameters the LCOE for a specific offshore wind project can be calculated (Fig. 1).

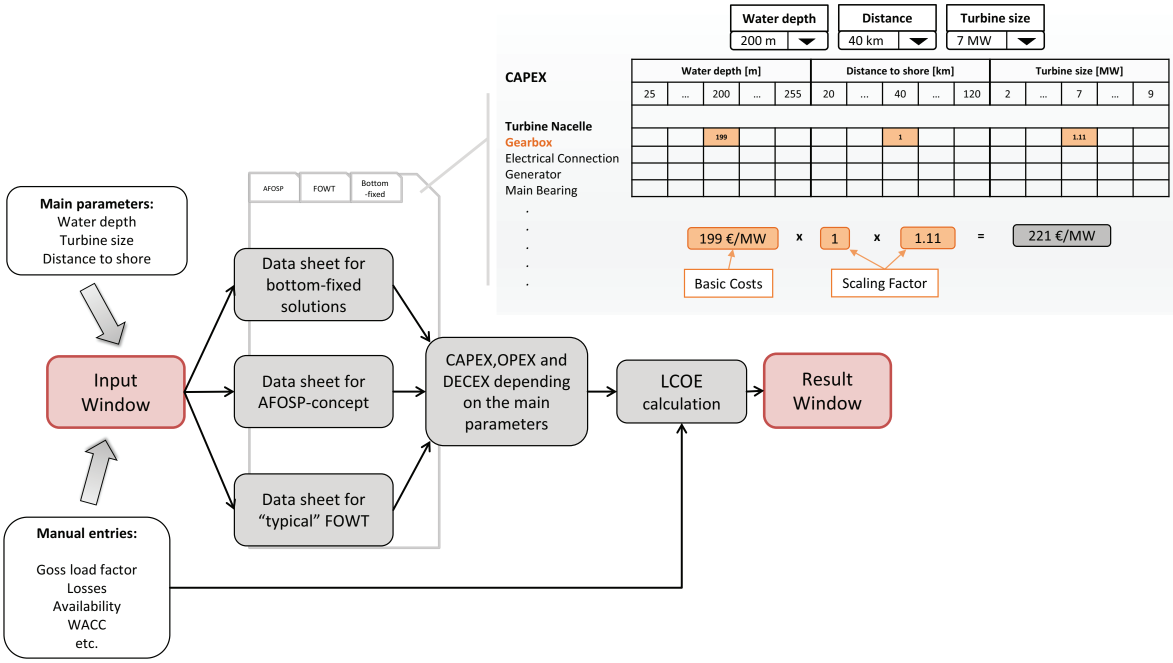


Fig. 1: Build-up LCOE calculation tool

In the example presented in Fig. 1, just the costs for the gearbox are observed. The tool picks the corresponding CAPEX for a gearbox installed in a water depth of 200 m. These basic costs are then multiplied with a scaling factor, which considers the distance to shore. In contrast to the installation costs, listed in an extra cost category, the acquisition costs of the gearbox are independent from this parameter, thus the scaling factor 1 is used in this case. To build a 7 MW offshore wind turbine a bigger and disproportionate more expensive gearbox is needed, therefore the scaling factor 1.11 is used in this example. According to the scheme illustrated above, every of the 40 cost categories of the LCOE tool is calculated individually for every of the analyzed three substructure types.

2.2. Data sheets

This paper intends to present an overview of the tool's general functionality and some main findings. Thus more detailed information regarding the origin of parameters, cost functions and specific assumptions for the respective substructure types can be gathered directly from the tool-description or looked up in the corresponding student thesis [5].

In an extensive literature study, information on reported costs for different substructure types was compiled, missing data calculated and assumed and fed into the LCOE tool to derive CAPEX, OPEX and DECEX for the various cost categories. Based on those literature values, cost functions have been established to predict the development under changing main parameters e.g. in water depths where, until now, no bottom-fixed wind farm has been installed.

An overview of the main qualitative differences among the regarded foundation types is illustrated in Table 1 in Appendix A. This table presents some selected averaged basic costs and corresponding scaling functions. Hereby the different background colors of the cells highlight variations between the regarded substructure types, whereas the dependency of the costs categories on the main parameters is written as cell entries. As an example, f(w,t) implies that this costs vary with water depth and turbine size, but not with the parameter distance to shore. If there is an entry written in brackets, like it is the case for the acquisition costs for mooring lines and anchors, respectively suction piles, then f((w), t) shows that just one of the costs depends on the water depth. In this case, just the expenses for mooring lines vary with water depth.

To evaluate the economic viability of the AFOSP design, the developed tool compares this concept to other floating and bottom-fixed offshore solutions. Hereby especially bottom-fixed foundations are associated with relatively high levels of available and reliable data. This observation was used to minimize the uncertainties, calculating the LCOE for a technology which is still at an early stage of development, as it is the case for floating turbines. In order to provide a reasonable picture of the floating wind market with its various concepts, data of four different prototypes (Sway Single-tension leg, WindFloat Tri-floater, Blue H Multi-tension leg and Sway upwind concept) have been included in the dataset with the aim to represent a typical floating substructure (compare Table 1 in Appendix A).

3. Results

The outcome of this study are economic indicators used to determine the profitability of a deep offshore wind project under changing input parameters.

