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List of Abbreviations

Acronym	Description
AGHO	AlgemeenHavenbedijf Oostende (the Port Administration)
BACI	Before-After-Control-Impact
CA	[LEANWIND] Consortium Agreement
CFC	Chlorofluorocarbon
COWRIE	Collaborative Offshore Wind Research into the Environment
DC	Dissemination Committee
DX.Y	Deliverable X [WP no]. Y [sequence no.]
EC	European Commission
EMF	Electromagnetic Field
GA	[LEANWIND] Grant Agreement
GBF	Gravity Based Foundation
GWP	Global Warming Potential
IAG	Industry Advisory Group
IP	Intellectual Property
IPCC	Intergovernmental Panel for Climate Change
ISO	International Standards Organisation
LCA	Life Cycle Assessment
O&M	Operation and Maintenance
ODP	Ozone Depletion Potential
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic

REBO	Renewable Energy Base Oostende B.V.
VOC	Volatile Organic Compound

Executive Summary

This report provides an overview of the environmental and non-technical impacts that the innovations of the LEANWIND project could haveon the local environment and communities. More specifically, the environmental impacts refer to the installation of new, fixed and floating foundation systems, whereas the non-technical impacts refer to socio-economic effects resulted from large offshore wind energydevelopments.

The report comprises threemain parts:

- The first part of the report applies the *Leopold matrix methodology* in order to assess the environmental impacts of selected LEANWIND innovations. This was done through literature review and interviews with wind industry experts. The first part also includes abrief outline of the socio-economic benefits brought by offshore wind farms andsome considerations relating tosocial acceptance.
- The second part of the report consists of a life-cycle analysis conducted for innovative steel foundations that have been developed for the LEANWIND project as well as a gravity-based foundation (GBF) that is floated to site.
- This LEANWIND report also presents an assessment of non-technical impacts of the Port of Ostend (Belgium) having become established as a base for development of the offshore wind industry since first Belgian offshore wind project began in 2007. The assessment addresses societal aspects with an emphasis on topics related to the growth of the off-shore wind business in and around Ostend. The analysis is aimed at shedding light on the impact of the offshore wind sector on Ostend, as well as on the impact of Ostend port and city on the offshore wind sector.

Leopold matrix analysis – main results

After applyingthe OSPAR [1] environmental impacts defined in the guidelines for construction and operation of offshore windfarms to the LEANWIND innovations,we asked wind industry experts to rate their impacts. The Leopold matrix analysis shows that only a few of the interactions analysed are likely to involve impacts of amagnitude, significance, probability and duration to deserve comprehensive treatment. These impacts are:

- disturbance from construction vessels and operation & maintenance (O&M) vessels;
- construction noise, loss or change of habitat;
- scouring and scour[2]protection; and
- electromagnetic fields.

For each of these impacts, the study provides insights into state of the art knowledge, existing mitigation techniques and examples of best practice.

[1] OSPAR, Guidance on Environmental Considerations for Offshore Wind Farm Development, 2008

[2] Scour refers to the phenomena of seabed erosion around the turbine foundation, this effect can be mitigated by using a scour protection around substructures

The various types of foundation developed byLEANWIND show different environmental performance in terms of magnitude and degree of their impacts. For example, the buoyant gravity-base foundation (GBF)increases loss or change of habitat, whereas the semi-submersible platform scores better,as seabed preparation is not required.

The high majority of impacts discussed in the report have a probability of occurrence of more than 50% or are certain to occur. Most impacts having a moderate negative effect on the environment occur in the construction phase, which means their duration is temporary. In general, all types of foundations impact habitats, however these are expected to be recovered within the windfarm lifetime.

Social acceptance and socio-economic benefits

Both onshore and offshore wind energy form an important part of energy policy goals internationally as many countries strive to meet their renewable energy obligations. However, many projects face community concerns and in some cases opposition, with potential implications for the cost and overall level of wind energy deployment. To achieve renewable energy policy objectives, social acceptance needs to focus simultaneously on the relevant stakeholders, such as policy makers, regulators, developers, local communities and special interest groups.

The main community concerns in the case of offshore wind are linked to visual impacts, noise and marine life conservation as well as overlapping interests with other sectors (e.g. fisheries andtourism). In order to avoid opposition, project developers have developed a series of tailored-made stakeholder engagement strategies responding to specific projects and community needs. The main pillars towards a successful stakeholder engagement strategy include providing information, engaging local communities and sharing benefits.

