Business Case Energyhub@Sea

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List of Abbreviations

AHTS	Anchor handling, towage and service vessel
CAPEX	Capital expenditures
CTV	Crew transport vessel
DNV GL	Det Norske Veritas Germanischer Lloyd
EU	European Union
FNPV(C)	Financial net present value of investment
FNPV(K)	Financial net present value of capital
GICON	Großmann Ingenieur Consult GmbH
GW	Giga Watt
Kwh	Kilo Watt hour
LWET	Lehrstuhl für Windenergietechnik
Mwh	Mega Watt hour
Nm	Nautical mile
NPV	Net present value
O&M	Operations and maintenance
Operations and maintenance	Opportunity energy costs
OPEX	Operational expenditures

1. Introduction

While in the past, besides transportation, the offshore business was dominated by the oil industry, in more recent years the enterprises venturing the seas have become more diverse. Offshore agriculture e.g. fish farms is contributing to the new mix. Equally, if not more important, renewable energy generation is moving offshore. This may happen through tidal power plants, as well as offshore wind turbines and floating solar pannels. Most of these new business opportunities demand a support structure to perform maintenance or to allow the export of products or energy to shore. The oil industry has all these structures developed for their purposes, but with new products, new challenges emerge. The EU-project Space@Sea acknowledges these challenges and aiming to provide a solution by designing a standardized multi-purpose offshore platform [9].

The aim of this report is to establish a business case for the use of the Space@Sea base module as a floating offshore hotel and maintenance platform for wind parks: the Energyhub@Sea. The hub provides living and working space for the maintenance employees as well as storage space for spare parts incl. a workshop to repair small components [9]. The question to be answered is, whether Space@Sea is able to fulfil these purposes while being more cost efficient than alternative solutions.

Said question is answered by showing the possible future development of the offshore wind industry, and the resulting demand to develop new concepts like Space@Sea. Similarly, focused concepts, both existing and newly developed, are reviewed. Subsequently, a cost analysis for the Energyhub@Sea is performed combined with presenting a cash flow statement for its lifespan based on a dynamic financial model in comparison to two different solutions. These will be a ground mounted offshore Platform and a leased mothership. A risk assessment, as well as parameter alterations are made for all three alternatives before a conclusion on the economic feasibility of the Energyhub@Sea is presented.

2. State of the art

To understand the scope of this business case, it is important to know the key aspects of the Space@Sea project as well as the projected development of the offshore wind market. Furthermore, as the Energyhub@Sea aims at providing accommodation and working space for offshore workers, it is important to take a look at previous, current and possible future solutions for the same problem. At this chapters' end, an overview of offshore concrete construction is provided.

2.1 The Space@Sea project

Space@Sea is an ongoing EU-project aiming to develop new ways to create both working and living areas at sea. The main objective is to provide "sustainable and affordable work space at sea by developing a standardized and cost efficient modular island with low ecological impact" [9]. With more people living in cities close to shore and an ever increasing demand for maritime transportation the need for a multipurpose floating structure is rising. The Space@Sea project aims to develop and standardize such structure in order to reduce costs compared to current, individually engineered solutions [9].

The project is planning to fulfil four different use-cases: "Aquafarming, energy production and distribution, transport and logistics and living" [9]. They are visualized in Figure 2.1. Each individual application is described as follows:

- **Energyhub@Sea:** An offshore base to provide energy distribution to shore and to accommodate a maintenance facility for operations and maintenance (O&M) tasks. The possibility to generate renewable energy at the hub itself is also taken into consideration [9].
- **Living@Sea:** As the demand for offshore hotel and living space is rising, Living@sea is a concept to provide accommodation. Starting with the demand of maintenance workers for offshore wind parks, this concept is planning to expand up to housing the workers families as well and eventually scaling up to whole cities placed on the base modules [9].
- **Farming@Sea:** This possible application investigates the possibilities of food production offshore. The aim is to make the Space@Sea platform self-sustaining by growing crops offshore or doing fish farming. Also microalgae are considered as food sources [9].
- **Transport&Logistics@Sea:** An offshore hub as port extension is going to be developed. This is expected to help ports deal with increasing transportation demands and limited space ashore. Ships could be handled at an artificial Space@Sea island. In a first step, several of the floaters can be used as a mere port extension, with the offshore hub as a far stretching goal. [9].

In order to seize economies of scale for the platform concept, every use-case shares the same base module, a floater made of concrete, represented by the triangles in Figure 2.1, that can be combined to various shaped floating artificial islands. Different additions will be made to the base module, depending on the use case.

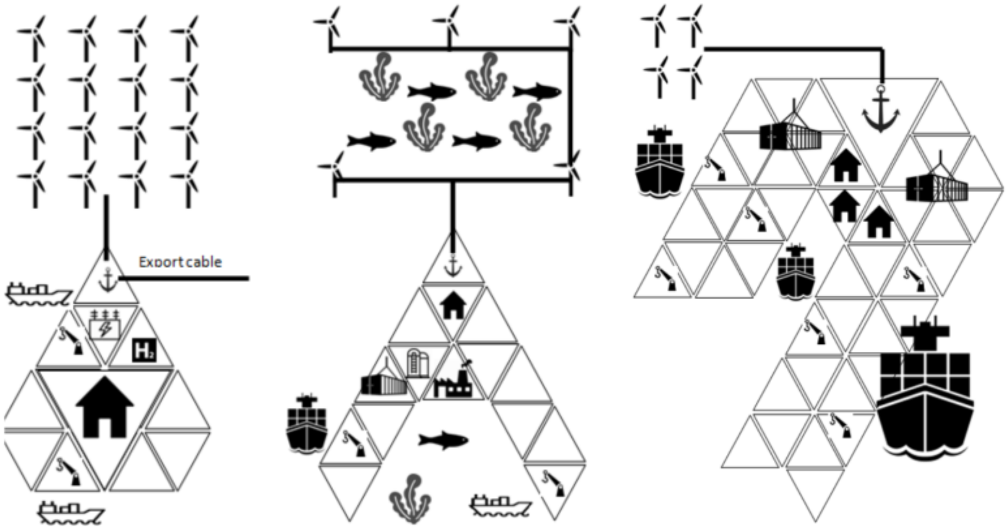


Figure 2.1 Different use cases for the Space@Sea platform: energy production and distribution (left), aquafarming (middle), logistics (right) [9]

Figure 2.2 shows the Energyhub@Sea version with the shared base module in dark grey. Added for this concept are the concrete storage facility on top of the base module, the yellow columns, that allow for greater tolerable wave height and the living module on top of the columns, that provides working and living space for the offshore workers. This combination shows one of the most simplistic Space@Sea use-cases, with only one base module used. More could be added, to allow for e.g. energy production in order to make the hub self-sustaining.

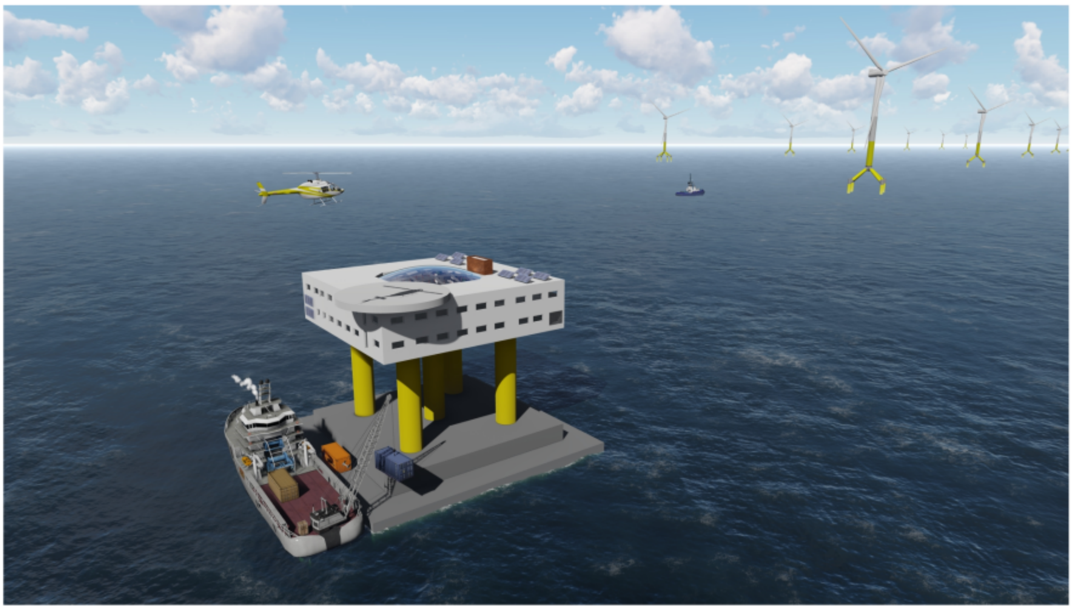


Figure 2.2 Rendering of the Energyhub@Sea purposed for the North Sea (Mediterranean build is without columns, LWET/GICON)

With these different developments and possible applications, the Space@Sea project will try to fulfil its objective given by the European commission: "To turn the potential of growing demand for resources and maritime services including transport, sustainability capturing and demonstrating the potential of seas and oceans into an asset for Europe"[9].

2.2 Offshore wind development

Contrary to the declining newly installed capacity for onshore wind energy, at least in Germany [16], offshore wind energy installations are increasing in capacity. According to PWCs report “Unlocking Europe’s offshore Wind potential”, 2017 alone saw an increase of installed capacity of offshore wind energy by 2.8 GW [26]. With already a few wind park bids being placed without the need of government subsidies, offshore wind is getting increasingly competitive in the energy market [26].

The prospects for the future are looking equally bright. With the EU-goal to become energy-wise more sustainable, wind energy is becoming one of the keys to transition to a more environmentally friendly energy grid. According to the study “Unleashing Europe’s offshore wind potential” by Hundleby and Freeman sees huge opportunities for offshore wind in the upcoming years. The researchers presented two different scenarios, a more realistic baseline scenario and a more optimistic upside scenario. They differ in various assumptions regarding the future of both technology and economy until 2030. However, according to the report, in 2030 between seven and eleven percent of the EU‘s electricity demand will be fulfilled by Offshore Wind energy [11].

In the first part of their report, the authors investigated the technical resource potential for the northern European shores. They state that around 50,205 TWh/year can be produced [11]. It also shows that the major part of the technical resource potential is located more than 12 nm away from shore, as shown by Figure 2.3. As the water depth is increasing further away from shore, new, eventually floating technologies might be needed to harness that resource potential. Simultaneously shore based maintenance becomes increasingly challenging.

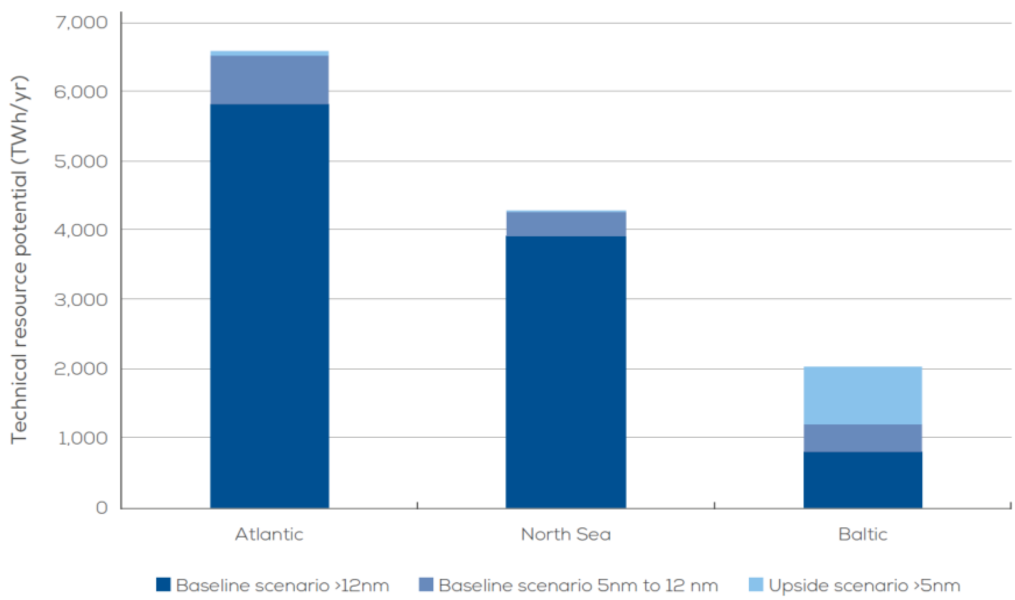


Figure 2.3 Technical resource potential in dependence of distance to shore [11]

Accordingly, Figure 2.4 shows the economically attractive resource potential depends on the used foundation. The third column, stating a potential of approximately 350 TWh/year for floating structures in the baseline scenario and 2750 TWh/year for the upside scenario is indicating the need for floating solutions. This is underlined by the upside scenario, with the reduction in floating structure costs being one of the key scenario assumptions [11].

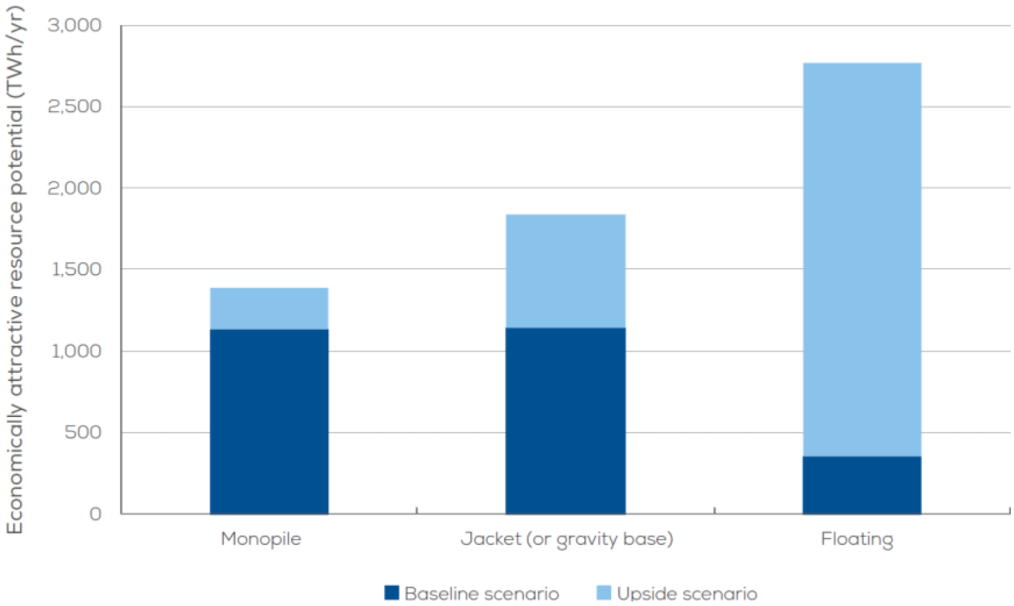


Figure 2.4 Economically attractive resource potential depending on foundation [11]

Despite these forecasts, the offshore wind industry is facing some threats, that might limit its potential. Beckman stated in 2016, that the major challenges with the huge growth of the sector are remaining at a sufficient quality level as well as dealing with the increasingly difficult environmental conditions further away from shore. Also the general economic development should be watched carefully, since an increase in interest rates might pose some new difficulties to planned wind parks. Finally, the article mentions, that legislative decisions play a huge role for the development, since decisions on subsidies and possible locations should be, but are not always made for long terms [2].