3.1. Reference Scenario

As mentioned before, the LCOE strongly depends on many different input parameters. Therefore it is necessary to define a reference scenario, which allows a comparison on a common ground. Based on this scenario, sensitivity analyses are executed, varying the different input parameters originating from a reference point.

This reference scenario intends to draw a realistic picture of typical site conditions and represents the state of the art in the offshore wind industry. One site specific parameter, which has a huge influence on the LCOE and therefore on the competitiveness of an offshore wind farm is its net annual energy production. The assumed capacity factor of 51 % represents an offshore site with very good wind conditions. Performance measurements for the Hywind Spar, a model quite similar to the AFOSP design, however confirm that such a capacity factor can be reached [6]. The final amount of the actual losses depends on many site specific parameters and has to be selected for every location individually. In the reference scenario these losses are estimated for a typical deep offshore site (Fig. 8 in Appendix B)

Definition of system boundaries valid for the cost model is another important step to get comparable results. Depending on the selection of these boundaries, cost categories like the expenditure for export cables and transmission charges have to be included calculating the LCOE. The results of the tool should be applicable on sites all over the world, regardless of country specific and local peculiarities. Thus Option 1 with larger system boundaries is implemented in the LCOE tool (compare Fig. 9 in Appendix C). This scenario includes the energy transport and transformation to an onshore grid connection point. Option 2 estimates that the transmission charges are paid by the transmission network operator and that just the expenditure for an array cable connection inside the wind farm has to be paid directly by a potential investor. Countries like Germany, where these costs are outside the system boundaries, offer a great country specific cost reduction potential, because especially the transmission charges contribute a major part of the expenditure to the total LCOE (compare Fig. 2).

The illustrated cost breakdown compares the cost-effectiveness of bottom-fixed substructures, typical floating steel platforms and the AFOSP concept under reference scenario conditions. An installation of bottom-fixed solutions in deep water sites is, as expected, economically not feasible with LCOE of 29.86 €ct/kWh. The selected water depth of 150 m for the reference scenario leads to a high material effort for jacket structures and consequently to increasing installation costs.

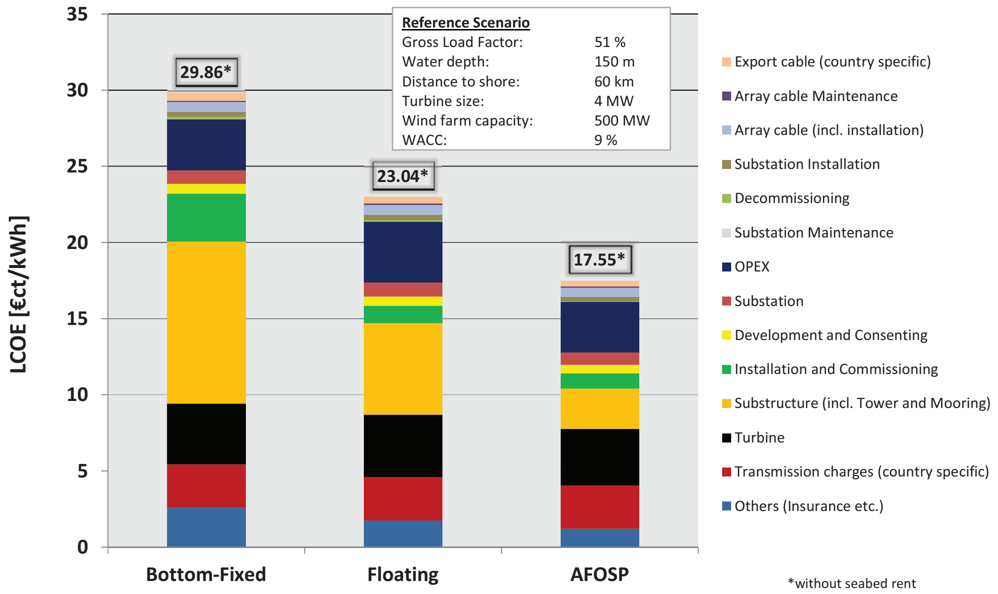


Fig. 2: LCOE comparison under reference scenario conditions

It can be observed that the acquisition costs for the turbines are equal for all regarded substructure types. It is assumed that the same turbine models, installed on bottom-fixed foundations, are also used for their floating counterparts, because there are so far no specific large scale turbines for floating applications on the market. Other cost categories which are independent of the regarded substructure type are the expenditure for transmission charges, cabling and substation.

The results for the reference scenario indicate that the AFSOP concept, with its monolithic concrete design, can be a cost-effective option in terms of LCOE for deep waters. This structure is relatively simple to manufacture in an automated process, because a minimum of welds is needed. Precast concrete industry is established in nearly every country, which allows a construction close to site with reduced delivery costs. Cement makes the structure less sensitive to corrosion and reduces therefore the O&M effort. As a consequence of the less sensitive design to the rough offshore climate, the foundation lifetime can be extended to 40 or 50 years. Regarding the installation phase, the design of the AFOSP spar buoy allows a horizontal transport to site. In this case, only a small tug boat, with a low daily rent and fuel consumption is required to tow the foundation to its final site. The main disadvantage of the AFOSP solution, compared to some competitors in the floating industry, is its restriction to water depths over 150 m because of the spar buoy's large draft.