Life-cycle analysis (LCA) – Innovative fixed and floating foundations

A life-cycle analysis was performed to the innovative steel foundations that have been developed for the LEANWIND project. The first of these is the floating jacket foundation, which is similar to a conventional jacket foundation but can be towed to site before ballasting to the seabed, and instead of piles it is fixed to the seabed with suction buckets. The second is a floating foundation that is towed to site and moored in position. It can also easily be towed back to shore for maintenance. The third is a gravity base foundation (GBF) that is also designed to float for transport to site before ballasting for installation on the seabed. All of these foundations have been designed for installation at West Gabbard, UK, for a sea depth of up to 100m. In order to focus on the comparative impacts of the LEANWIND foundations, the impacts of the turbine itself have not been considered in this study.

By examining the environmental impacts of these new foundation designs over their whole life cycle, the ultimate goal of the analysis is to demonstrate whether they perform better than existing solutions. This also helps detecting those areas with a possible higher environmental impact to refine future design iterations, thus minimising the resulting environmental impact.

The analysis found that the environmental impacts of the floating foundation are generally higher than for the other two types of foundations, due to the greater use of steel per unit of energy produced, but it is important to note that there is much more flexibility over the choice of installation location for this type of foundation.

The jacket foundation has lower impacts than the GBF in 5 out of 8 of the impact categoriesstudied, suggesting that it might be the better option in terms of environmental impacts, but making it difficult to draw a definitive conclusion. The GBF performs worst in terms of the photochemical oxidation/ozone creation potential, due to the high emissions of pollutants during operation of sea vessels for seabed preparation. The jacket foundation performs worst in terms of the ozone and abiotic depletion potentials, both due to the manufacturing processes or materials used for the manufacture of steel for the main structure and aluminium alloy for the sacrificial anodes. Therefore, encouraging vessel innovations to achieve better performance (e.g. in endurance, capacity, fuel consumption) and optimising the design of the jacket foundation for minimum steel and aluminium use are the two areas that provide the greatest potential for further decreasing the environmental impact of these designs.

When one key impact, the global warming potential, is compared to that in other published studies, it is found that both of the steel LEANWIND solutions perform well relative to their competitors. (Only one other study on GBF was found and it hascomparable results to the LEANWIND solution.) In the case of the jacket foundation, its impacts are found to be considerably lower than those for a similar sized foundation for a similar water depth, probably due to the lower impacts of the floater/suction bucket design.

The analysis has also highlighted the key areas for potentially reducing the environmental impacts of these foundations, mainly by:

- minimising the fuel consumption of sea vessels;
- optimising the design of the steel foundations for minimal use of steel; and

reducing the length of floating foundation-mooring lines or sharing mooring lines.

Case-study of the Port of Oostende becoming established as a base for Offshore Wind

This assessment expanded over the original LEANWIND plan from a short desk study to include a series of interviews with stakeholders and actors involved in and around the Port of Ostend, draws on work done in the framework of the project and in particular of WP8, “Economic and Market Assessment”. The interviews analysed were performed with representatives of industry, local community and other stakeholders and the results are analysed drawing on other reported sources. The interviews were conducted between March 2016 and March 2017 at various offshore wind occasions in Ostend.

In particular, the report provides insights on key results achieved in terms of:

- The success of Ostend in becoming an established offshore wind port base during the past decade;

- The importance of clustering effects [3] on the various market segments related to offshore wind and on individual companies;

[3] It is commonly accepted to refer collectively to businesses active in and related to Ports as clusters. In some countries, including Belgium, distinction is made between “maritime” and “non-maritime” clusters, including in public statistics quantifying the economic impacts of ports. In this context, the offshore wind cluster might perhaps be more precisely described as a sub-cluster under the maritime cluster.

- The attitudes and actions of the companies and other stakeholders that have been established in the Ostend port area to do business in offshore wind;

- The long lead times characterising growth in offshore wind developments, investments in port infrastructure taking several years to reap benefits;

Results are provided in the form of responses by the group of interviewees to 10 opinion statements, sorted into five thematically related pairs, and to an 11th statement related to the recent falls in costs for new offshore wind developments in several EU countries.

The results and findings are hoped to be of some value also for the wider European and international development of the offshore wind industry.

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1. Environmental and socio-economic impacts of selected LEANWIND innovations

1.1 Introduction

The offshore wind industry has grown rapidly over the past two decades. Wind energyis nowa mainstream, competitive and strategic energy technology that brings considerable economic benefits to the European society. WindEurope estimated in 2015 the annual turnover in the wind sector to be €72billion. The offshore wind energy sectorcurrently provides 96,000 jobs in the European Union and by 2030 could reach 184,000direct and indirect jobs[4].