The up- and downsides of the offshore wind industry are best shown in a SWOT-Matrix (strength, weaknesses, opportunities, threats), as shown in Table 2.1, that summarizes the previous chapter. More bullet points may be found for each category.

Despite the risks and challenges, Hundleby and Freeman [2017] state, that in 2030, "offshore wind could in theory generate between 2,600 and 6,000 TWh at a cost of €65/MWh or below"[11]. This would represent between 80 % and 180 % of the EU‘s demand [11].

Table 2.1 SWOT-Analysis for the offshore wind sector

SWOT Analysis	
Strengths	**Weaknesses**
-Competitvely priced (cheaper than new nuclear) -Accepted by the general public -CO_2 neutral power generation	-Often depending on subsidies -High construction and maintenance costs compared to onshore wind
Opportunities	**Threats**
-Europe‘s goal to use more renewables -Improvements in technology enable more remote locations	-Possible increase of interest rates -More extreme weather conditions due to climate change

2.3 Offshore accommodation

Alongside with moving workplaces offshore, accommodation for the workers is needed, as daily commuting becomes difficult with increased shore distance. Especially regarding offshore wind parks, solutions to provide accommodation need to be found, as the resource potential is lying further offshore [11]. Several different approaches are being developed. For wind parks closer to shore, daily commuting using crew transport vessels (CTVs) from shore directly to the turbines seems to be the preferred solution [5]. For production sites further offshore, solutions may be a platform or a ship designed or repurposed for the O&M Task, as shown below.

2.3.1 Offshore platforms

The first Industry starting to build platforms offshore was the oil industry. Platforms were built as early as 1947 in the Gulf of Mexico [4]. Until 2005 more than 10,000 platforms had been built. With the majority made of steel, only a few dozens were made using concrete. Several different types of platforms are known, divided into floating and bottom fixed platforms. As fixed structures are becoming increasingly expensive with greater water depth, floating ones propose a viable alternative [4]. Nowadays platforms are also built for other purposes than producing crude oil or gas. One use case is building of transformer stations or accommodation platforms for offshore wind parks. While the upper structure may differ from traditional (oil) rigs, the foundations used are often similar.

As of 2015, three offshore platforms were in use or in construction for accommodation of O&M workers in proximity to a wind park. Horns Rev 2, Global Tech 1 and Dan Tysk. Both Dan Tysk and Horns Rev 2 have their accommodation platforms next to the transformer stations. The former is a jacket based platform, while the latter is situated on a monopile. In the case of Global Tech 1, the accommodation facility is built on top of the substation [25].

Monopile foundations are a cylindrical pile driven into the soil, to fix the upper structure to the sea floor. The pile usually consists of a mix of steel and concrete. Due to this rather simple form, they are relatively easy to design, produce, transport, and install compared to other concepts. However, the simplicity comes with rapidly increasing diameters with greater water depth, thus it is mostly used in depth between zero and 30 m [12].

The jacket foundation is one of the most common offshore structures. It achieves good stability against waves and is typically used in water depths up to 180 m [4]. Its "structure components are the Jacket legs, braces"[4], joints between the legs and the braces and if needed, appurtenances and skirt pile sleeves [4]. They form a "three-dimensional space frame"[4]. The term jacket has evolved from the spaceframe providing an enclosure to the oil drilling equipment on such platforms. The superstructure on top of the jacket usually consists of two or three decks [4]. Figure 2.5 shows a platform with a jacket as base structure.

Figure 2.5 Schematic figure of a jacket based fixed offshore platform [4]

While more offshore platform concepts, both bottom fixed and floating exist, according to van der Heijden [25] only the two described above are currently used for O&M platforms in the offshore wind industry. Especially the floating solutions are often specialized solutions suited for the needs of the oil industry, and not directly transferable to different sectors.

2.3.2 Ship based solutions

Besides bottom fixed accommodation platforms, as shown by Lorentzen [15], floating accommodation concepts have been developed within the offshore industry. They are mostly used by the oil and gas industry. Traditionally mono-hull barges, as well as semi-submersible barges have been used. However in more recent years, also traditional ships are more often used as floating hotels. The general use is accommodation of workers while setting up new oil drilling rigs, or while working on a rig. Using a ship as a floating hotel promises advantages in mobility, lower capital costs, as well as increased flexibility [22]. According to the DNV GL, in 2015, no floating hotel ships are in use for O&M purposes at a wind park, however they acknowledge the possibility to use this concept [22].

Furthermore, they propose offshore support vessels as a possible solution for the maintenance problems. These are ships of greater size than conventional CTVs, that can stay at sea for up to a few weeks. Also they can operate in more severe weather conditions and provide accommodation for both crew and technicians. In opposition to traditional floating hotels, they are equipped with an access system to allow both crew and spare parts transfer to and from the wind turbines. According to the report, a few of these vessels are currently used for offshore O&M [25].

A step further in handling the O&M challenge in wind parks is the mothership approach. Dalgic et al. [5] describe it as follows: "a mothership[...] is a large vessel that can accommodate multiple crew transfer vessels alongside "[5]. They are specifically designed to host smaller vessels, that perform the task of transferring the technicians. This brings the advantage compared to the previous ship based solutions, that multiple CTVs can be deployed simultaneously. The mothership can stay several days or weeks in close proximity to the wind park and perform the necessary operations. The reduced travelling time for wind parks further offshore and thus the increased working time are the main advantage, compared to a land based O&M strategy. This would lead to increased operational times for the wind park. However the challenge of such a specialized ship is mainly in the huge capital expenses [5] [24]. Even though the advantages can clearly be seen, motherships are still an "emerging technology "and not used currently [25]. Figure 2.6 shows a summary of Offshore accommodation platforms.

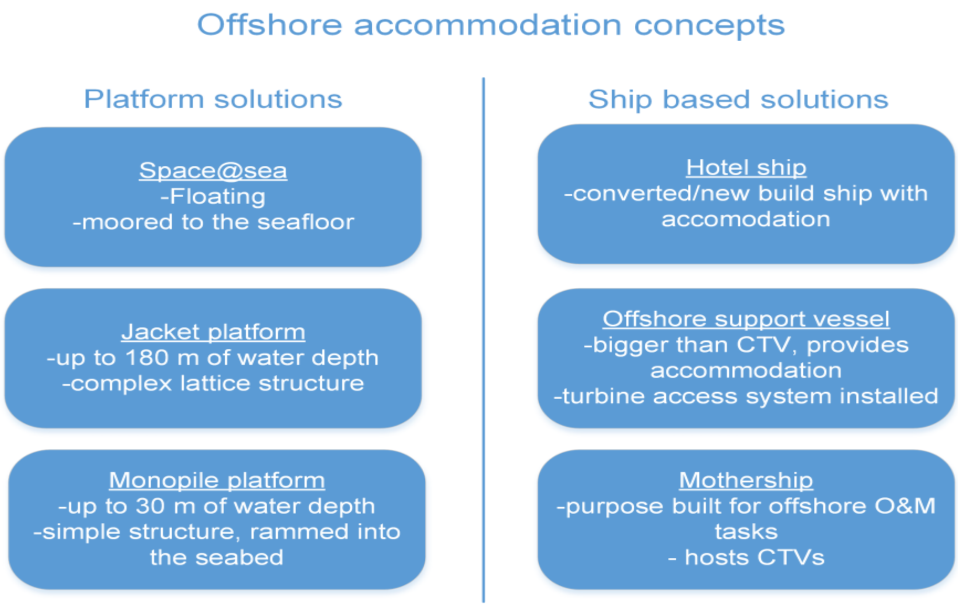


Figure 2.6 Overview of offshore accommodation concepts

2.4 Offshore concrete structures

Space@Sea tries to solve one of the most relevant problems of offshore structures, their high capital expenditures (CAPEX), by applying a standardized concrete structure as base module for multiple purposes.

Although steel is the dominant material in modern shipbuilding, other materials such as wood, aluminium or reinforced plastic fibreglass appear regularly. Concrete however has not found great acceptance in shipbuilding yet. Regarding platforms, the offshore industry is increasingly acknowledging the advantages concrete has over steel [23]. While only a very few concrete ships have been built, e.g. the barges by Alfred A. Yee, the material is much broader represented in offshore structure construction. the first concrete platform was deployed in 1950 in the gulf of Mexico, followed by more than 1000 small concrete platforms in that area [23].

In the following years, the concrete projects grew bigger, with the "Troll A" platform being one of the biggest ever made. It was built in one piece in 1996 and then towed to its final location in the North Sea [13]. Nowadays two common offshore concrete structure types can be distinguished. Gravity base structures and floating structures. While the former often consists of a set of concrete tanks and a few columns to host the upper structure, the latter can be divided into two subsections. Tension leg platforms consist of a cylindrical pontoon providing the lift and columns to support the deck. The floater is fixed vertically to the seabed, prohibiting vertical motion. The barge type basically is a floating hull, that is moored to the seabed, often used for storage [23].

This development towards a broader use of concrete for offshore structures is based on several advantages concrete offers compared to steel. According to Pérez Fernández and Lamas Pardo [23] the following can be named:

- high durability
- almost maintenance free material
- ability to carry heavy topsides
- lower maintenance costs
- lower manufacturing costs
- great fire resistance

While the increased weight limited the use of concrete for shipbuilding, it is not such a big disadvantage for offshore structures. As these platforms are not supposed to move regularly, the increased fuel consumption and displacement are not as disadvantageous, possibly leading to a broader use of concrete in the future [23].

3. Input data and assumptions

The business case‘s scope is to give an approximation of the Energyhub@Sea‘s costs for its proposed 25 year lifespan. Additionally two alternative ways to perform the O&M activities are proposed and calculated. For the comparison a sizable amount of input data is needed. It is shown in the following chapter. Any eventual assumptions that need to be made are also clarified in the following chapters.

3.1 Wind Park

All three possible solutions are sharing the same wind park for the baseline scenario. The data is shown in Table 3.1. The wind park itself is situated in the Mediterranean Sea, south of France, as shown in Figure 3.1. With its 100 turbines, it is expected to produce approximately 3500 GWh per year. For the baseline scenario, a water depth of 100 m is assumed for the accommodation platforms location.

Table 3.1 Wind park data

Wind park data		
item	value	unit
number of turbines	100	-
capacity of turbines	10	MW
distance to shore	32.4	nm
water depth	100-200	m
expected yearly output	3500	GWh
life cycle	25	years

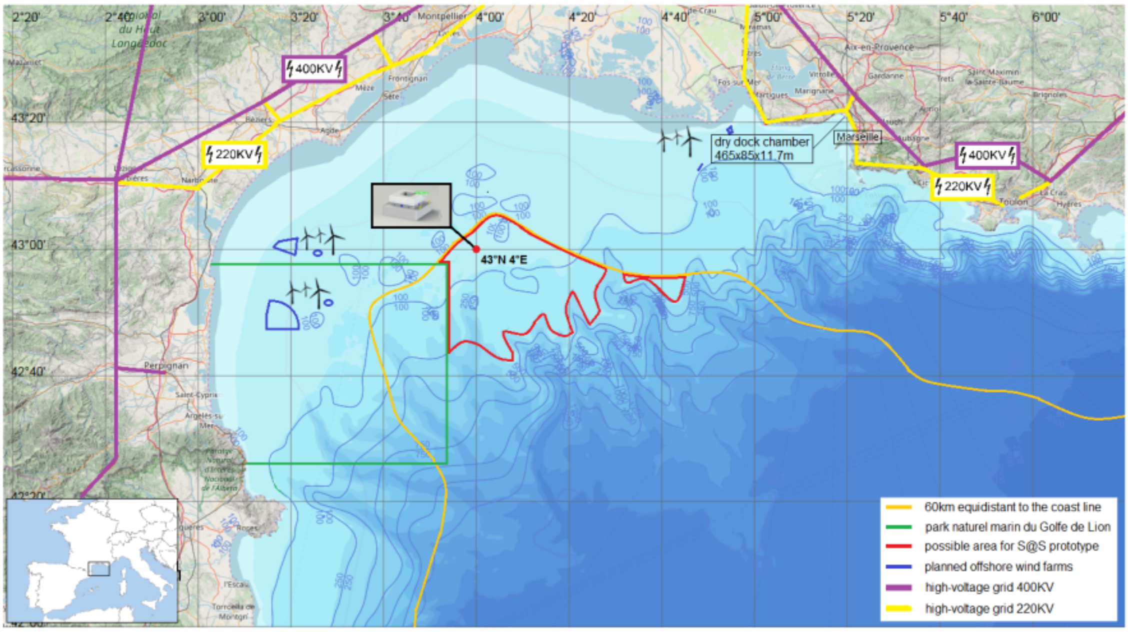


Figure 3.1 Geographical location of the case study wind park (LWET/GICON)

3.2 Financial data

Also shared by all three alternatives are the basic financial parameters. They are shown in Table 3.2. Regarding the cost side of the business case, one important factor are the capital costs. These are mainly determined by the percentage of private equity, loans and their interest rates. For the loan a payback concept and an interest rate are chosen, as shown in Table 3.2. Most of the financial data is chosen according to the “Guide to cost benefit analysis of investment projects” published by Laissy [14] on behalf of the EU. few values are defined in the business cases assignment (labelled “task” in the table). Taxes are not included in this business case.

Table 3.2 Financial data for the business case

Financial data			
item	**value**	**unit**	**source**
discount rate	4	%	Laissy [2014]
tax rate	0	%	assumption
Union assistance on initial costs	0	%	assumption
public contribution	0	%	task
private equity	20	%	task
private loan	80	%	task
equity capital costs	0	%	assumption
loan interest rate	4	%	Laissy [2014]
loan duration	10	years	assumption
payback start period	3		assumption
annual salary increase	1.94	%	Wage data

Since all three scenarios are supposed to be for the same wind park, all three share the same data for salaries as shown in Table 3.3. The values are taken from the latest structure of earnings survey by the EU. The items are EU-averages taken from the subsection electricity, gas, steam and air conditioning supply. The occupation categories chosen for each job are shown in the Table as well as the salaries for each category.