3.2. Sensitivity Analysis

A sensitivity analysis was performed in order to understand the uncertainties in the assessment, the impact of specific parameters and the consequences of certain assumptions. Some findings, gathered during this study are presented in the following section.

Fig. 3 highlights again the high sensitivity of the cost of energy for bottom-fixed wind farms to water depth. It could be illustrated that for a site, located in water depths over 90 m and about 20 km away from shore, even a not yet marketable technology like FOWTs represents the favorable choice in terms of cost-effectiveness.

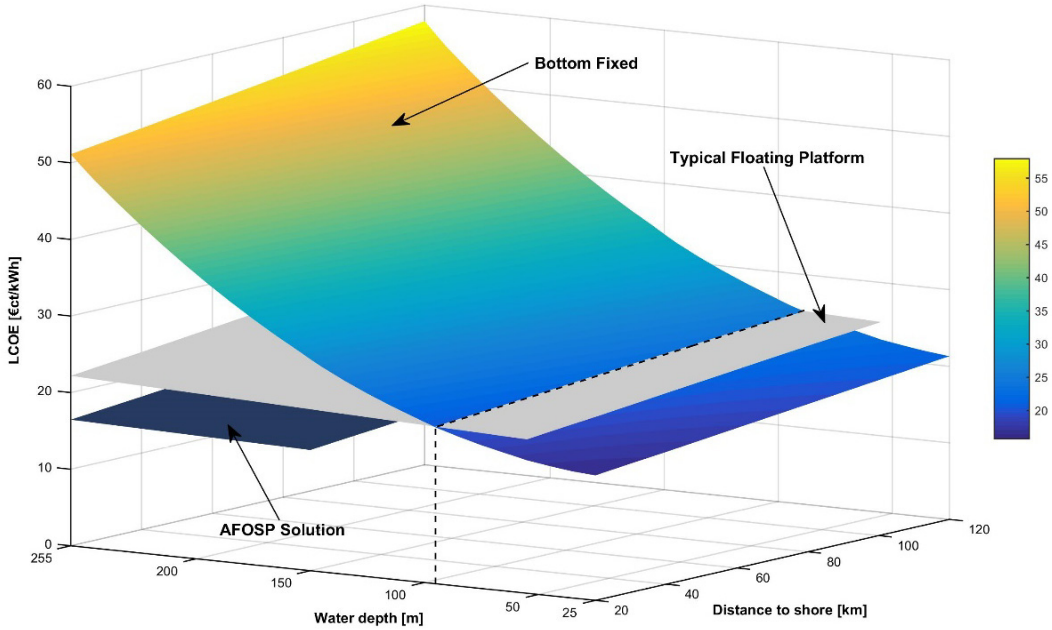


Fig. 3: LCOE for all analyzed substructure types as a function of water depth and distance to shore

The results of the individual variable sensitivities suggest several additional insights. It could be demonstrated that changes in a project's capacity factor have a significant impact on the LCOE of bottom-fixed structures as well as on the cost of energy of the AFOSP solution. A reduction for example from 51 % to 45 % increases the total LCOE by about 14 % for both substructure types (compare Fig. 4 and Fig. 5).

Another parameter with a significant impact in a fast moving sector like the wind industry is the rated power of the installed wind turbines. On the one hand a higher turbine power leads to an increase in nacelle weight and to greater loads on the substructure, therefore the foundation needs to be designed bigger and stronger. This trend is accompanied by higher material expenditure and installation effort for each substructure. But on the other hand fewer foundations have to be planned, installed, maintained and manufactured to reach a certain wind farm capacity, if larger turbines can be used. Therefore it has to be analyzed which of the explained effects have a greater influence on the total LCOE. In this analysis it could be demonstrated that the current trend towards larger turbines has indeed a huge cost reduction potential.

The impact of manufacturing costs and commodity prices on the LCOE of the AFOSP solution is much lower, compared to its bottom-fixed counterparts mostly made out of steel. Fig. 4 indicates that an increase in the steel price by 10 % would lead to rising total costs of about 5 %. However, the costs for the AFOSP solution with its monolithic concrete design are not as reliant on the commodity prices as the LCOE of steel structures, because of the lower substructure weight in the regarded water depths and the minor concrete price, compared to the price for stainless steel. Additionally, the cement price was relatively constant in recent years, compared to the highly volatile price for steel [7]. Nevertheless the consequences of a weight reduction scenario were evaluated, estimating a 5 % mass reduction in steel reinforcements and concrete. This savings were compensated by an increase in ballast mass to keep the overall dynamic behavior of the AFOSP platform. It could be illustrated that the increased use of ballast, respectively black slag, with a lower specific price reduces on the one hand the platform costs by about 4 %, but on the other hand the effect on the total LCOE was with 0.4 % quite low. This minor effect on the total cost of energy is based on the low percentage of the substructure costs on the total LCOE (compare Fig. 2).