In 2015 and 2016 alone, around 4.5 GW of new offshore wind energycapacity was connected to the European grid. Europe's offshore cumulative installed capacity at the end of 2016 reached 12.6 GW. This installed capacity is now capable of producing approximately 46.4TWh in a normal wind year, being enough to cover 1.7% of the EU's total electricity consumption[5].

As knowledge and experience increase with the development of the sector, the understanding of environmental impacts also improves. The objective of this task is to examine the environmental and non-technical impacts of innovations and large wind farm developments of the LEANWIND project with a particular focus on life-cycle analysis. The findings will be incorporated in a holistic economic model (Task 8.1 – Full life-cycle cost tool including CAPEX and OPEX), ensuring that the technology innovations and system optimisations developed throughout the project will result indirect cost savings.Therefore, clearly definingthe scope of the analysis and what environmental and non-technical impactsrefer to is crucial:

I. **The environmental impacts** resulting from the installation of new foundation systems (fixed and floating) will be the main focus of the report. More details about the methodology used to assess these impactswill be provided in the next section of this report.
II. **The non-technical impacts** refer to socio-economic impacts on the local communities, such as local employment and growth, the role of ports for the coastal communities, as well as synergies with other sea users.Limited attention will be given to this chapter, as this will be analysed in a separate **case study focused on the benefits of ports.** A short overview of the **social acceptance dimension** of offshore wind farms willalso be provided.

1.2 LEANWIND foundations

The three foundations considered in this report (both in the Leopold analysis and in the LCA analysis) are the floating jacket foundation, the floating foundation and the GBF, all developed for the LEANWIND project.

The floating jacket foundation is detailed in the report "Fixed Platform Design Framework"[6]. It is a 4-legged steel lattice structure, intended for installation at water

[4]WindEurope, "Wind Energy scenarios to 2030", 2015
[5]WindEurope, "The European offshore wind industry – key trends and statistics 2016", 2017
[6] LEANWIND Deliverable 2.4, "Fixed Platform Design Framework", Executive summary available at http://www.leanwind.eu/wp-content/uploads/GA_614020_LEANWIND_D2.4_executive-summary.pdf

depths of up to 60 m, and is estimated to be 73.5 m tall. Unlike conventional jacket foundations, it does not require piles, instead having floater/suction buckets that will allow the foundation to be towed to site and then act as anchors to fix the foundation to the seabed once installed. It has been designed to support the LEANWIND 8 MW wind turbine.

The floating foundation will be described in detail in the report “Floating Substructures Design Framework”[7]. It is a semi-submerged triangular design, formed from steel sections, and held in place by a 3-catenary-line mooring system. Unlike existing foundation designs, this will be installed with the turbine already assembled on top, and it is likely that the entire turbine and foundation will be towed back to shore for any significant maintenance activities. It has been designed to support the NREL 5 MW wind turbine.

The gravity base foundation (GBF) is a reinforced concrete caisson described in detail in the report “Fixed Platform Design Framework”[8]. It is designed to be manufactured in a floating dock, and will be towed to site before being sunk on to a pre-prepared seabed. It has also been designed to support the LEANWIND 8 MW wind turbine.

1.3 Methodology

In order to delineate which LEANWIND innovations have an environmental impact on the local environment we used a method of rating environmental impacts called the **Leopold matrix**[9],where the innovations were integrated with the environmental impacts listed by OSPAR in their guidance document on environmental impacts for offshore wind farms.

Respondents[10] were asked to judge on the **magnitude, significance, probability and duration** of the impacts against the definitions provided (see legend explained below). It is important to have these four measures clearly defined as whilst similar, they contain important differences. An impact that could be catastrophic for example may not necessarily be a likely occurrence. Once all results were filled in, the factors most likely to occur that carry a significant impact werefurther discussed to determine what is the state of the art mitigation that could be applied. This part of the analysis was based on literature review.The main sources of information used are articles available in scientific journals, and papers presented at international conferences (i.e. WindEurope's Annual and Offshore Wind Energy Conferences).

For the validation of the best practice exchange and main mitigation techniques of adverse environmental impacts, WindEurope consulted itsSustainability Task Force specialised in environmental issues relating to wind energy.