Table 3.3 Assumed wages for O&M staff

Assumed monthly wages for O&M staff			
occupation	**occupation category**	**salary**	**source**
maintenance technician	technicians and associate professionals	3301€	Weicker [2014]
CTV crew	plant and machine operators and assemblers	2232€	Weicker [2014]
office and organization staff	professionals	4259€	Weicker [2014]
board& lodging staff	manual workers	2606€	Weicker [2014]

3.2.1 Financial assumptions

Following assumptions are made regarding financial numbers shown in Table 3.2:

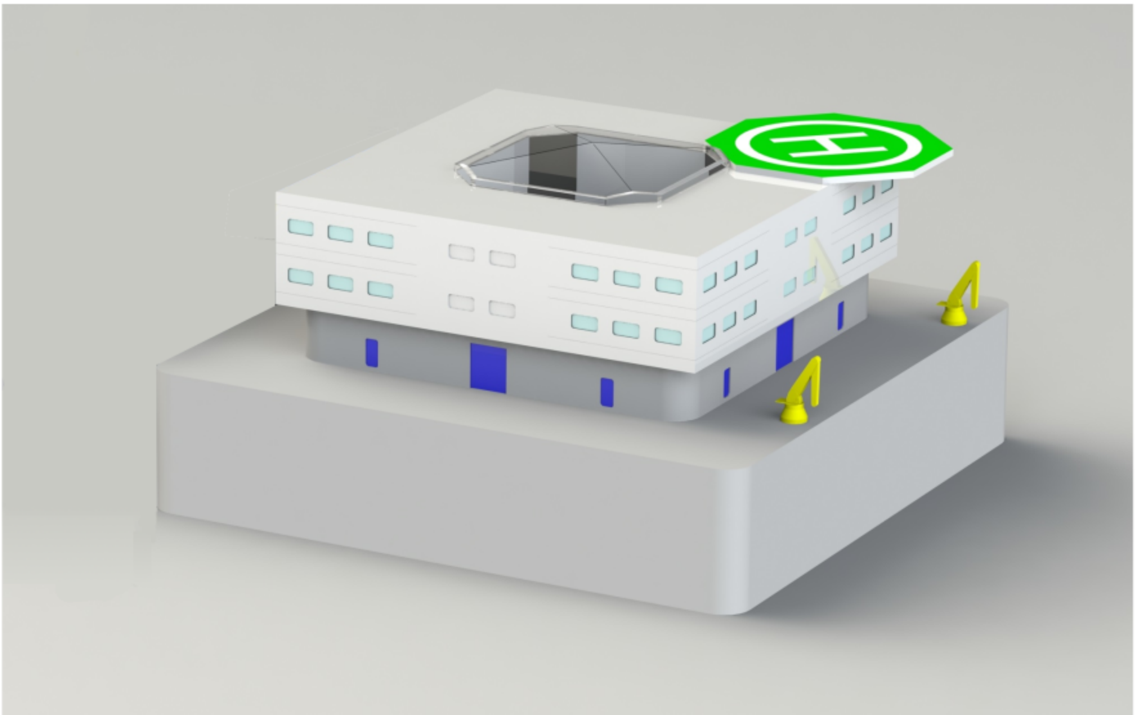
- **tax rate:** Regarding income tax a rate of zero percent is assumed. For this business case only net costs are considered.
- **Union assistance, public contribution:** While Laissy [14] names funding by the European Union and public contribution as a reasonable method, this case presents a solely privately funded venture. Hence both values are taken as zero.
- **equity capital costs:** Since no revenues are generated by the maintenance platform itself, no equity capital costs are assumed.
- **loan duration & payback start:** 10 years is a reasonable time to pay back the loan taken for the building of the structure, while deferring the payback to year three allows the wind park to start being profitable before cash outflows for the loan start.

In addition to the assumptions stated above, for both the Energyhub@Sea and the fixed platform contingency costs will be applied. According to Para-González et al.[19] these are a cost addition on the initially calculated new building price. They are added in order to take the likelihood of increased costs into account. It is established that, for a similarly priced ship these costs are rated at 4.8-5.2 % [19]. Thus, five percent are being used for the Energyhub@Sea and the fixed platform. The factor is multiplied with the initial construction costs, to obtain the contingency costs.

3.3 Energyhub@Sea

According to the Proposal of Flikkema et al. [9], the minimalist form of the Energyhub@Sea is to be used. It consists of one floater (named base module) with a concrete storage facility on top, as well as the living module for the workers. It is shown in Figure 3.2. The required data for this business case is explained in the following chapter.

Figure 3.2 Rendering of the Energyhub@Sea (LWET/GICON)



The technical parameters of the hub and some operational data are shown in Table 3.4 and Table 3.5 respectively. Both data sets are provided by the existing concepts for the Space@Sea base module, as well as first designs of the Energyhub@Sea.

3.3.1 Energyhub@Sea: assumptions

In order to provide an overview of the Energyhubs costs, several assumptions were made. Especially the cost data is based mainly on assumptions, as well as adjusting known financial numbers of similar projects to fit the Energyhub@Sea.

Table 3.4 Energyhub@Sea technical data

Energyhub@Sea technical data			
item	**value**	**unit**	**source**
weight of living module	800	tons	Dierken [2019]
weight of base platform	9300	tons	Dierken [2019]
wind park operational time	93	%	Dalgic et al. [2015]
interior spaces			
living	522	m^2	Adam [2018]
corridors/stairs	400	m^2	Adam [2018]
kitchen/canteen	200	m^2	Adam [2018]
food storage	100	m^2	Adam [2018]
offices	50	m^2	Adam [2018]
conference rooms	35	m^2	Adam [2018]
health rooms	15	m^2	Adam [2018]
social rooms	150	m^2	Adam [2018]
other items needed			
lifeboats	2		Dierken [2019]
climate control	1472	m^2	Dierken [2019]
elevators	2		Dierken [2019]
water purification	4000	l/day	Dierken [2019]
water desalination	4000	l/day	Dierken [2019]

Table 3.5 Energyhub@Sea operational data

Energyhub@Sea operational data			
item	**value**	**unit**	**source**
energy consumption	280	MWh	Dierken [2019]
energy costs	0,139	€/KWh	energy costs, 2019
work shifts	2		task
required personnel			
maintenance technician	18		Adam [2018]
CTV crew	6		Adam [2018]
office and organization staff	2		Adam [2018]
board& lodging staff	6		Adam [2018]

Initial costs

Regarding the square meter prices for each room category, a regular 12 m 2 for cruise liners is calculated at €20,000 [7]. These costs are taken as reference for the Energyhub@Sea's cabins. As not as many and equally standardized cabins are going to be used for the Energyhub, costs are expected to be 50% higher, at €30,000. Regarding the other categories, Expense statistics for new building of equally purposed houses [3] were considered to determine the factor from :

$$f_{room} = \frac{referenceitemprice}{housingreferenceprice} \tag{3.1}$$

The factor was used to determine the m^2-prices of the other room categories, based on the price for the living quarters. The results are shown in Table 3.6. A first design impression of the central social room is shown in Figure 3.3.

Figure 3.3 Architectural vision of the Energyhubs interior (LWET/GICON)

Table 3.6 Energyhub@Sea: room prices per m^2[3]

Energyhub@Sea m^2 prices				
room category	**reference building**	**reference price[€/m^2]**	**factor**	**room price[€/m^2]**
living	housing	1,695	1.00	2,500
corridors/stairs	factory	982	0.58	1,448.38
kitchen/canteen	restaurant	1,773	1.05	2,615.04
food storage	other	2,182	1.29	3,218.29
offices	Office	1,842	1.09	2,716.81
conference	Office	1,842	1.09	2,716.81
health rooms	medical	2,160	1.27	3,185.84
social rooms	office	1842	1.09	2,716,81
storage facility	factory	982	0.58	1,448.38

One specialty of the Energyhub is, that it is a floating structure, hence it needs to be moored to the seafloor. It is assumed that the requirements and costs will be equal to the mooring of a floating offshore wind turbine, adjusted regarding the weight difference. The living modules weight is increased by 20% to 960 t for this calculation and others not regarding its steel weight itself, as additional weight will be added by furniture, the personnel itself, spare parts etc. once the platform is in use. The base values for the windfloat concept, as shown by Myhr et al. [18] are taken into the calculations. They are adjusted using the weight factor wf_{hub} :

$$wf_{hub} = \frac{weightEnergyhub@Sea}{weightwindfloat} \tag{3.2}$$

With the weight of the Windfloat turbine being 3100t, 2500t for the foundation and 600t for the turbine [18] and the hubs assumed weight being 10260 t, wf_{hub} is 3.31. The resulting numbers taken into calculation are shown in Table 3.7. For the platform‘s installation, meaning the costs to install the mooring system as well as towing the platform to the site, the numbers shown by Myhr et al. [18] for the Windfloat platform are used once again.

Table 3.7 Windfloat and Energyhub mooring data (Windfloat values taken from Myhr et al. [18])

Energyhub@sea data platform mooring			
item	windfloat value	Ernergyhub value	unit
weight adjustment factor	1	3.31	
required anchors	4	14	
price per anchor	114,000	114,000	€
weight of each anchor	17	17	t
Number of Mooring cables	4	14	
cable price	200	200	€/m of depth

Regarding the platforms transportation, it is assumed, that the assembly of the platform takes place within twice the shore distance of its later location and that it can reach a cruising speed, when towed, of 3 kts. It will be towed to the mooring location and moored to the previously installed anchors. According to Myhr et al. [18], two types of ships are used:

- **tug boat:** Used for towing operations, requires a crew of 14, and has a lease price of €17,000 per day.
- **Anchor handling, towage and service vessel (AHTS):** used for towing operations as well as anchor installation. It requires a crew of 35, and has a lease price of €91,000 per day.

Three operations have to be performed, in order to fixate the platform at its location: platform towage, anchor installation and platform anchoring. Their numbers are shown in Table 3.8. The weather probability is a factor that needs to be taken into account, since certain operations can only be performed in appropriate weather conditions. As the ships are leased for longer amounts of time, the net working hours are multiplied with $\frac{1}{weatherfactor}$ to obtain the working hours actually needed.

Table 3.8 Energy hub@Sea installation operations (based on [18])

Energyhub@sea installation operations			
operation	duration[h]	wheather probability	required ship
platform towage	179.73	0.75	7 tugs, 4 AHTS
anchor installation	6 per anchor	0.55	1 AHTS
platform anchoring	8	0.60	4 AHTS

The second unique selling point of the Energyhub is its concrete floater. According to Pérez Fernández and Lamas Pardo [23] the construction of concrete ships is approximately 16 % cheaper than for equal steel ships [23]. With concrete structures being as much as 3.25 times heavier for the same purpose [29] it can be assumed, that concrete per ton is circa 74 % cheaper than steel. As a steel price of 3000 €/ton is considered [7], the assumed concrete price would be 775.38 €/ton.

Certainly a major point in a project‘s budgeting are the development costs. For the Energyhub, they are assumed to have a similar share to the initial costs, as for the windfloat turbine. They are at 6.06 % of the initial costs [18].

Operational costs

The operational costs contain, besides the already mentioned labour costs, energy costs and general expenditures. Regarding the energy costs, the following is assumed: Dierken [7] stated, that the hub‘s annual energy demand would be 280 MWh. It is assumed, that the required energy is provided by the wind park next to the platform. Thus the energy costs are calculated as opportunity costs. The German average net energy price for 2018 of 0.14 $\frac{€}{kwh}$ is taken into account [8].

General expenditure consists of several individual expenses. The biggest one is CTV Maintenance and operations. This is assumed to be as much as €2,755,964 per year [21]. While Phillips et al. [21] originally stated this value for a 500 MW wind park, it is assumed, that it will apply for the base line scenario as well, as the assumed 10 MW turbines reduce the amount of individual wind engines. For the general maintenance of the platform a base value of €275,596.40 [21], similar to a transformer platform, is taken into account. However, Pérez Fernández and Lamas Pardo [23] states, that maintenance for similar to steel concrete structures is two thirds less expensive [23]. Hence, for the concrete parts of the hub, the maintenance costs are reduced, giving a reduced value of €194,573.27 per year for the hub. This value will increase by 0.5 % per year. Additionally replacement costs for furniture are calculated as being €36,333 per year [7].

One major cost factor is crew supply. it contains food costs, other consumer goods, and water handling costs. Food consumption is assumed to be as much as an average German household consumes, €257 per person and month [10], leading to annual costs of €98,668 per year. other consumer goods are calculated with €50 per month and crew member, leading to €19,200 per year. For water handling, costs for desalination of 26.5 cents per litre were calculated [6], leading to costs of €380,952 per year. A list of the operational costs is shown in Table 3.9, in sum they are €3,509.107 in each period.

Table 3.9 Energyhub@Sea operational expenses

Energyhub@sea operational costs	
item	**annual costs [€]**
energy	38,696
CTV O&M	2,755,964
platform maintenance	194,573
furniture	36,333
crew supply	498,820

3.4 Alternative scenario: fixed platform

The obvious alternative to a floating platform like the Energyhub@Sea is a fixed platform with a jacket as base structure. Such platforms are in use for decades now, e. g. as an oil rig and have proven their reliability. However, with increasing water depth their costs start to rise exponentially [4]. For this case study it is assumed that the Energyhub@Sea and the fixed platform are similar, apart from their foundation. This means, that technical data and costs for the living module, fuel, energy and wages are based on the same numbers.

Since the concrete base module of the Energyhub@Sea contains a storage facility, that cannot be included in the jacket foundation, it has to be added to the fixed platforms living module. This increases its steel weight and available space to the values shown in Table 3.10. Similar to the Energyhub@Sea's living module its weight is be further increased by 20 % to 1162.2 t after the steel cost calculations to account for weight brought into the module.

Table 3.10 Fixed platform living module data

living module data		
item	**value**	**unit**
living module weight	968.48	t
additional storage space	310	m^2

3.4.1 Fixed platform assumptions

Regarding the foundation, like for the Energyhub@Sea, a comparable jacked foundation offshore wind turbine, as described by Myhr et al. [18] is used to provide the basic numbers, again adjusted for the water depth and increased weight of the platform. Myhr et al. [18] presented a case for 30 m water depth. This business cases baseline scenario is set at a depth of 100 m. Also the living module on the jacket structure is significantly heavier (1162.2 t compared to 600 t for the turbine). The adjusted numbers are shown in Table 3.11. The weight of the jacket is determined by the following formula:

$$M_{Fpjacket} = \frac{M_{turbine}}{M_{tjacket}} * \frac{\mathrm{d}}{30} \tag{3.3}$$

$$d = waterdepth$$

$$M_{turbine} = weightofthewindturbine$$

$$M_{tjacket} = weightoftheturbinesjacket$$

$$M_{Fpjacket} = weightoftheplatformsjacket$$

The jacket price is calculated by determining the price per ton of upper structure and meter of water depth. For the jacket wind turbine values are presented by Myhr et al. [18], and then multiplied this value with the numbers for the fixed platforms living module weight and the baseline scenarios water depth. The corresponding data is shown in Table 3.11.