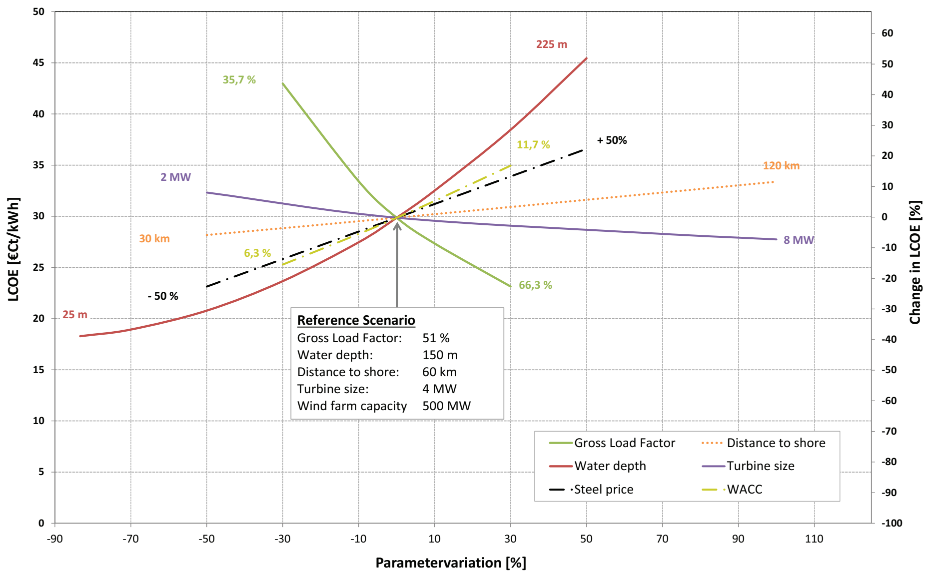


Fig. 4 Results sensitivity analysis bottom-fixed structures

In the capital-intensive wind industry, WACC have a significant impact on the LCOE and there are several factors affecting the amount of the WACC. For example the perceived risks of offshore wind construction and operation, overall availability of capital and the relative attractiveness of deep offshore wind compared to other asset classes. These circumstances lead to a variation of the WACC from one project to another. The conducted sensitivity analysis shows that a reduction of the WACC by one percent point to 8 %, leads to a decrease of the LCOE for the AFOSP by about 6 % (Fig. 5).

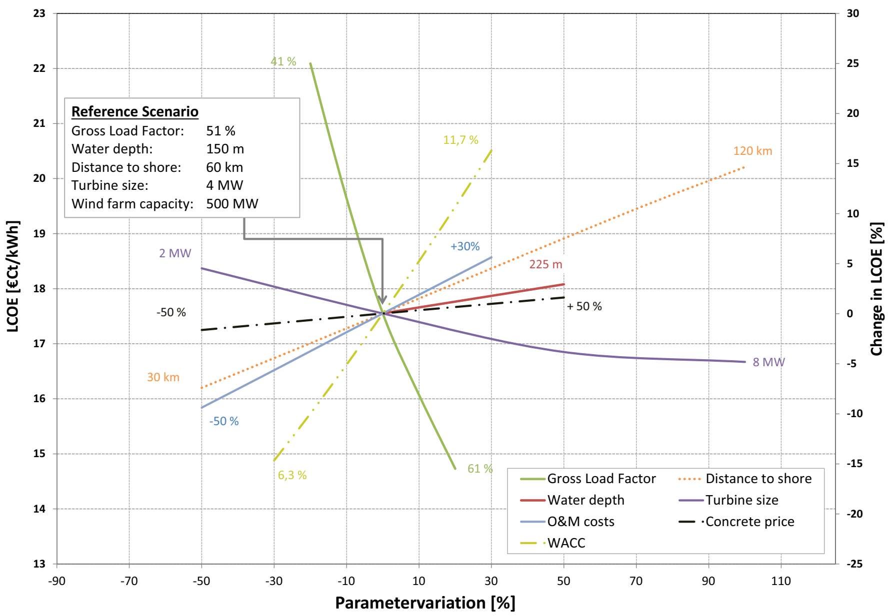


Fig. 5: Results sensitivity analysis AFOSP solution

Fig. 5 additionally shows the sensitivity of the LCOE for the AFOSP design to the costs for O&M activities. In reality it is not possible to analyze this parameter independently, because it is strongly connected to other factors like distance to shore and used turbine size. The intention behind this differentiated approach is it to show how important it is, for participants in the offshore market, to select the most cost-effective maintenance strategy for every site and foundation type.

At real case offshore sites there is often some sort of correlation between water depth and distance to the nearest coastline. But due to the fact that this correlation can look differently for every site, the decision was made to analyze these two parameters in the LCOE calculation tool individually. Fig. 4 hints that on an economic perspective, it is preferable to avoid deep water sites and rather accept a site with longer transit times for installation and O&M activities, when planning a bottom-fixed wind farm. In contrast to the characteristics of bottom-fixed structures, the cost of energy for the AFOSP solution increases with about 0.5 €ct/kWh per 100 m just slightly with water depth. Regarding the AFOSP solution, just the costs for mooring lines and array, respectively export cables, are affected directly by increasing water depth. The higher material expense for deep water sites, lead to a slightly increase in decommissioning costs and costs for construction contingency. Nevertheless the influence of a larger distance to shore is with about 0.04 €ct/kWh per kilometer more significant, regarding the total LCOE.