The following definitions apply to the evaluation criteria used for this analysis[11]:

[7] LEANWIND Deliverable 2.5, “Floating Platform Design Framework”, Executive Summary available at http://www.leanwind.eu/wp-content/uploads/GA_614020_LEANWIND_D2.5_executive-summary.pdf
[8]LEANWIND Deliverable 2.4, “Fixed Platform Design Framework”, Executive Summary available at http://www.leanwind.eu/wp-content/uploads/GA_614020_LEANWIND_D2.4_executive-summary.pdf
[9] Luna B. Leopold, Frank E. Clarke, Bruce B. Hanshaw, and James R. Balsley. GEOLOGICAL SURVEY CIRCULAR 645. Washington 1971.
[10]Iberdrola, ACCIONA, EDPR, UEDIN, WindEurope and Tecnalia.
[11] Luna B. Leopold, Frank E. Clarke, Bruce B. Hanshaw, and James R. Balsley. GEOLOGICAL SURVEY CIRCULAR 645. Washington 1971.

- **Magnitude:** refers to extent or intensity and can be measured on a numerical scale of minus five (-5) to plus five (+5), with five (5) representing large magnitude andone (1)representing small magnitude for positive environmental impacts. The same applies for negative impacts. The assignment of numerical values to the magnitude of an interaction should be based on an objective evaluation of facts[12].
- **Significance:** the significance of an interaction is related to its importance, or an assessment of consequences of the anticipated interaction. In our analysis it refers mainly to the geographical scale of the impact. The measurement scale of significance ranges from one (1) to five (5), with five indicating a very important relation and one indicating an interaction of low importance.
- **Probability:** it refers to the probability of an environmental impact happening. The scale of measurement ranges from one (1) to three (3), where one is a possible impact (< 50%) and three is a certain impact (100%).
- **Duration:** is defined as the temporal scale of the impact. In our analysis there are two types of impacts: temporary and permanent.

Table 1Leopold matrix definitions given to survey respondents

NUMBER	MAGNITUDE	DEFINITION
5	**Great**	The impact is predicted to have a long term positive effect on the environment on a global scale
4	**Major**	The impact is predicted to provide a leading advantage to the environment and the community
3	**Moderate**	The impact is predicted to have a positive impact on the environment
2	**Slight**	The impact is defined to have a mild but positive impact on the environment
1	**Negligible**	The impact is defined to have a minor positive impacton the environment
-1	**Negligible**	The negative impacton the environment is identified as modest, almost non-existent
-2	**Slight**	The negative impact is minor with a short-term effect on the local environment without changes to the distribution or status of the species.
-3	**Moderate**	The negative impact is identified as mild, short-term and reversible without changing overall integrity of the natural habitat and the community
-4	**Major**	The negative impact ispredicted to result in a primary change to the environment with a long-term effect
-5	**Catastrophic**	The impact is predicted to result in an adverse and irreversible effect on a global scale

NUMBER	SIGNIFICANCE	DEFINITION

[12]Nallathiga, Ramakrishna, “Dessertification Assessment using Matrix method of EIA,” Fifth international conference on operations research for development, December 2005, https://www.researchgate.net/publication/275329853_Desertification_Assessment_using_Matrix_method_of_EIA

5	**Great**	Impact of cross-border character
4	**Major**	Impact of national character
3	**Moderate**	Impact of regional character
2	**Slight**	Impact of importance to themunicipality
1	**Negligible**	Impact on turbine location

NUMBER	PROBABILITY	DEFINITION
3	Impact is certain	100% probability
2	Impact is probable	probability of over 50%
1	Impact is possible	probability of less than 50%

NUMBER	DURATION
2	Long-term/Permanent
1	Occasional/temporary

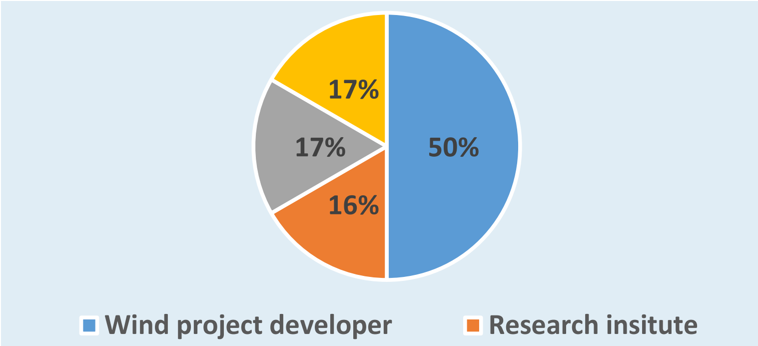
We encountered one important limitation when attempting to disseminate the survey to a wider audience: in order to be able to evaluate fully the environmental impacts of the LEANWIND innovations, the respondent must be acquainted with the innovations and understand how they were built and how they function. At this stage of LEANWIND activities, only the project partners truly understand the innovations. Also due to Intellectual Property (IP) limitations, they seemed to be the best placed to rate the impact of such innovations on the environment. Nonetheless, this also implies a certain level of subjectivity. In addition, completing this environmental impacts rating exercise requiresconsiderable time and effort, which only project partners were willing to contribute.