Table 3.11 Wind turbine and fixed platform foundation data (turbine values taken from Myhr et al. [18])

Fixed platform jacket data			
item	**Turbine value**	**fixed platform value**	**unit**
weight of turbine/living module	600	968.48	t
adjustment factor wf_{fp}	1	1.94	-
weight of the jacket	825	5500	t
price per ton of upper structure	17667	17667	€/t
jacket decommissioning costs	80	80	% of initial costs

The installation costs for the platform are calculated similarly. Base value once again is the installation of a jacket based wind turbine in 30 m of water depth. It is assumed that half of the reference costs are fixed, and half are depending on the water depth. The relation between water depth and price is assumed to be declining, as shown in the following formula:

$$C_{fpins} = \frac{C_{turbineins}}{2} + \frac{C_{turbineins}}{60} * wf_{fp} \tag{3.4}$$

$$d = waterdepth$$

$$C_{fpins} = installationcostsofthefixedplatform$$

$$C_{turbineins} = installationcostsofthereferenceturbine$$

$$wf_{fp} = weightadjestmentfactorforthefixedplatform$$

The weight factor wf_{fp} is defined as the weight ratio between the fixed platforms living module and the 600t weighing wind turbine on top of the jacket.

Development and consenting costs were assumed to be similar to a bottom fixed jacket wind turbine, being 8.7 % of the initial costs [18]. Decommissioning for the whole platform is also assumed to be similar, clocking in at 80 % of the initial Investment [18].

3.5 Alternative scenario: mothership approach

The mothership is an advanced ship based O&M solution, thus it is considered as the second alternative to the Energyhub@Sea for this business case. As the charter costs for such a specialized ship are high, a seasonal approach is chosen [5] as it is common for this industry sector. The ship is also not owned as it is for the platform approaches because it is not common for offshore operators to own and operate such a ship. The reason for charter is quite simple because of costs. The charter a ship for a limited time is cheaper as to keep it under work for 20-25years for O&M of different offshore windfarms. For platforms this is different because of the less uncertainties for planning. The ship would be chartered for three months only- hence reducing both the charter and the employment costs. However, for the operational time period the same number of crew as for the other two platforms is calculated. A time charter is assumed. The charterer only has to pay for fuel and labour. The same values as for the other two platforms regarding general expenditures, such as food are taken into the calculations. Since the operational time of the wind park is decreasing for this alternative, opportunity costs based on the net energy price in Germany are taken into consideration. The required values are shown in Table 3.12

Table 3.12 Mothership scenario data

mothership scenario data			
item	**value**	**unit**	**source**
charter rate	62009	€/day	Dalgic et al. [2015]
fuel consumption stationary	1.51	t/h	Dalgic et al. [2015]
fuel consumption operational	3.025	t/h	Dalgic et al. [2015]
cruising speed	8.5	kts	Dalgic et al. [2015]
fuel price	757.89	€	Dalgic et al. [2015]
operation time	3	months	
wind park operational time	87	%	Dalgic et al. [2015]

3.5.1 Mothership approach assumptions

The key assumption regarding the mothership is its operational and stationary time. It is projected, that the mothership returns to the port for every crew change- so once in 14 days. The traveling time is calculated as operational time, while the time at the wind park is calculated as stationary, leading to lower fuel consumption. Per month, the operational time is calculated as 82 hours, the stationary time as 638 hours. Food and other consumer goods costs for the crew are supposed to be similar to the Energyhub@Sea. However, since the mothership enters a port regularly, it is assumed, that no desalination treatment costs will occur, as fresh water would be stored in tanks and provided from shore.

4. Cost analyses

The input data detailed in section 3 is used to predict the costs for running each of the three alternatives in combination with the base line scenario‘s wind park. The initial costs are displayed. A cash flow statement is made. Additionally, both a static cost comparison and two dynamic financial net present values (FNPV) are presented and calculated for each of the three alternatives and the 25-year runtime of the investment.

4.1 Predicted cash flows

In this section, the predicted annual cash flows for each of the three scenarios will be presented. However, as the periods are widely equal, only three periods are presented for each of the three solutions, as well as their overall results. Some costs are increasing during the 25 year run time. Among others, the labour costs are suspected to rise during the 25 year period. Their increase is shown in Appendix A.1. The Energy costs, similar for both the Energyhub@Sea and the fixed platform are shown in Appendix A.2. The replacement and loan costs for the two platform solutions are displayed in detail in Appendix A.3 and A.4 respectively.

4.1.1 Energyhub@Sea

The Energyhub@Sea‘s initial costs are shown in Table 4.1. Most expensive is the construction of the steel and concrete carcass (41% of the overall initial costs), followed by the technical and start-up costs (29.9 %), including transport and mooring of the platform, as well as the anchorage installation. Interior costs are estimated to be close to four million euros (16.5%). Both the contingency reserve and development and consenting costs are calculated being over €1,000,000 at 4.5% and 5.5% respectively. The smallest amount is reserved for required machinery aboard the Energyhub, at 2.7 % of the initial costs. The overall initial costs for the baseline scenario are estimated to be €23,432,150.

Table 4.1 Initial costs of the Energyhub@Sea

Initial costs of the Energyhub@Sea		
category	**costs[€]**	**costs[%]**
living module interior	3,864,425	16.5
steel and concrete carcass	9,611,077	41
machinery	624,728	2.7
development and consenting	1,278,698	5.5
contingency reserve	1,054,926	4.5
summed up construction costs	**16,433,854**	**70.1**
technical and startup costs	6,998,296	29.9
overall initial costs	**23,432,150**	**100**

Table 4.2 shows the cash flow of the Energyhub@Sea. Three periods were chosen, to give an overview over the running costs. Period 2, gives an overview over the costs right at the projects start, without the irregular initial investment. Period ten is in the middle of the projects lifespan, while still showing the added costs for loan payback. Period 24 shows the operating costs at the end of the design life, without giving a too high estimate due to the decommissioning costs, that would be added if period 25 was shown. Appendix A.6 shows the cash flows for each period. It can be seen, that individual items increase over the lifespan of the project, as is indicated by comparing the expenses of period two to 24. The cash flow increased by €1,277,356 over 23 years. However it can be seen, that the periods during which the loan is paid back, are the most cash flow intensive ones. Period ten for example, has a cash flow of €8,827,728. This is over €1.5 million higher, than period 24, towards the end of the projects lifetime.

Table 4.2 Energyhub@Sea: Cash flows for periods 2,10 and 25

Energyhub@Sea Cash flows			
cost category	**period 2 [€]**	**period 10 [€]**	**period 24 [€]**
replacement	195,546	203,506	218,224
labour	2,372,282	2,766,454	3,620,331
energy	38,725	38,960	39,374
general expenditures	3,291,138	3,291,138	3,291,138
loan	-	2,496,072	-
total cash flow	**5,897,692**	**8,796,129**	**7,169,066**

At the end of the design life of the wind park, costs for decommissioning of the platform are taken into consideration. Although Pérez Fernández and Lamas Pardo [23] state that offshore concrete structures can be used for 50 to 75 years without significant increase in maintenance costs [23], it is assumed, that the hub will be completely decommissioned. The corresponding costs are calculated to be €16,450,773. With the scrap value of €804,450 taken into account, the costs are: €15,417,760,53.

4.1.2 Fixed platform

The fixed platforms cost structure is similar to the Energyhub's and shown in Table 4.3. The data shows, that for the baseline scenarios 100 m water depth, the steel construction costs comprise mainly of the foundation price, being €20,532,127 or 61.2 % of the overall initial costs. The living module construction is only responsible for €2,905,435 of the overall price (10.2 %). Some of the stated costs are similar to the Energyhub@Sea, namely living module interior and machinery. As the overall initial costs of the fixed platform are higher than for the Energyhub, these costs items are responsible for smaller parts of the overall initial costs. Since development, consenting costs and contingency reserve are calculated as percentages of the construction costs, they are considerably higher than the Energyhubs.

Table 4.3 Initial costs of the fixed platform

Initial costs of the fixed platform		
category	**costs [€]**	**costs[%]**
living module interior	3,864,425	10.2
steel construction	23,437,561	61.2
machinery	624,728	1.7
development and consenting	2,901,533	7.7
contingency reserve	1,668,381	4.4
summed up construction costs	**32,496,629**	**85.7**
technical and start-up costs	5,440,923	14.3
overall initial costs	**37,937,553**	**100**

The expenses for all periods are shown in Appendix A.7. Table 4.4 gives an overview of the same three periods also presented for the Energyhub@Sea. It can be seen, that the expenses increase over the lifespan of the fixed platform. While the increase is approximately €1.3 million between periods two and 24, the most capital intensive periods, besides periods one and 25, are the ones where the loan has to be paid back. For the baseline scenario, these are periods 3 to 12, with loan costs of €4,107,784 per year. This leads to overall expenses for period 10 of nearly €10.5 million, considerably higher, than even the much later period 24. In general the expenses are slightly over the Energyhub@Sea level, mainly due to higher replacement and maintenance costs.

Table 4.4 Fixed platform: Cash flows for periods 2,10 and 24

Fixed platform cash flows			
cost category	**period 2**	**period 10**	**period 24**
replacement	276,974	288,249	309,096
labour	2,372,282	2,766,454	3,620,331
energy	38,725	38,960	39,374
general expenditures	3,291,138	3,291,138	3,291,138
loan	-	4,041,236	-
total cash flow	**5,979,120**	**10,426,037**	**7,259,938**

At the end of the design life span of 25 years, the fixed platform is supposed to be scrapped and decommissioned. The initial Decommissioning costs of €22,341,371 are expected to be reduced by the scrap value of €4,190,686 to €18,150,684.

4.1.3 Mothership approach

One of the main advantages of the mothership is, that no initial costs occur, as the mothership is chartered. Thus, only the operational cash flows for the three periods, two, ten and 24 are presented. They are enlisted in Table 4.5. As the expenses are expected to be covered by the wind parks revenues and no initial investment is necessary, no loan costs occur. The assumed charter terms see the responsibility for replacement and maintenance with the ship owner, hence, no replacement costs are calculated. The labour costs are also considerably lower, than for the other two options, as the mothership is only on duty for three months. The main annual expenses come from the charter being at €5.5 million, followed by €1.6 million for fuel. Overall the mothership has outflows of approximately €8 million per year. A complete Table of the expenses per period is shown in appendix A.8.

As the mothership is returned to the owner at the end of the wind parks life cycle and the lease, no decommissioning costs occur.

Table 4.5 Mothership: Cash flows for periods 2,10 and 25

Mothership approach cash flows			
cost category	**period 2**	**period 10**	**period 24**
replacement	-	-	-
labour	593,071	691,613	905,083
fuel	1,637,043	1,637,043	1,637,043
general expenditures	189,888	189,888	189,888
charter rate	5,580,827	5,580,827	5,580,827
loan	-	-	-
total cash flow	**8,000,828**	**8,099,371**	**8,312,840**

4.2 Cost comparison

A cost comparison is one of the easiest ways to compare investment alternatives. Only expenses will be compared, no revenues are taken into account [20]. This makes it perfectly suitable for this business case, as the wind parks revenues are not calculated.

One hurdle for this calculation are the calculated capital costs. They consist of depreciation and interest, both on equity capital and loan. An annual average is calculated by the following formula [20]:

$$K_c = \frac{I_0}{T} + \frac{i * I_0}{2} \quad (4.1)$$

$$K_c = calulatorycapitalcosts$$

$$I_0 = initialcosts$$

$$T = numberofperiods(25)$$

$$i = interestrate(4\%)$$

For this calculation, the assumption that the interest on equity capital is equal to the interest rate for the loan, at four percent, is made. Combined with the operational costs for each period, accumulated over the lifetime of the project, a total of costs can be given for each alternative. This sum is shown in Table 4.6.

Regarding the initial costs, the mothership is favourable, with no initial costs at all. Regarding the two platforms, it can be seen, that the Energyhub@Sea is considerably cheaper with €23.4 million compared to €38 million for the fixed platform.

During the design life cycle the Energyhub@Sea again performs better than the fixed platform, with €174 million compared to €183.5 million. This is mainly due to higher expenses for maintenance and capital on the fixed platform side. However for this category the Mothership approach shows the highest numbers, at €203 Million, mainly because of the high charter rates and fuel costs each period.

Decommissioning again shows a difference between the platforms, the Energyhub promises to be cheaper with estimated €15.6 million, in opposition to the fixed platforms €18.1 million. Once again, the leased mothership shows its advantage in not having decommissioning costs at all.

The estimated sub totals show the mothership as most favourable alternative, with estimated costs of €203.7 million. The Energyhub@Sea is around €10 million more expensive, at €214.1 million. The fixed platform appears to be the most expensive one with €240 million spent during the 25 year period. However, while the mothership at first seems reasonable, with no initial costs and lowest overall costs, it is important to consider the increased downtime for the wind park. According to Dalgic et al. [5] it can be assumed that, the wind park would lose six percent of its availability. This leads to losses due to unsold energy of over €29 million per year (as shown in appendix A.5) because of the additional downtime of the turbines. It is assumed that based on specific charter periods and the O&M needs of the wind park the loss because of less sold electricity leading to a lifetime loss of €732 million. This measure is considered in the total line of Table 4.6. It shows, that the mothership is by far the least favourable of the three alternatives, although being appealing at first glance. The Energyhub shows to have the least total costs and should, based on the cost comparison method be built in the baseline scenario.

Table 4.6 Cost comparison between Energyhub@Sea, fixed platform and mothership

Cost comparison between the scenarios			
category	**Energyhub @Sea [€]**	**fixed platform [€]**	**mothership approach [€]**
initial costs	23,432,151	37,937,553	-
life cycle costs	174,108,844	183,513,448	203,686,546
decommissioning costs	15,646,323	18,150,685	-
sub total	**213,187,318**	**239,601,686**	**203,686,546**
opportunity energy costs	-	-	732,163,942
total	**213,187,318**	**239,601,686**	**935,850,488**

While this chapter gives a first impression on the financial performance for the three alternatives it is important to keep in mind its downsides. An assumption regarding equity capital costs had to be made. Perridon et al. [20] see the biggest drawback of this method in it not regarding the time in which costs occur, hence no rediscount is considered [20]. This may lead to differences in results compared to the following dynamic analysis.

4.3 Net present value

In addition to the static approach, that the cost comparison method is, a dynamic model is used, to compare the base line scenarios three alternatives. This is the net present value (NPV) calculation. Its main advantages are firstly that it does not work with averages for the capital costs, as instead, the real values for each period are taken. Secondly, the different times when costs occur are taken into account by discounting them to their present value [20]. Two different net present values, according to Laissy [14] will be presented. No internal rates of return are shown, as their calculation demands at least one profitable period. This is not the case here, as only expenses are considered in the business case.