In a supplementary study, the sensitivity of the LCOE to an extended platform lifetime was analyzed. The expected service life of concrete structures like the AFOSP solution is estimated up to 50 years, instead of 20 years for steel ones [8], because a monolithic concrete design is better suited to cope with the rough offshore conditions. This design feature makes the structure less sensitive to damages caused by corrosion and enables the usage of two consecutive turbines during the life cycle of one platform (compare Fig. 10 in Appendix D). With the expected extension of the turbine lifetime to 25 years in the near future, it could be feasible to utilize the whole potential of such type of structures. The cost reduction potential of a lifetime extension from 20 years to 40 years, which is assumed in the reference scenario, is about 5.8 %. At first glance, such a cost reduction seems marginal, but in the highly competitive energy market this could give concrete platforms a decisive edge over its competitors.

4. Target LCOE for offshore wind energy plants

For a new concept like the AFOSP solution it is important to have a benchmark to judge one's own competitiveness in comparison with other participants in the offshore market. The LCOE represents a common way to compare the cost-effectiveness across power generators, therefore an independent benchmark has been determined to assess the results illustrated in the previous chapter. Hereby two separated target LCOE-values have been established, because in a long term perspective the analyzed floating prototypes have to competitive with FOWT as well as with bottom-fixed solutions.

4.1. Target LCOE for bottom-fixed solutions

Fig. 6 presents different cost of energy for bottom-fixed wind turbines. At this point it is sometimes just possible to present a range of values, because the LCOE varies with parameters like capacity factor, distance to shore, water depth etc. and has therefore to be regarded as a site specific value. To underline the awareness that the one true LCOE-value of a specific technology does not exist, some LCOE of offshore wind farms installed in different countries are additionally illustrated.

4.2. Target LCOE for floating concepts

In contrast to its bottom-fixed counterparts, most of the floating concepts are at an early development stage. To get reliable information, a full scale prototype of the respective concept has to be installed and grid connected for a certain period. When determining a target LCOE for floating solutions, information on cost structures has therefore sometimes be estimated, because there is a lack of reliable benchmark LCOE-values.

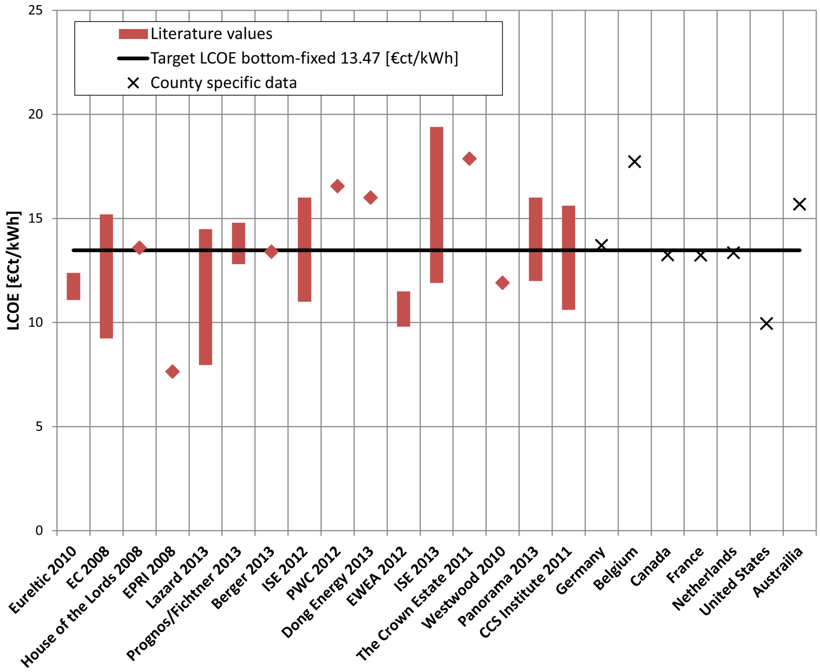


Fig. 6: Target LCOE for bottom-fixed offshore turbines [9]-[21]

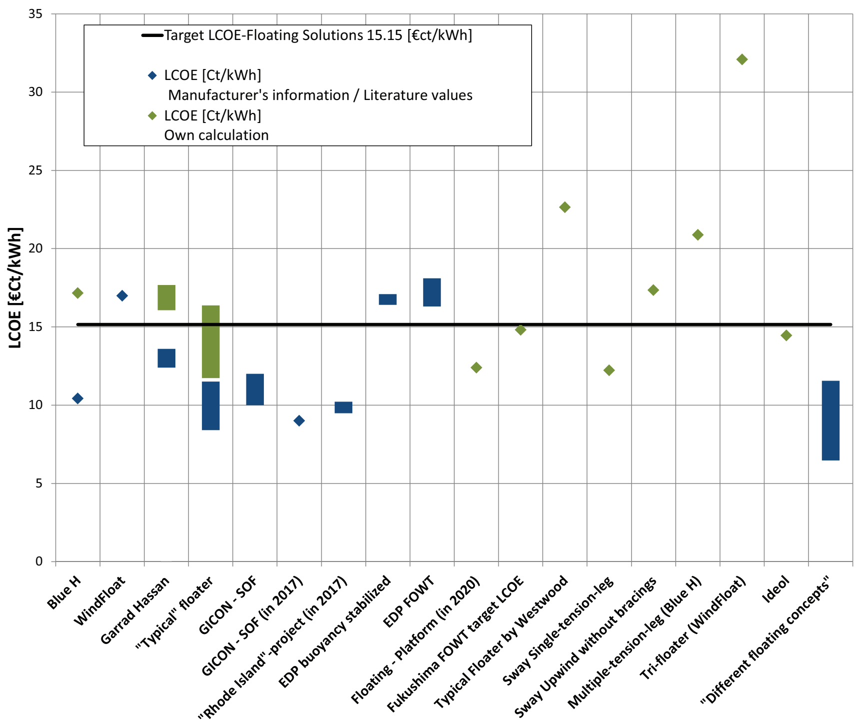


Fig. 7: Target LCOE for FOWTs [22]-[33]