The total number of respondents to the survey is six and theyrepresent the following stakeholder categories:

- wind project developers;
- industry associations;
- research institutes; and
- academia.

Figure 1 below shows the share of participation per stakeholder group, withproject developers representinghalf of the respondents.

Figure 1 Survey - share of participation per stakeholder group



From the full list of LEANWIND project innovations WindEurope made a selection of innovations believed to have a potential environmental impact, consequently therefined list was sent to the participants.

Table 2 and 3 depict the environmental impacts ofthe LEANWIND project innovations; the crossed cells mean that the respondents rated those project innovations while the empty cells means that the respondents did not rate the innovations. This is explained by the fact that there is little information available on innovations due to IP issues inside the project.

There five innovations that were rated most by the respondents are further analysed in this report. They are:

1. Design of a cylindrical caisson buoyant GBF;
2. Design of a floating jacket;
3. Use of suction buckets with a floating jacket;
4. Design of an innovative semi-submersible platform; and
5. Cable laying, burial and trenching.

The innovations referring to new installation vessels concepts orto optimisation of O&M strategies may have a potential positive impacts on the environment if the innovations proposed can for instance achieve the decrease of the number of trips necessary to the wind farm (i.e. for moving personnel). The environmental benefit wouldbereducedfuel consumption. Nonetheless, in order to evaluate and quantify what the environmental impact would be, we would need data from real life projects and this information was not available when the analysis was carried out.

Table 2 Leopold matrix – construction phase

	CONSTRUCTION PHASE																																									
LEANWIND Innovation	**Disturbance from construction vessels and equipment**						**Chemical pollutants**						**Construction noise impacts**						**Increased turbidity**						**Visual effects**						**Loss or change of habitat**						**Waste and Debris**					
Respondent	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association
Cylindrical Caisson buoyant GBF	x	x	x	x	x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x
Modification of the soil-structure models employed in the design of XL Monopiles	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x
Design of a floating jacket & floatability studies	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x
Use of suction buckets with a floating jacket	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x
Design of a an innovative semi-sub platform	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x
Identify and assess novel turbine transport methodologies					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Identify and assess novel turbine assembly strategies					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Identifying and planning the deployment strategies for the innovative foundation concepts					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Cable laying, burial and trenching				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x
Challenges and installation strategies for scour protection					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Development of Installation vessel recommendation software.					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Three novel installation vessel concepts will be selected to enter the initial design phase					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Evaluation of the 3 vessel concepts leading to the selection of the best one.					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Design Criteria and parameters have been developed for the novel service vessel					x	x					x	x					x	x					x	x					x	x					x	x					x	x
One O&M vessel in the concept design					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Novel Lifting Concepts					x	x					x	x					x	x					x	x					x	x					x	x					x	x

Table 3 Leopold matrix – operational phase

	OPERATIONAL PHASE																																															
LEANWIND Innovation	Disturbance from maintenance vessels and equipment						Scouring and scour protection						Chemical pollutants						Electric and magnetic fields						Operational noise effects						Birds – collision						Barrier effects on fauna						Visual impact and public perceptions					
Respondent	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association	Developer 1	Developer 2	Developer 3	Research Institute	Academia	Wind industry association
Cylindrical Caisson buoyant GBF	x	x	x	x	x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x
Modification of the soil-structure models employed in the design of XL Monopiles	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x
Design of a floating jacket & floatability studies	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x
Use of suction buckets with a floating jacket	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x			x	x
Design of a an innovative semi-sub platform	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x
Identify and assess novel turbine transport methodologies					x	x					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Identify and assess novel turbine assembly strategies					x	x					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Identifying and planning the deployment strategies for the innovative foundation concepts					x	x					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Cable laying, burial and trenching				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x				x	x	x
Challenges and installation strategies for scour protection					x	x					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Development of Installation vessel recommendation software.					x	x					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Three novel installation vessel concepts will be selected to enter the initial design phase					x	x					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Evaluation of the 3 vessel concepts leading to the selection of the best one.					x	x					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Design Criteria and parameters have been developed for the novel service vessel					x	x					x	x					x	x					x	x					x	x					x	x					x	x					x	x
One O&M vessel in the concept design					x	x					x	x					x	x					x	x					x	x					x	x					x	x					x	x
Novel Lifting Concepts					x	x					x	x					x	x					x	x					x	x					x	x					x	x					x	x