4.3.1 Financial net present value of investment

The aim of this NPV, the financial net present value of investment (FNPV(C)) is determining the performance of an investment alternative, regardless of its financing. It is defined as the sum of investment and operating costs subtracted from the net revenues of each period. Expenses for loan and equity capital are not taken into account. The initial investment is fully taken into account for the first period. These values are than discounted and added up to the FNPV(C), as shown in the following formula [14]:

$$FNPV(C) = \sum_{t=0}^{n} a_t S_t = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \cdots + \frac{S_n}{(1+i)^n} \qquad (4.2)$$

$$t = period$$

$$S_t = balanceofcashflow \in periodt$$

$$a_t = financialdiscountfactor$$

$$i = financialdiscountrate(4\%)$$

The results are similar to the costs comparison. Table 4.7 shows the individual values for each alternative. Initially the mothership is cheapest, with an estimated NPV of -126.1 million euros. However, including the previously explained opportunity energy costs, the correlating FNPV(C) is at a staggering -583.6 million euros, leaving only the other two alternatives to be considered. The Energyhub@Sea has a 11.5 % smaller value than the fixed platform, -128.7 million compared to -144.9 million euros. Thus, this method confirms the Energyhub@Sea as the most cost-efficient choice for the baseline scenario.

Table 4.7 FNPV(C) for the three alternatives

FNPV(C) of the investment alternatives	
alternative	**FNPV(C) [€]**
Energyhub@Sea	-128,081,050
fixed platform	-144,299,235
mothership approach	-126,839,702
mothership approach (inc. op. costs)	-583,663,457

4.3.2 Financial net present value of capital

The financial net present value of capital (FNPV(K)) is determined by the same formula as the FNPV(C). Only the determination of the balance of cash flow (S_t) differs. For the outflows the following is considered: "operating costs, national, public and private capital contributions to the project, the financial resources from loans at the time in which they are reimbursed, the related interest on loans" [14] as well as replacement costs. The FNPV(K) then is the discounted cash flow for each year, summed up over the number of years [14].

Although the capital costs are now taken into account, the values and results do not show much difference. The baseline scenarios financing saw 80 % of the initial investment covered by a loan, with the remaining 20% paid by the owner of the wind park. As for the mothership no initial investment was needed, no loan had to be taken. This leads to the values shown in Table 4.8 being exactly the same as the ones previously shown in Table 4.7. The Eneryghub@Sea FNPV(K) is approximately, €700,000higher than its FNPV(C), an increase of 0.54%. The fixed platform showed an increase of 0.78% or 1.1 million euros. The overall results remain the same. The Energyhub is the most preferable option followed by the fixed platform and then the mothership. Moreover, this calculation shows, that the impacof of the source of financing is relatively minor, as shown by the small differences between FNPV(C) and FNPV(K). However, interest rates, especially on equity capital may increase the results may vary accordingly.

Table 4.8 FNPV(K) for the three alternatives

FNPV(K) of the investment alternatives	
alternative	**FNPV(K) [€]**
Energyhub@Sea	-128,774,309
fixed platform	-145,421,648
mothership approach	-126,839,702
mothership approach (inc. op. Costs)	-583,663,457

4.4 Other business benefits

Besides the strict financial measures, other business benefits were identified. The three concepts are fulfilling them to different degrees. The benefits are:

- **Provide maintenance basis:** A place/facility to base the maintenance operations on and accommodate workers.
- **Low costs:** A rather important benefit, providing a solution with both low capital and operational expenses.
- **High wind park availability:** Good percentage of wind park operational time.
- **Business flexibility:** e.g. low capital costs, possible reuse or relocation of platform.
- **Innovation:** Adoption of new technologies- allows the company to position itself as being innovative.
- **Best living conditions:** Obviously the working and living conditions should be the best possible.

They are shown in Figure 4.1. It shows the three alternatives on the left and the business benefits for the wind park operator on the right. All three concepts provide a maintenance basis. Lowest costs can be found with the Energyhub@Sea and partly with the mother ship, if opportunity energy costs are not included. It also offers the financial benefit of not having capital expenses. The two platform solutions provide the highest possible wind park availability. The mothership is lacking in this matter, but provides the most flexibility to the business, because it is leased and not moored/fixed in place in opposition to the two platforms. The Energyhub@Sea offers a little flexibility, as it could technically be moved to different locations. On the innovation side, bottom fixed platforms have been built for several decades now, while a floating concrete structure as well as a mother ship are new approaches, that can present a company as a technological leader in that field. Lastly the living conditions are presumably best on the fixed platform, as it is least influenced by the sea state. Both Energyhub and mothership are behind in that matter.

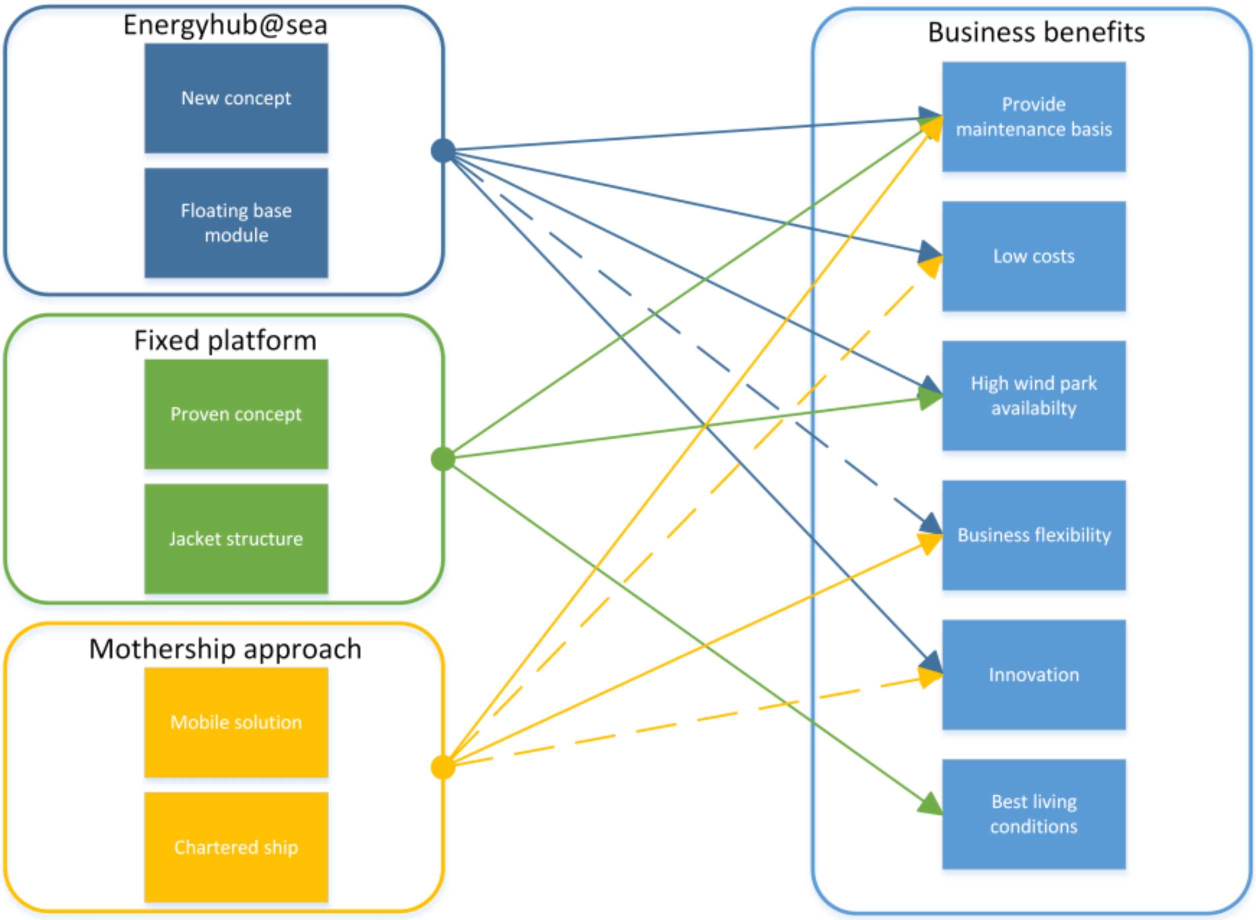


Figure 4.1 Contribution to various business benefits by the three scenarios

Overall that the Energyhub@Sea shows the most connections to the benefits (five) followed by the mother ship (four) and the fixed platform (three). Depending on the importance of each individual benefit, this may be an additional indicator for deciding towards a certain solution.

5. Risk assessment

As this business case is executed within the early stages of the Space@Sea project and with the project being a new design itself, the presented calculations are flawed with risks. It is important to acknowledge those risks in a systematic way. This is why, at first a qualitative risk register is presented and afterwards, a quantitative sensitivity analysis is performed for some key factors.

5.1 Risk register

"A risk register is a document or database which records each risk pertaining to a project" [17]. It allows to save and display risk data obtained during the risk identification process. From this further analysis and risk management is made possible [17].

The identified risks are evaluated in their probability and impact on the business case outcomes. For both categories three levels were defined: low, medium and high. Depending on these two scores each individual risk is rated on the same scale. As this first step is a solely qualitative measure, the classification is based on empirical perception during the research process for the business case. The registers are divided similar to the data presented in chapter 3.

5.1.1 Financial risks

The financial data risks, as presented in Table 5.1, are rated between low and medium. The low rated risks include loan duration and payback start. The Impact of the loan is very minor, as shown by the little differences between FNPV(C) and FNPV(K). Equally the probability for them to alter is not very high. Rated low is also the annual salary increase, it was determined looking at salary increases from the past few years so the forecast should be accurate. Additionally its impact is not very significant as the value is close to two percent. Interest and discount rates are rated medium. While they were given by various sources, the actual capital market values may vary, and thus lead to different results. Equally as they touch most of the calculation, but not in a major way, their impact was rated medium.

Table 5.1 Risk register for the financial data and assumptions

Financial risks register				
reference	category	impact	probability	rating
FD	financial data			
FD1	discount rate	medium	medium	medium
FD2	equity capital costs	medium	medium	medium
FD3	loan interest rate	medium	medium	medium
FD4	loan duration	low	low	low
FD5	payback start period	low	low	low
FD6	annual salary increase	low	low	low
FD7	salaries	high	low	medium
FD8	net energy price	low	medium	medium

The salaries have a high impact on the business case, as they are accumulated €74 million for the platforms and €18.5 million for the mothership respectively. However, they were determined by looking at EU averages for the sector, so the probability of them varying much is low, leading to a medium overall rating. Nonetheless, as their impact is rated high, an additional sensitivity analysis is performed for the salaries.

5.1.2 Energyhub@Sea risks

The Energhub@sea‘s risk register is divided into three sections, as can be seen in Table 5.2. The technical data is all rated medium, as it is relatively early in the project planning stage, and changes may still occur and influence the results of the business case. Equally the operational data is rated mostly medium, due to the low probability ratings. They are relatively fixed at this project stage, or secured by sources.

The construction data shows most uncertainties and thus the highest rated risks, with mooring and installation costs, m^2-prices for rooms and concrete construction price being rated high. The latter is taken into the parameter alteration, while the former two are further analysed within the sensitivity analysis. As the initial costs are one of the big differences between the three alternatives, and the main material varies between the concepts, also the steel price will be taken into the parameter adjustments. The remaining two items pose a medium risk, but could be refined if more data were available.

Table 5.2 Risk register for the Energyhub@Sea cost estimation

Energyhub@Sea risk register				
reference	**category**	**impact**	**probability**	**rating**
.TD	**technical data**			
TD1	weights	medium	low	medium
TD2	interior sizes	medium	low	medium
TD3	Machinery needed	low	medium	medium
OD	**operational data**			
OD1	Energy consumption	low	low	low
OD2	wind park operational time	high	low	medium
OD3	required work shifts	high	low	medium
OD4	required personnel	medium	low	medium
CD	**construction data**			
CD1	m^2 prices	high	medium	high
CD2	concrete construction price	high	medium	high
CD3	steel construction price	high	low	medium
CD4	mooring and installation costs	high	medium	high
CD5	shipyard location	low	medium	medium
CD6	Decommissioning costs	medium	low	medium

5.1.3 Fixed platform risks

The fixed platform scenario shares much data with the Energyhub@Sea, resulting in several risks already being assessed in chapter 5.1.2. Among the shared risks are all operational data risks, the construction data risks CD1, CD3 to CD5 and the technical data risks TD2 and TD3. Thus the separate risk assessment, as shown in Table 5.3, is much smaller. As the Energyhub has a concrete built storage facility, weight to build a similar facility had to be added to the fixed platforms living module, leaving an uncertainty regarding its correctness. Additionally, the impact of the weight is crucial to the overall construction price, leading to a high rating. Also the jacket construction costs appear to be a high rated risk for similar reasons. Both of them are further explored in the sensitivity analysis.

Table 5.3 Risk register for the fixed platform cost estimation

fixed platform risk register				
reference	**category**	**impact**	**probability**	**rating**
TD	**technical data**			
TD1	weights	high	medium	high
CD	**construction data**			
CD1	Jacket construction costs	high	medium	high
CD2	Decommissioning costs	medium	low	medium

5.1.4 Mothership risks

One of the biggest uncertainties for the other two scenarios is their initial costs. As these do not incur for the mothership, its risk register consists of fewer items, than the other two. As the mothership is relatively well described in literature, all its risks are rated medium, as shown in Table 5.4. While some have a big impact, the probability of the data being wrong is low and vice versa. As a big portion of the motherships costs originate from one variable, the wind park available time, it is chosen for the parameter & adjustments ration.

Table 5.4 Risk register for the mothership cost estimation

mothership approach risk register				
reference	**category**	**impact**	**probability**	**rating**
OD	**operational data**			
OD1	charter rate	high	low	medium
OD2	fuel consumption	low	medium	medium
OD3	operation/stationary time	low	high	medium
OD4	wind park operational time	high	low	medium

5.2 Sensitivity analysis

In opposition to the risk register, the sensitivity analysis is a quantitative method to assess threats to the project. It "is used to determine the effect on the whole project of changing one of its risk variables" [17]. Usually it is presented in terms of the FNPV of the investment. A range is defined for each selected parameter to be varied. Then the influence on the outcome is calculated. This shows the robustness of investment alternatives to variability within the key assumptions. The results are usually presented in a table chart or a diagram [17].

A few variables, found to have a high risk rating in the above performed risk register, are varied and shown here. However, as some are selected for the parameter alteration, they will not appear in the sensitivity analysis.

5.2.1 FNPV(K) sensitivity to the assumed wages

The basic data for wages is shared by all three projects. However, both Energyhub@Sea and the fixed platform are taking wages for the whole year into account, whereas the mothership does so only for three months. Accordingly the influence of variation to wages differs between the three alternatives. The baseline scenarios value was varied by 20 percent above and below the initial value.