However, to get an idea of the magnitude of the cost of energy, the LCCA approach combined with parameters from the reference scenario (Chapter 3.1) like the WACC and the net electricity output have been used to get comparable results. In some studies just the CAPEX or OPEX were published. In this cases, the cost distribution of a typical floating wind farm by [34] is used to calculate the LCOE with equation (1). These results, based on own calculations, are highlighted in green in Fig. 7. Due to the difficulties getting reliable information of such a young industry, a large spread between the individual LCOE-values can be observed.

Nevertheless, the mean values illustrate that the target LCOE for floating wind turbines is with 15.15 €ct/kWh about 1.7 €ct/kWh higher, compared to the target LCOE estimated for bottom-fixed solutions.

5. Conclusion and Outlook

The presented LCOE calculation tool supports investment decisions of potential investors by analyzing the economic feasibility of deep offshore wind farms. Hereby important questions, which should be answered prior a final investment decision, like the technology selection and the influence of financial as well as site specific parameters on the profitability of an offshore wind project are addressed.

The analyzed concrete design under reference scenario conditions does with 17.55 €ct/kWh neither yet reach the estimated benchmark for bottom-fixed structures in shallow waters nor the one representing FOWTs. However, the performed sensitivity analyses for all substructure types illustrate, that even small parameter variations can be decisive and have a huge impact on the total LCOE.

It could be shown for instance that especially the selected capacity factor and WACC have a huge effect on the economic feasibility of an offshore wind project. The former illustrates that the wind farm planer should focus attention on selecting a site with a high average wind speed at hub height. Another funding was that a weight reduction of 5 % decreases the platform costs by about 4 %. However, the impact of these savings on the total cost effectiveness of the AFOP platform are negligible. A wind turbine manufacturer should therefore, at first place, verify the share of a component in the LCOE breakdown before undertaking major efforts to reduce the cost of certain cost categories. The utilization of concrete instead of steel makes the substructure more resistant against corrosion; therefore an extension of the platform lifetime to 40 years is possible with leads to a cost reduction of 5.8 %.

Another issue which is currently a hot topic in the offshore industry is the effect of fluctuating commodity and manufacturing prices on the profitability of a wind farm. During this study it could be shown that the impact of these changes on the LCOE is much higher for bottom-fixed solutions made out of steel then for concrete platforms like the AFOPS concept. A more obvious result was that an installation of a bottom-fixed wind farm at a water depth of 150 m is economically not feasible. Nevertheless leads an approximated 50 % decrease in water depth to a LCOE reduction by about 30 %.

It has to be mentioned that the tool can be extended arbitrarily. As an example, a bottom-up approach has been implemented, which predicts the LCOE cost reduction potential for commercially available floaters. Thus technological enhancements and additionally improvements in the supply chain by increasing competition, vertical and horizontal collaboration and economy of scale are taken into consideration for every cost category and input parameter.

The results presented in this study indicate that besides future technical innovations, other elements like learning curve effects and supply chain enhancements are strongly needed for FOWTs to be competitive in the offshore market. Here collaborations between the different players and also competitors should be intensified through new project partnerships, because exchange of lessons learned is crucial and will provide benefits for all stakeholders. If these factors can be bundled, a cost reduction of up to almost 40 % in the next ten years has been determined in a case study using the implemented bottom-up approach. Analyzing the predicted technical innovations and their impact on the total LCOE, especially the increase in turbine size seems to have a huge cost reduction potential. The shift towards turbines with a higher rated power leads to a reduction of the specific costs for many elements during a wind farm's lifecycle and simultaneously increases the annual energy production. In terms of possible enhancements within the supply chain, it could be illustrated that the AFOSP development team is on the right track by using existing synergies with the oil and gas industry.

Appendix A.

Table 1.1: Overview of the differences between the analyzed types of foundation; mainly based on [32], [35]-[40]

Cost function f(main parameters) / Basic costs at 35 m water depth

Different Basic cost between AFSOP and Floating

Abbreviations: water depth: **w** distance to shore: **d** turbine size: **t** (linear, exponential,.. etc.) function of x: **f**(x)

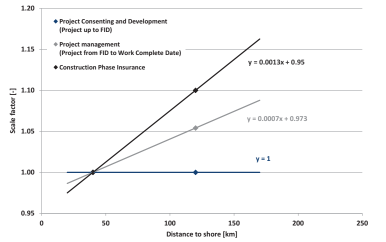
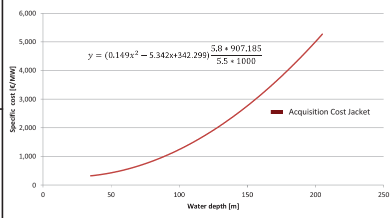
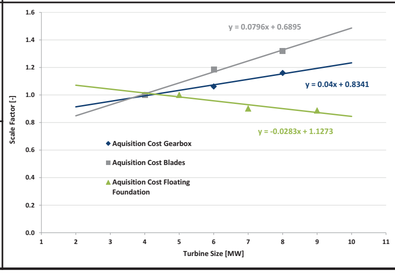
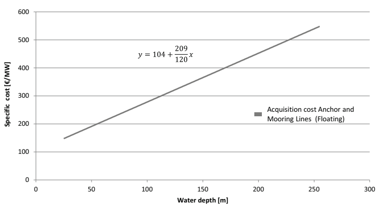
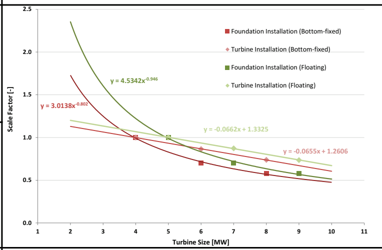
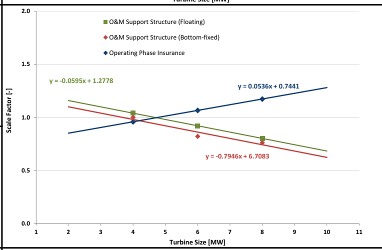
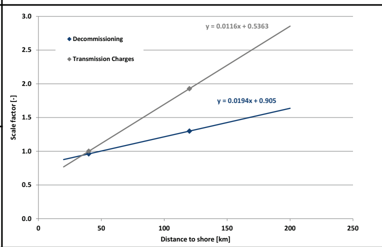
Summarized Cost categories	Bottom-fixed	Floating	Example Cost functions	Comments/ Key assumptions
Project Consenting and Development Project Management Construction Phase Insurance	f((w),d,t) 226 000 €/MW	f(d,t) 226 000 €/MW		• For bottom-fixed solutions: Costs increase with water depth, except expense for Project Consenting and Development up to the final investment decision (FID)
Tower	f(w,t) 167 000 €/MW	f(w,t) 112 000 €/MW		• AFOSP-concept: Costs for tower included in foundation costs (monolithic structure)
Jacket (Monopile in water depths < 35m) Transition Piece	f(w,t) 446 000 €/MW	-		• Cost calculation based on weight estimation of jacket/ monopile structures • Specific material and manufacturing costs: 5,8 €/kg
Pin Piles Transition Piece	f(w,t) 123 000 €/MW	-		• Conservative approach, due to higher wave loads for deep water sites • Costs for material and manufacturing: 2 €/kg
Floating Foundations	-	f(t) 1 252 000 €/MW		• AFOSP: Based on material/production cost estimation • Floating: Mean value of several floating concepts
Turbine (Rotor + Nacelle)	f(t) 1 196 000 €/MW	f(t) 1 196 000 €/MW		• Turbine model independent from considered type of foundation • As an example for an Rotor- respectively Nacelle-component, the cost function of the gearbox and the turbine blades are illustrated

Table 1.2 Overview of the differences between the analyzed types of foundation; mainly based on [32], [35]-[40]

Cost function f(main parameters)
Basic costs at 35 m water depth

Different Basic cost between AFSOP and Floating

Abbreviations: water depth: **w** distance to shore: **d** turbine size: **t** (linear, exponential,.. etc.) function of x: **f**(x)

Summarized Cost categories	Bottom-fixed	Floating	Example Cost functions	Comments/ Key assumptions
Mooring Lines/ Anchors/ Suction Piles	-	f((w),t) 165 000 €/MW		• Different material and manufacturing costs: For AFOSP: Pin Piles and Mooring Lines with larger diameter For Floating: Anchors and Mooring Lines • Anchors/ Pin Piles independent from water depth • For AFOSP: Mooring Lines and Suction Piles are independent from turbine size, because the required yaw stiffness is just very slightly affected by the installed turbine capacity
Substation (incl. Installation)	f(w,d) 286 000 €/MW	f(w,d) 286 000 €/MW		• Material and production costs independent from distance to shore • Costs for substation independent from considered concept
Foundation and Turbine Installation Construction Contingency	f((w),d,t) 508 000 €/MW	f((w),d,t) 275 000 €/MW		• Bottom-fixed: Installation costs raise with water depth • Turbine installation independent from water depth • Difference in basic value and behavior with distance to shore due to different installation methods for every substructure type • Construction Contingency: 12.5 % of total CAPEX
Cable Installation	f(w,d,(t)) 141 000 €/MW	f(w,d,(t)) 141 000 €/MW		
O&M Support Structure	f(d,t) 3 000 €/MW/yr	f(d,t) 24 000 €/MW/yr		• Maintenance costs for concrete structures ca. 10 % of comparable steel foundations, due to the lower expenditure for corrosion protection
O&M (excl. O&M Support Structure)	f(w,d,t) 114 000 €/MW/yr	f(w,d,t) 115 000 €/MW/yr		• Independent from regarded type of foundation
Cables	f(w,d,t) 93 000 €/MW	f(w,d,t) 93 000 €/MW		• Costs for cables independent from considered concept • Separation in export and array cables
Transmission Charges	f(d) 80 000 €/MW/yr	f(d) 80 000 €/MW/yr		• Independent from regarded substructure type
Decommissioning	f(w,t) 135 000 €/MW	f(w,t) 168 000 €/MW		• Revenues generated from recycling / resale of some components included • Connected to total CAPEX

Appendix B.