The results are shown in Table 5.5. The FNPV(K) of each alternative is influenced, however, the result of the scenario is untouched. The Energyhub@Sea remains the most favourable option, even if wages alter by ±20 %.

Table 5.5 Sensitivity of FNPV(K) to wage variation

Sensitivity of FNPV(K) to annual wages			
variation [%]	**Energyhub @Sea** [€]	**Fixed platform** [€]	**Mothership approach** [€]
-20	-119,882,214	-136,529,553	-581,440,433
-10	-124,328,261	-140,975,601	-582,329,642
-4	-126,995,890	-143,643,229	-583,218,851
±0	-128,774,309	-145,421,648	-583,663,457
+4	-130,552,727	-147,200,067	-584,108,061
+10	-133,220,357	-149,867,696	-584,774,969
+20	-137,666,404	-154,313,743	-585,886,480

Figure 5.1 shows the relative changes to the FNPV(K) of the three alternatives over the change to the assumed annual wages. As it can be seen the relative change is biggest for the Energyhub@Sea, where wages are a bigger part of the overall costs than for the other two alternatives. If the wages where 20 percent lower or higher, the result would be changed by ±6.91 %. The fixed platform is situated in the middle with ±6.11 %. The mothership scenario, with its much higher FNPV(C) and wages only being paid three months per year, is even less sensitive to changes of this parameter. A ±20 % change only leads ±0.38 % of FNPV(K) change.

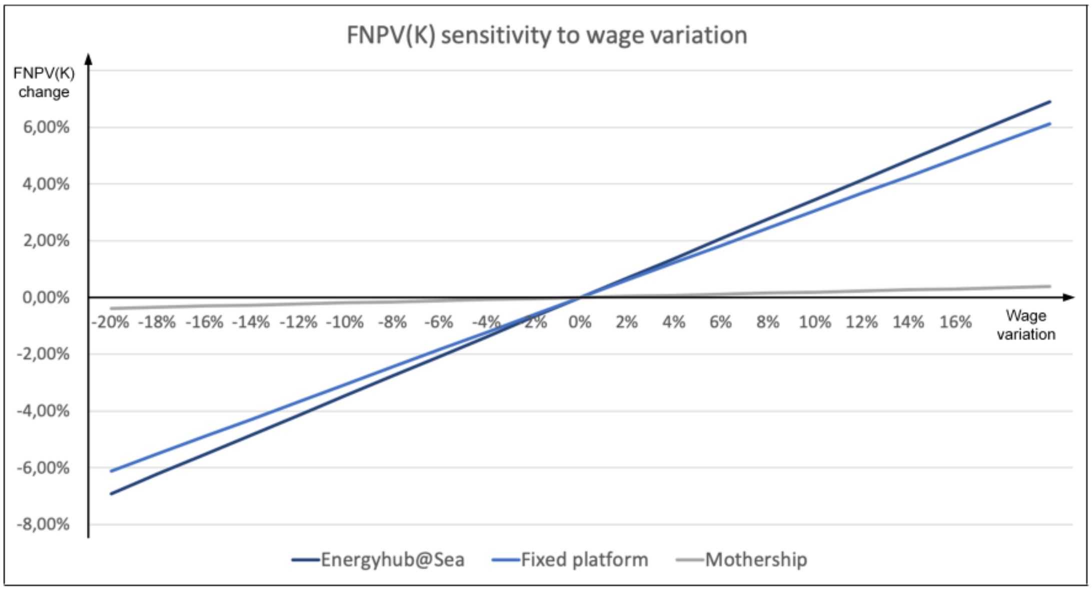


Figure 5.1 FNPV(K) sensitivity to wage variation

5.2.2 FNPV(K) sensitivity to the discount rate

The discount rate has a great impact on most dynamic financial calculations. However, as it is included the same way in each calculation the relative impacts are similar, as shown in Figure 5.2. An increase to 10 % in discount rate leads to roughly 40 % decrease in FNPV© for each alternative. On the other hand side, a decrease of the discount rate to 0 % leads to an increase of roughly 60 %.

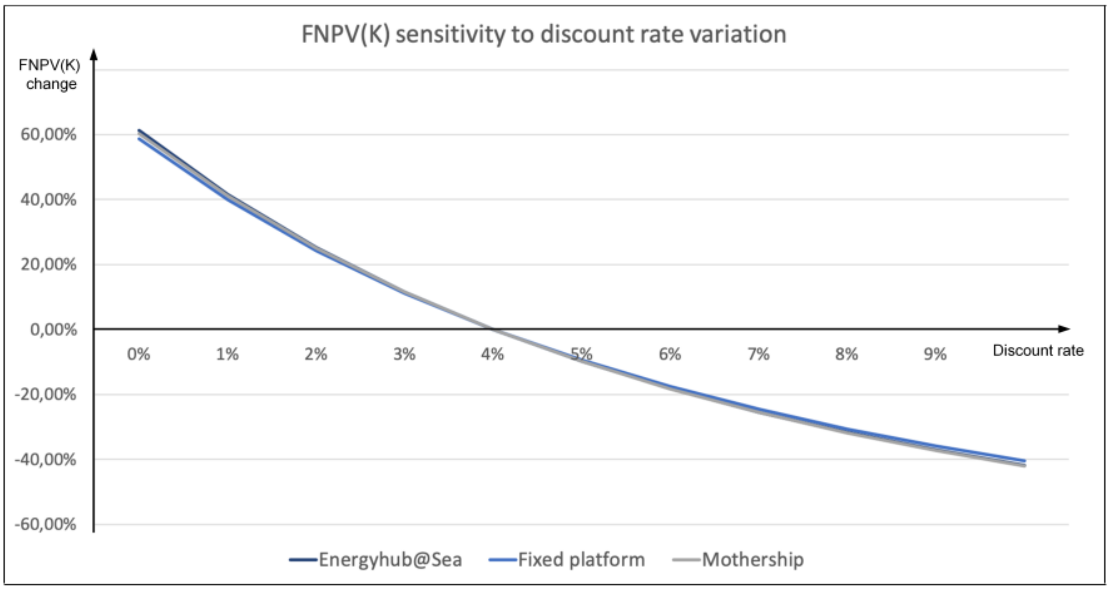


Figure 5.2 FNPV(K) sensitivity to discount rate variation

In absolute terms, as can be seen in Table 5.6, is to notice, that with lower discount rate the Energyhubs financial advantage grows, whereas, with increasing values, the difference between the three alternative becomes smaller. For example, with a 10 % discount rate the difference between Energyhub@Sea and fixed platform is €11.5 million and with a 0 % discount rate €16 million.

Table 5.6 FNPV(K) sensitivity to discount rate change

FNPV(K) sensitivity to discount rate change			
discount rate [%]	Energyhub @Sea [€]	fixed platform [€]	mothership approach [€]
0	-207,686,240	-230,695,229	-935,850,488
2	-161,350,024	-180,733,235	-730,116,449
4	-128,774,309	-145,421,648	-583,663,457
6	-105,318,957	-119,845,188	-477,181,351
8	-88,032,881	-100,875,407	-398,147,359
10	-75,005,504	-86,484,282	-338,305,994

5.2.3 Sensitivity to interior pricing

A central assumption of this business case is the determination of the interior prices, based on values seen in the cruise ship industry. In order to quantify the impact of them varying, a sensitivity analysis for the Energyhub@Sea as well as the fixed platform is performed regarding both the FNPV(K) and the initial costs of each alternative.

The alteration shows, that the FNPV(K) is influenced only in a minor way. A ±20% change in interior pricing only leads to a ±0.89 % for the Energyhub@Sea and ±0.76 % for the fixed platform respectively. However, the impact on the initial costs is more significant.

Table 5.7 shows the development of the initial costs for both concepts depending on the variation of the interior pricing. It can be seen, that a ±20 % alteration would lead to a change in pricing of approximately €1 million for each platform. As the progress is linear, the other values are corresponding.

The linear correlation is also shown in Figure 5.3. It shows, that the relative impact of the variable changing is bigger for the Energyhub@Sea. This is because the interior pricing is a bigger part of the initial investment, and thus influencing the overall costs in a stronger way than for the fixed platform. However, the influence is not crucial, as it changes the baseline scenarios values only to a maximum of ±3.66 % for the Energyhub@Sea and 2.32% for the fixed platform respectively.

Table 5.7 Initial cost sensitivity to interior pricing change

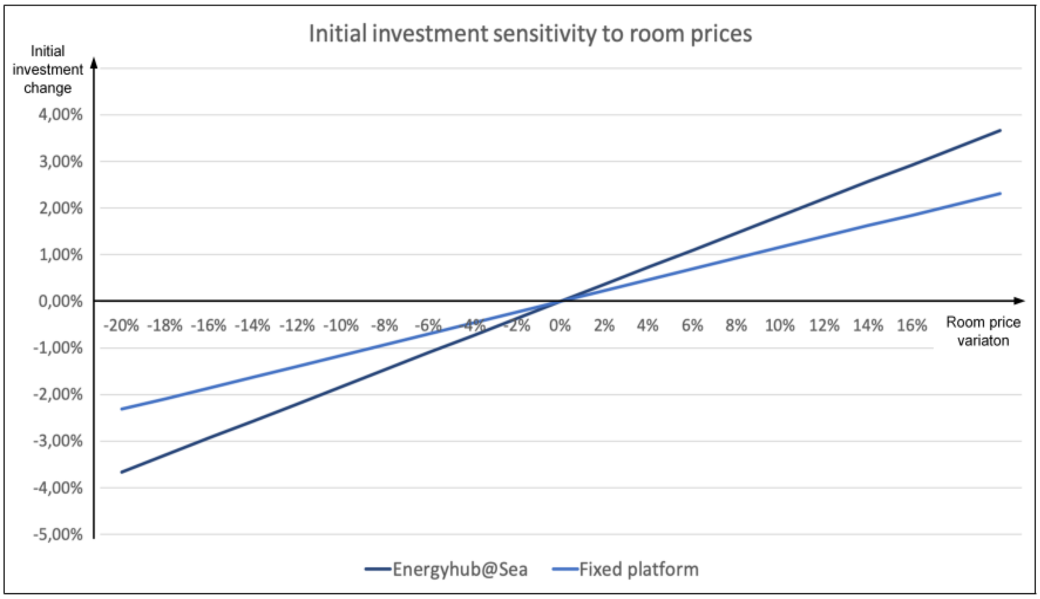


Figure 5.3 Initial investment sensitivity to interior price variation

5.2.4 Sensitivity to mooring and installation cost variation

This variable makes up for a big portion of the initial costs of the moored/ bottom fixed concepts. As its determination was based on several assumptions, it is chosen for the sensitivity analysis. Regarding the FNPV(K) of the two alternatives, the impact is slightly more significant than for the interior pricing, showing a ±1.24% and ±0.84% for the Energyhub and fixed platforms FNPV(K) for a ±20 % variation of mooring/installation costs.

Table 5.8 shows the impact of different percentages of variation of the mooring/installation costs to the initial costs of the two scenarios. These are more significant, than for the FNPV(K). However, a ±10 % variation would only lead to €800 thousand of change for the Energyhub@Sea, and €600 thousand for the fixed platform. This can be explained by the different values taken into consideration. As previously stated, the Energyhub@Seas installation is forecasted to be more expensive, at €6.998.296 compared to the only €5.440.923 for the fixed platform. This leads to greater deviation in the Energyhubs initial costs.

Table 5.8 Initial cost sensitivity to mooring and installation cost variation

Inital cost sensitivity to mooring/installation costs		
variation [%]	**Energyhub @Sea [€]**	**fixed platform [€]**
-20	21,877,680	36,700,334
-10	22,654,916	37,318,944
-4	23,121,257	37,690,109
±0	23,432,151	37,937,553
+4	23,743,045	38,184,997
+10	24,209,386	38,556,162
+20	24,986,621	39,174,772

This can also be seen in Figure 5.4. It shows a linear correlation between mooring cost variation and impact on the initial costs. The impact on the Energyhub would be ±6.63% for the maximum simulated variance of ±20%. The same variation for the fixed platform only leads to initial cost growth/shrinkage of ±3.26 %. This is explained by the different absolute values as well as the different initial costs for the two projects.

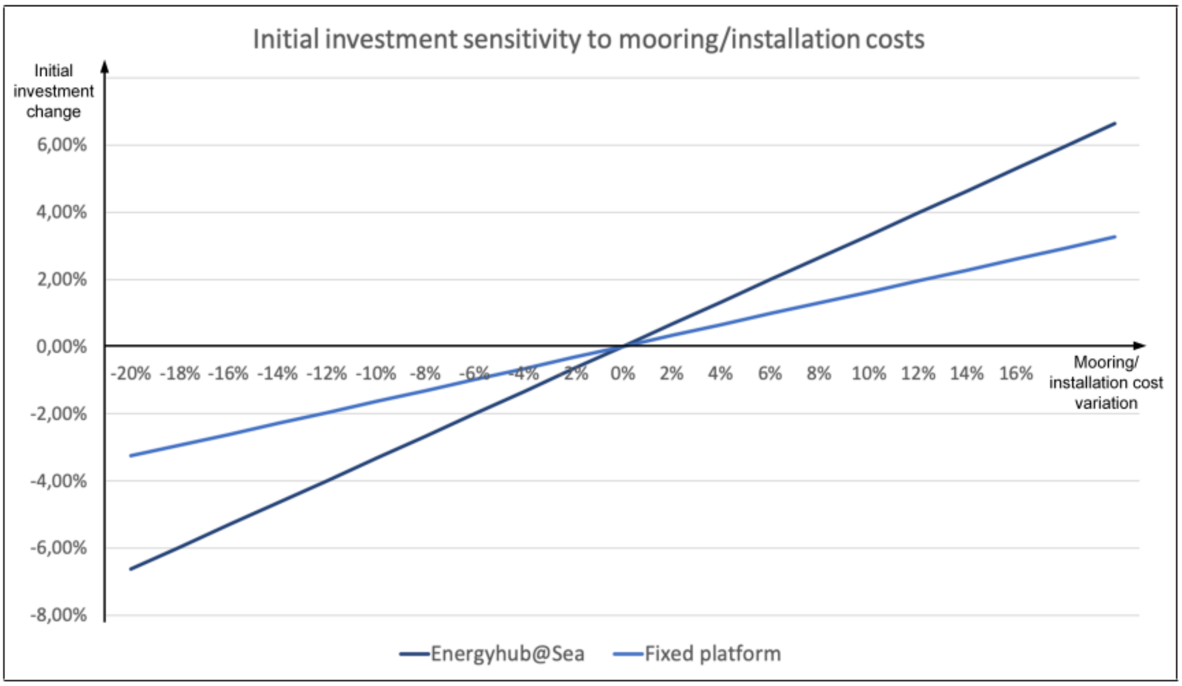


Figure 5.4 Initial costs sensitivity to mooring and installation cost variation

5.2.5 Fixed platform: sensitivity to living module weight and jacket price variation

The fixed platforms costs are influenced in a significant way by two parameters, the living module weight and the jacket price. The jacket price itself is determined by water depth and living module weight, nevertheless an individual assessment for the latter is performed.