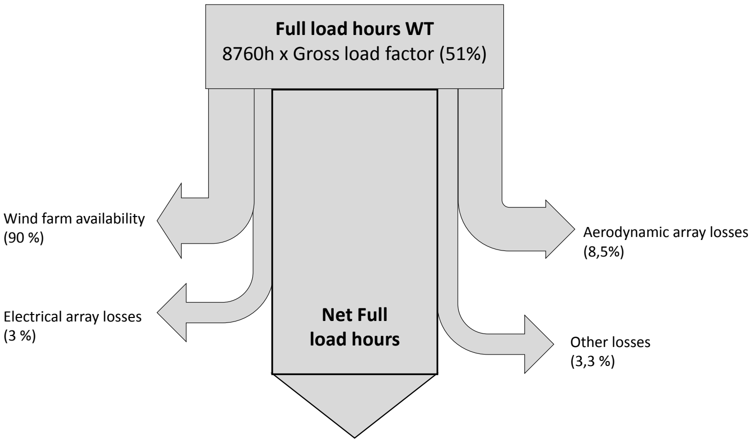


Fig. 8: Sankey diagram of the energy yield parameters (losses assumed in the reference scenario in brackets)

Appendix C.

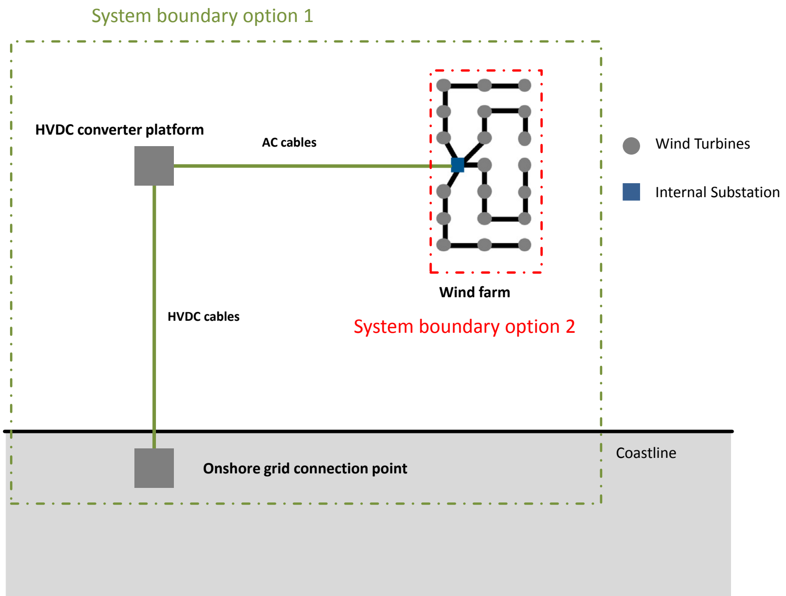


Fig. 9: System boundaries options implemented in the LCOE calculation tool

Appendix D.

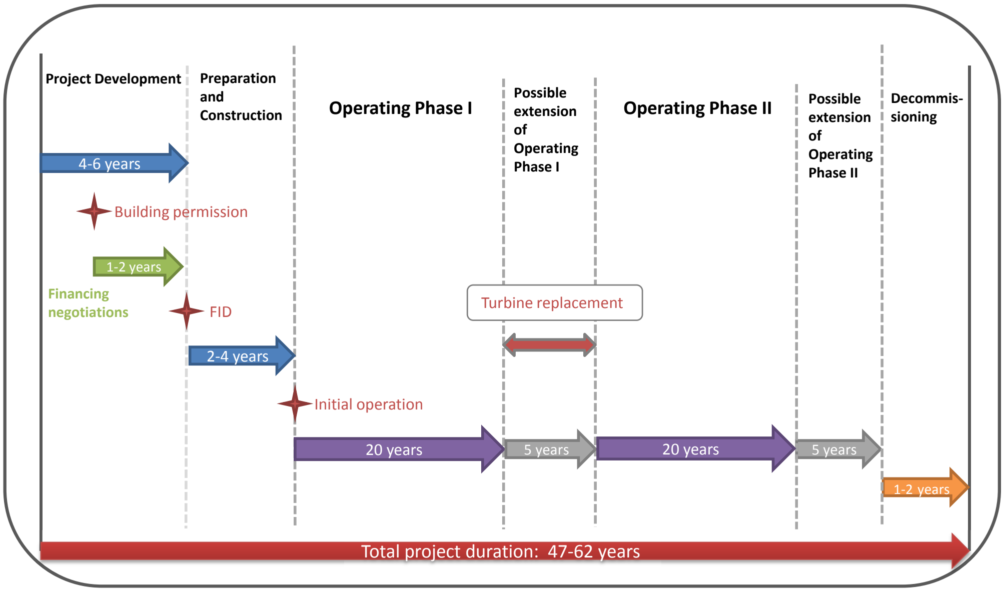


Fig. 10: Timeline of an offshore wind project using floating concrete platforms

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