Both variables, based on the method of calculation, have a linear correlation to the FNPV(K) and the initial costs. Weight variation shows a slightly bigger impact than jacket price alteration, being at ±4.94 % and ±4.03 % respectively, for a ±20 % in initial variables.

Regarding impact on initial costs in absolute and relative terms, Table 5.9 shows the results of the analysis. It can be seen that the impact of both variables changing is quite significant, leading to a reduction or increase of up to ±16.2 % and ±12.31%.

Table 5.9 Fixed platform: Initial cost sensitivity to living module weight or jacket price change

Inital cost sensitivity to weight/ jacket price				
variation [%]	weight		jacket price	
	costs [€]	change [%]	costs [€]	change [%]
-20	31,792,095	-16.20	33,268,726	-12.31
-10	34,864,824	-8.10	35,603,139	-6.15
-4	36,708,461	-3.24	37,003,788	-2.46
±0	37,937,553	±0.00	37,937,553	±0.00
+4	39,166,644	+3.24	38,871,318	+2.46
+10	41,010,282	+8.10	40,271,966	+6.15
+20	44,083,011	+16.20	42,606,380	+12.31

5.2.6 Mothership: sensitivity to wind park available time variation

The mothership approach is the only one of the three concepts, that includes opportunity energy costs. They are based on the difference in projected wind park availability and the net energy price. The availability factor is the variable chosen for this variation. Six different availability percentages are presented. starting at 84%, over the baseline scenarios 87% up to the 93% assumed for both fixed platform and Energyhub@Sea.

The results show an influence greater than for all other variables investigated during the sensitivity analysis. The FNPV(K) varies from a +39% to -78% change compared to the baseline scenario. The latter would lead to the mothership being a better alternative than both the Energyhub@Sea and the fixed platform. The break-even points are at a wind park availability for the mothership of 92.76 % for the fixed platform and 92.97 % for the energyhub.

Table 5.10 Mothership: FNPV(K) sensitivity to wind park available time

FNPV(K) sensitivity to wind park available time		
available time [%]	FNPV(K)	
	costs [€]	change [%]
84	-812,075,334	+39
86	-659,800,749	+13
87	-583,663,457	±0
89	-431,388,872	-26
91	-279,114,287	-52
93	-126,839,702	-78

5.3 Risk Management

The above shown risks are best managed by acknowledging their existence in the first place. However, as the business case is performed in a rather early project stage, most of them can be reduced by carefully monitoring the projects development and including more data if available. Also, some of the assumptions used to obtain the results may be obsolete with the project moving forwards, as more precise data will become available. Regarding the risks for the two alternatives, it is advisable to consult more literature describing their cost structure and performance, in order to refine the assumptions made, and thereby reduce the risks they carry.

The financial side should also be monitored carefully. While the last years have been quite stable, the financial markets may experience fluctuations, leading to alternating indications and variables for this business case.

In general it can be said, that the business case is based on solid assumptions, and that most of the high risk variables taken into the sensitivity analyses show only small impacts to the business case‘s final result, the FNPV(K) of the three alternatives.

6. Parameter alterations

As the Space@sea project and more specifically the Energyhub@Sea are relatively new ideas, this chapter, seeks to vary some of the baseline scenarios key points and assumptions, in order to understand under which circumstances the decision for the Energyhub@Sea compared to the two presented alternatives is favourable. This is widely similar to the sensitivity analysis shown in chapter 5.2. The main differences are however, that the focus of this chapter is on the Energyhub@Sea, and how it performance is changed compared to the alternatives by alternating some of its core cost items. As the mothership is not influenced by the variables chosen for the parameter alteration, it is not shown with the same level of detail as the other two solutions.

6.1 Water depth

The first alteration is considering the water depth. While the base case, calculated for 100 m of water depth, showed a significant financial preference for the Energyhub@Sea, this sub chapter investigates the influence of the seas deepness to the alternatives.

With 100 m of water depth, the Energyhub@Sea was established to be favourable. Thus, the parameter alteration is aimed at shallower water depths. Table 6.1 shows the FNPV(K) results, for simulated water depths from 10 to 100 meters. While the Energyhubs results only vary by €341,000, the fixed platform shows a difference of €29 million. This leads to the fixed platform being cheaper for water depths between zero and 40 m. From 50 m on, the Energyhub is cheaper to run. Further calculations show, that the exact break-even point would be at 47.97 m of water depth. In addition WP3 outcomes show that mooring of floating islands in shallow waters is not feasible which underlines this break-even point from another perspective.

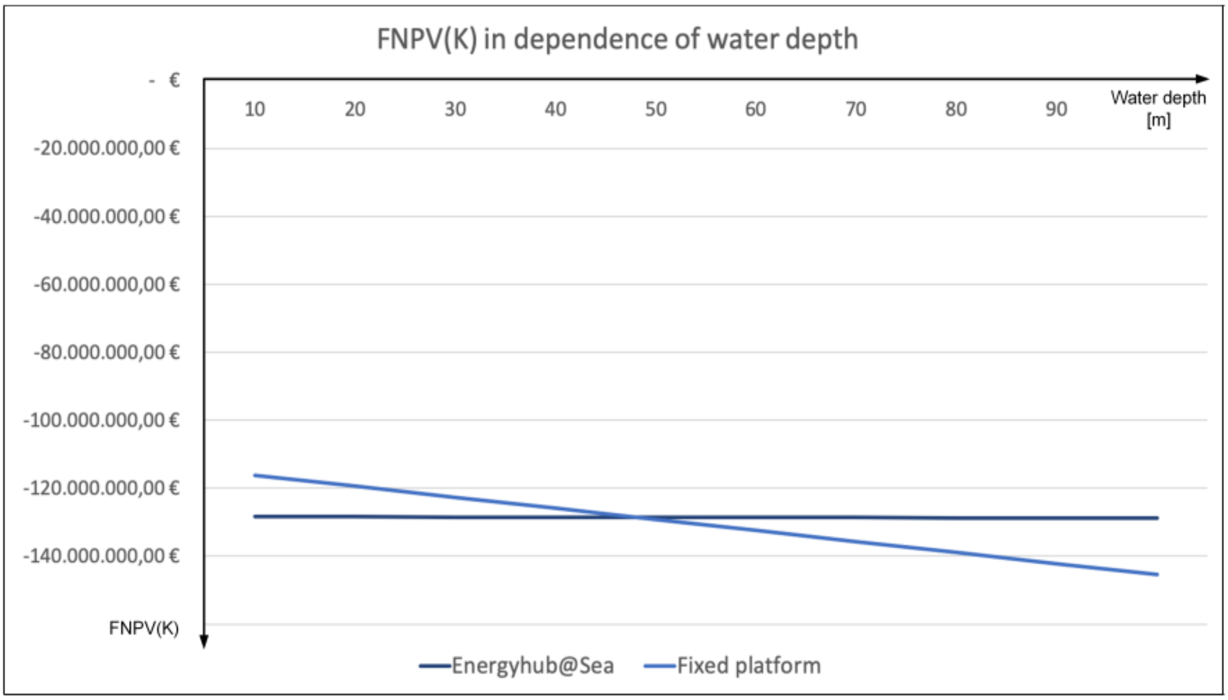
Figure 6.1 shows Table 6.1‘s data in graphic form. It can once more be observed, that the fixed platform‘s FNPV(K) is more dependent on the water depth, than the Energyhubs.

Table 6.1 FNPV(K) in dependence of water depth

FNPV(K) in dependence of water depth		
water depth [m]	**Energyhub @Sea [€]**	**fixed platform [€]**
10	-128,403,512	-116,190,449
20	-128,444,712	-119,458,621
30	-128,485,912	-122,717,583
40	-128,527,112	-125,970,665
50	-128,568,312	-129,219,425
60	-128,609,511	-132,464,769
70	-128,650,711	-135,707,294
80	-128,691,910	-138,947,419
90	-128,733,110	-142,185,457
100	-128,774,309	-145,421,648

The mothership is not influenced by this parameter at all, staying at its FNPV(K) of €- 583 million euros regardless of the water depth. It remains the least favourable option of the three alternatives.

Figure 6.1 Parameter alteration results for water depth



6.2 Concrete construction price

The unique selling position of the Energyhub@Sea results from its concept of a concrete base module, combined with an also concrete built storage facility. Compared to conventional platforms, which are mainly steel based, a strong dependency on the concrete construction price results [23]. For this parameter alteration, the construction price per ton is altered. As both the mothership and the fixed platform do not contain any concrete dependent calculations in their business case, only the Energyhub's values are expected to vary. All other parameters are remaining on the baseline scenarios values.

Table 6.2 shows the results for a price variation between €500 per ton and €1500 per ton. The baseline scenarios price was €775 per ton. It can be seen, that the influence on the FNPV(K) is quite significant, with a change of approximately €12 million between the two extreme pricings. As the price per ton for the concrete structures of the hub is one of the major uncertainties going forward, it is reassuring to see, that the breakeven point between fixed platform and Energyhub for the baseline scenario would be at a concrete price of €2110 per ton. An increase of €1335 compared to the initially assumed value.

Table 6.2 FNPV(K) in dependence of concrete pricing

FNPV(K) in dependence of concrete pricing	
concrete price [€/ton]	**FNVP(K)[€]**
500	-125,501,463
700	-127,867,802
900	-130,286,242
1100	-132,740,465
1300	-135,220,324
1500	-137,719,175

The fixed platform with its €145.4 million FNPV(K), as well as the mothership with its €- 583 million, are less favourable, even if the concrete price is twice as much as assumed. Figure 6.2 shows the data contained in the table above in a graphic form. While the FNPV(K) of the fixed platform is remaining at the same level, the graph for the Energyhub is closing in. However, a gap remains, indicating, that the Energyhub@Sea remains the least cost intensive alternative.

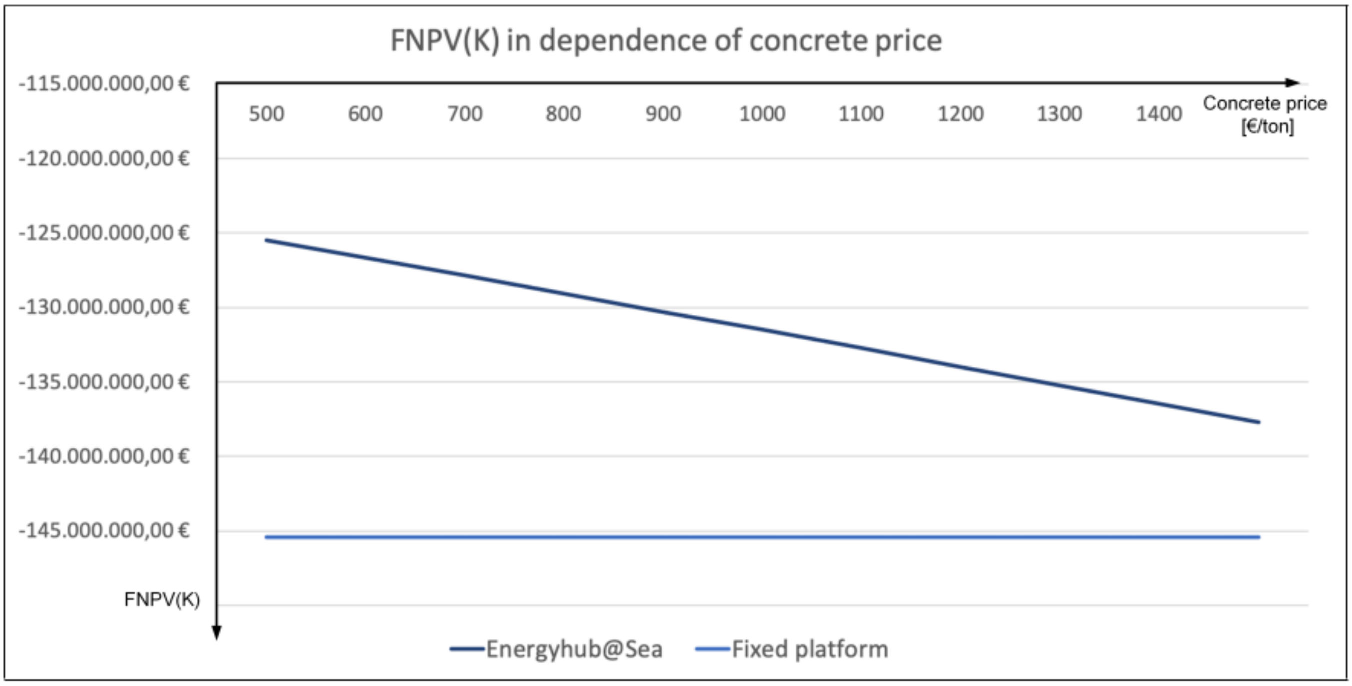


Figure 6.2 Parameter alteration results for concrete prices

6.3 Steel construction price

Steel is a resource used for construction of both the Energyhub@Sea and the fixed platform. The difference is in the masses needed for each platform. The Energyhub is projected to use 800 tons, whereas the fixed platform needs 5407 tons. The question is to which extent the variation of the steel price per ton decides whether one or the other project has a lower FNPV(K).

Table 6.3 shows the FNPV(K) results for a steel price ranging from €2000 per ton to €4000 per ton. The Energyhub@Seas results show a €2 million difference from bottom to top, the fixed platform €22 million.

While the gap between the two FNPV(K)'s narrows, as shown in Figure 6.3, it does not close. This hints at a lower breakeven point between the two platforms. Indeed, it is as low as €1327.76 per ton. This would mean a reduction in costs of almost 66% per ton. Figure 6.3 shows, that the fixed platform is more reliant on the steel price (indicated by the steeper trendline), than the Energyhub@Sea. As there is no intersection, it can be said, that the Energyhub@Sea is the most favourable option, even if a significant reduction of the steel construction prices is taken into consideration.

Table 6.3 FNPV(K) in dependence of steel price

FNPV(K) in dependence of steel price		
steel price [€/ton]	Energyhub @Sea [€]	Fixed platform [€]
2000	-127,584,323	-134,273,505
2200	-127,823,008	-136,503,133
2400	-128,061,338	-138,732,762
2600	-128,299,324	-140,962,391
2800	-128,536,977	-143,192,020
3000	-128,774,309	-145,421,648
3200	-129,011,329	-147,651,277
3400	-129,248,048	-149,880,906
3600	-129,484,475	-152,110,534
3800	-129,720,620	-154,340,163
4000	-129,956,489	-156,569,792

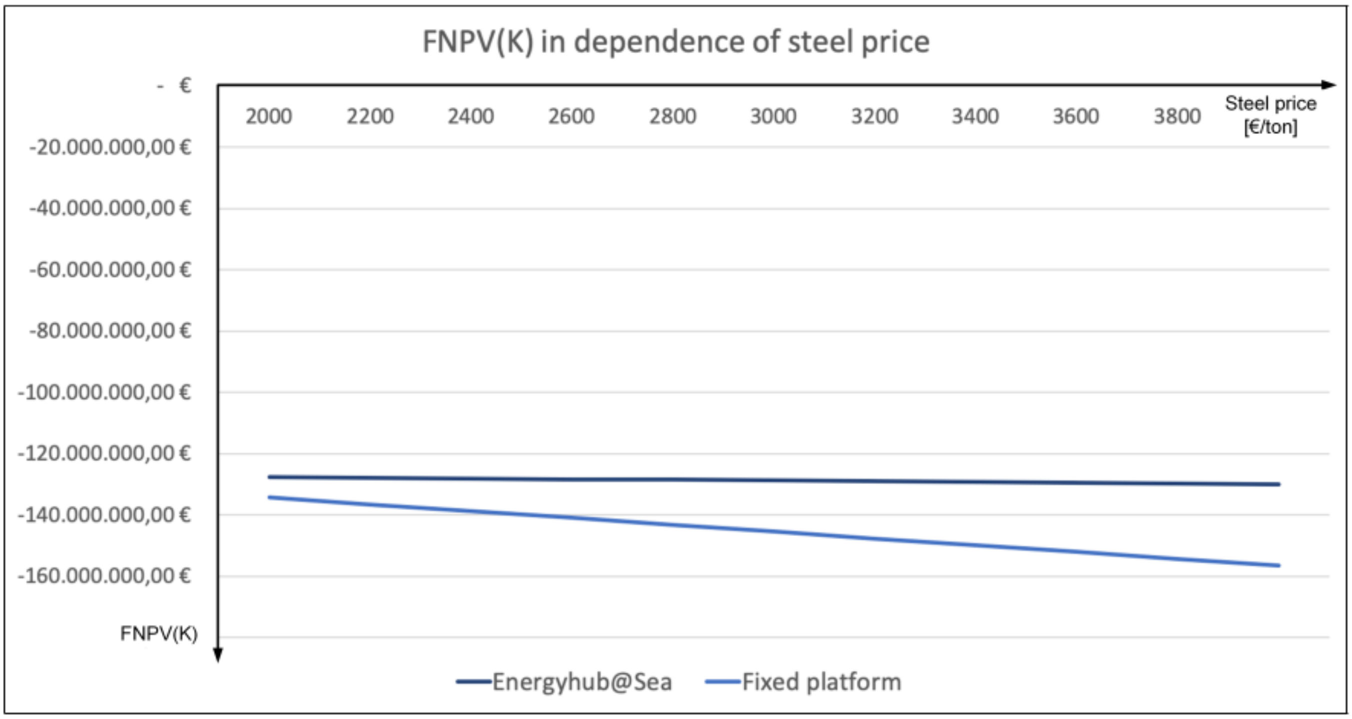


Figure 6.3 Parameter alteration results for steel prices

7. Conclusions and Recommendations

This deliverable established the development within the offshore wind industry, to plan and build wind parks further away from shore. It also shows the vast resource potential for wind energy both for floating wind turbines and turbines remotely located.

It was presented, that different kinds of offshore accommodation are either common these days, or newly developed for the purpose of operations and maintenance at offshore wind parks. The former are bottom fixed accommodation platforms and floating hotel ships, both known from the oil industry. The latter are the mothership, offshore support vessels and the Energyhub@Sea, three new concepts specifically designed to enable operations and maintenance for offshore wind parks.

A fictional wind park with 100 ten MWh turbines in 100 m of water depth was considered in order to perform a cost comparison between the three alternatives: Energyhub@Sea, the main objective of this business case, a fixed platform, as a few have been built for that purpose in recent years [25] and a mothership, a viable alternative to fixed platforms [24]. A business case for the Energyhub@Sea was made. The risks to the calculations were evaluated and a sensitivity analysis was performed for the most critical parameters. To broaden the view of the business case beyond the baseline scenario, parameter alterations were made for several key parameters.

The results for the baseline scenario‘s wind park showed that the Energyhub@Sea was the financially most favourable of the three alternatives. This perception was backed by the parameter alteration, where neither a steel nor a concrete price fluctuation seemed to change the result. Regarding water depth, it was established, that the Energyhub@Sea promises advantages for depths greater than 48 m. Furthermore, it was shown, that the Energyhub@Sea also promises to give non-financial benefits, such as Innovation and business flexibility to the operating company.

In order to enhance the business case for the Energyhub@Sea, future research may focus on a comparison to the current industry standard: land based maintenance. As it becomes increasingly expensive and time consuming for more remotely located wind parks [24], research regarding the influence on shore distance to the Energyhub@sea and the current solutions would be appropriate. Additionally, research could be focused on the non-financial benefits and maybe even try to express them as a financial dimension. A third point to work on, is in increasing the accuracy of this business case. As both Engergyhub@sea and a mothership have not been built yet, several assumptions had to be made. With new development, future research may focus on refining the business case by replacing some of the assumptions with more sophisticated data. Besides that, the baseline scenario should be altered to display more use cases for the Energyhub@Sea (e.g. North Sea build or with additional power production). Also regarding the construction some questions remain, as a special dock for concrete construction maybe needed [23].

In general this business case shows that the Energyhub@Sea can be a viable solution for the problem of offshore accommodation and a platform to perform operations and maintenance work on. A brief summary is presented in appendix A.9, showing a business case canvas for the Energyhub@Sea. It‘s financial performance is projected to be superior to the alternatives and it should thus be further developed and used for the baseline scenario‘s wind park.

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9. A. Appendices

9.1 Assumed labour costs over 25 years

The wages are assumed to increase by 1.94 % annually, leading to the expenses shown in Table A.1 for each period. The first column shows the expenses for the Energyhub@Sea and the fixed platform, the second one shows the reduced labour costs for the mothership.

Table A.1 Assumed annual wages for the three alternatives

Wages per period		
period	platform wages[€]	mothership wages [€]
1	2,327,136	581,784
2	2,372,282	593,071
3	2,418,305	604,576
4	2,465,220	616,305
5	2,513,045	628,261
6	2,561,798	640,450
7	2,611,497	652,874
8	2,662,160	665,540
9	2,713,806	678,452
10	2,766,454	691,613
11	2,820,123	705,031
12	2,874,833	718,708
13	2,930,605	732,651
14	2,987,459	746,865
15	3,045,416	761,354
16	3,104,497	776,124
17	3,164,724	791,181
18	3,226,120	806,530
19	3,288,706	822,177
20	3,352,507	838,127
21	3,417,546	854,386
22	3,483,846	870,962
23	3,551,433	887,858
24	3,620,331	905,083
25	3,690,565	922,641

9.2 Assumed annual energy costs for the platforms

The net energy price is calculated to increase 0.08% each year. The corresponding costs are shown in Table A.2.

Table A.2 Assumed annual energy costs

Energy costs per period	
period	energy costs[€]
1	38,696
2	38,725
3	38,754
4	38,784
5	38,813
6	38,842
7	38,872
8	38,901
9	38,930
10	38,960
11	38,989
12	39,019
13	39,048
14	39,078
15	39,107
16	39,137
17	39,166
18	39,196
19	39,225
20	39,255
21	39,285
22	39,314
23	39,344
24	39,374
25	39,404

9.3 Assumed annual replacement/ maintenance costs per platform

Replacement and maintenance costs are assumed to grow by 0.5 % per year, leading to the expenses shown in Table A.3.

Table A.3 Assumed annual replacement costs per platform

Replacement costs per platform		
period	Energyhub@Sea[€]	fixed platform[€]
1	194,573	275,596
2	195,546	276,974
3	196,524	278,359
4	197,506	279,751
5	198,494	281,150
6	199,486	282,556
7	200,484	283,968
8	201,486	285,388
9	202,494	286,815
10	203,506	288,249
11	204,524	289,690
12	205,546	291,139
13	206,574	292,595
14	207,607	294,058
15	208,645	295,528
16	209,688	297,005
17	210,737	298,491
18	211,790	299,983
19	212,849	301,483
20	213,914	302,990
21	214,983	304,505
22	216,058	306,028
23	217,138	307,558
24	218,224	309,096
25	219,315	310,641

9.4 Loan costs for Energyhub@Sea and fixed platform

For both cases the same loan scenario is assumed. It is an annuity loan. The payback starts in period three, for ten years. The interest rate is considered to be 4 %. The loan covers 80 % of the initial investment, €18,745,720 and €30,350,042 for the Energyhub@Sea and the fixed platform respectively. This leads to interests on the Energyhub@Sea of €6,215,000 leading to an accumulated outflow of €24,960,720. The accumulated outflow for the fixed platform is €40,412,360, including an interest of €10,062,318.

Table A.4 Loan payback concept for Energyhub@Sea and fixed platform

Loan payback per period		
period	**Energyhub@Sea[€]**	**fixed platform[€]**
1	-	-
2	-	-
3	2,496,072	4,041,236
4	2,496,072	4,041,236
5	2,496,072	4,041,236
6	2,496,072	4,041,236
7	2,496,072	4,041,236
8	2,496,072	4,041,236
9	2,496,072	4,041,236
10	2,496,072	4,041,236
11	2,496,072	4,041,236
12	2,496,072	4,041,236
13	-	-
14	-	-
15	-	-
16	-	-
17	-	-
18	-	-
19	-	-
20	-	-
21	-	-
22	-	-
23	-	-
24	-	-
25	-	-

9.5 Assumed net revenue losses for the mothership

With a six percent decrease in operational time, the energy not produced is calculated as opportunity costs for the mothership. With an 0.08% increase in net energy prices per year, the values shown in Table A.5 are assumed. They are calculated by multiplying the expected energy produced annually by the wind park with the availability loss compared to both the Energyhub@Sea and the fixed platform times the net energy price.

Table A.5 Lost revenues due to lower availability of the wind park

Opportunity energy costs	
period	**lost revenues [€]**
1	29,022,000
2	29,043,919
3	29,065,855
4	29,087,807
5	29,109,775
6	29,131,761
7	29,153,763
8	29,175,781
9	29,197,816
10	29,219,868
11	29,241,937
12	29,264,022
13	29,286,124
14	29,308,242
15	29,330,377
16	29,352,529
17	29,374,698
18	29,396,883
19	29,419,086
20	29,441,304
21	29,463,540
22	29,485,793
23	29,508,062
24	29,530,348
25	29,552,651

9.6 Energyhub@Sea expenses per period

Table A.6 shows the expenses projected for the Energyhub@Sea for each period of the baseline scenario. Operational expenses include personnel, energy costs and general expenditure. Investment costs comprised of initial investment which are partly financed by a loan, replacement costs and decommissioning costs.

Table A.6 Energyhub@Sea expenses per period

Energyhub@Sea expenses per period			
period	investment costs [€]	operational expenses [€]	sum[€]
1	4,881,003	5,656,970	10,537,973
2	195,546	5,702,145	5,897,692
3	2,692,596	5,748,197	8,440,793
4	2,693,578	5,795,141	8,488,720
5	2,694,566	5,842,996	8,537,562
6	2,695,558	5,891,778	8,587,336
7	2,696,556	5,941,506	8,638,062
8	2,697,558	5,992,199	8,689,757
9	2,698,566	6,043,874	8,742,440
10	2,699,578	6,096,551	8,796,129
11	2,700,596	6,150,250	8,850,846
12	2,701,618	6,204,990	8,906,608
13	206,574	6,260,791	6,467,365
14	207,607	6,317,674	6,525,281
15	208,645	6,375,661	6,584,306
16	209,688	6,434,771	6,644,459
17	210,737	6,495,028	6,705,765
18	211,790	6,556,453	6,768,244
19	212,849	6,619,069	6,831,919
20	213,914	6,682,900	6,896,814
21	214,983	6,747,968	6,962,951
22	216,058	6,814,298	7,030,356
23	217,138	6,881,915	7,099,053
24	218,224	6,950,842	7,169,066
25	15,865,638	7,021,106	22,886,745

9.7 Fixed platform expenses per period

Table A.7 shows the expenses projected for the fixed platform for each period of the baseline scenario. Operational expenses include personnel, energy costs and general expenditure. Investment costs comprised of initial investment, partly financed by the loan, replacement costs and decommissioning costs.

Table A.7 Fixed platform expenses per period

Fixed platform expenses per period			
period	**investment costs**	**operational expenses[€]**	**sum [€]**
1	7,863,107	5,656,970	13,520,077
2	276,974	5,702,145	5,979,120
3	4,319,595	5,748,197	10,067,792
4	4,320,987	5,795,141	10,116,129
5	4,322,386	5,842,996	10,165,382
6	4,323,792	5,891,778	10,215,570
7	4,325,205	5,941,506	10,266,711
8	4,326,624	5,992,199	10,318,823
9	4,328,051	6,043,874	10,371,925
10	4,329,485	6,096,551	10,426,037
11	4,330,927	6,150,250	10,481,177
12	4,332,375	6,204,990	10,537,365
13	292,595	6,260,791	6,553,386
14	294,058	6,317,674	6,611,732
15	295,528	6,375,661	6,671,188
16	297,005	6,434,771	6,731,777
17	298,491	6,495,028	6,793,518
18	299,983	6,556,453	6,856,436
19	301,483	6,619,069	6,920,552
20	302,990	6,682,900	6,985,890
21	304,505	6,747,968	7,052,474
22	306,028	6,814,298	7,120,326
23	307,558	6,881,915	7,189,473
24	309,096	6,950,842	7,259,938
25	18,461,326	7,021,106	25,482,432

9.8 Mothership expenses per period

Table A.8 shows the expenses projected for the mothership approach for each period of the baseline scenario. No investment costs are shown, as no such expenses occur. Operational expenses include personnel, charter costs, fuel costs and general expenditure.

Table A.8 Mothership expenses per period

Mothership expenses per period	
period	**operational expenses[€]**
1	7,989,542
2	8,000,828
3	8,012,334
4	8,024,063
5	8,036,019
6	8,048,207
7	8,060,632
8	8,073,298
9	8,086,209
10	8,099,371
11	8,112,788
12	8,126,466
13	8,140,409
14	8,154,622
15	8,169,112
16	8,183,882
17	8,198,939
18	8,214,288
19	8,229,934
20	8,245,885
21	8,262,144
22	8,278,719
23	8,295,616
24	8,312,840
25	8,330,399

9.9 Business case canvas for the Energyhub@Sea

Figure A.9 Business case canvas