2. Results of the Leopold matrix analysis

2.1 Design of a cylindrical caisson buoyantgravity based foundation (GBF)

Innovation description:

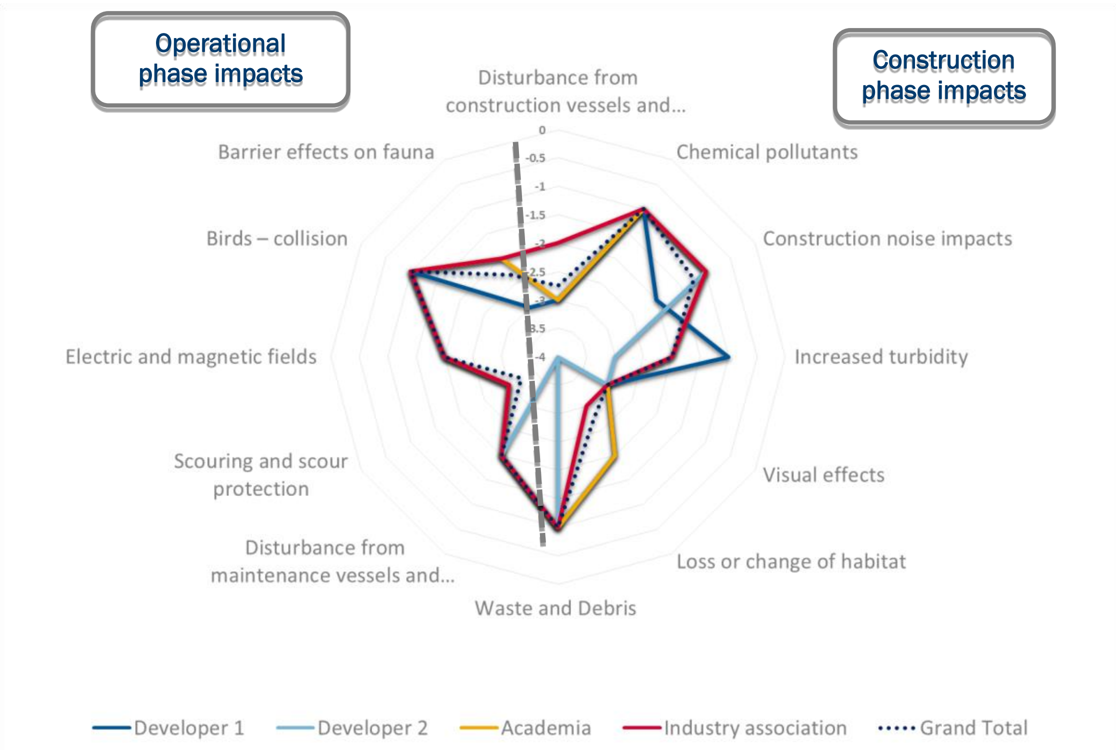
The GBF wasdesigned to be manufactured in a floating dock, and towed to site before being sunk on to a pre-prepared seabed (see section 1.2). The responsible project partner is ACCIONA ConstrucciónS.A. (ACCIONA).

MAGNITUDE analysis:

Figure 2below maps the magnitude of environmental impacts in the construction and operational phase resulted from the cylindrical caisson buoyant GBF. We can observe that most of the negative impacts occur during the construction phase; they refer mainly to disturbance from construction vessels and equipment, increased turbidity, loss or change of habitat, scouring and scour protection.

The movements of installation vessels, machinery and personnel during construction could have a disturbing effect on the local biota and on the sediment regime (slight to moderate negative effect). If the level of disturbance is likely to have a significant effect on birds or marine mammals, management rules can be set by the consenting authorities to mitigate this potential impact (i.e. scheduling the installation timing and routes to avoid sensitive locations and times).

Figure 2 MAGNITUDE of environmental impacts of cylindrical caisson buoyant GBF



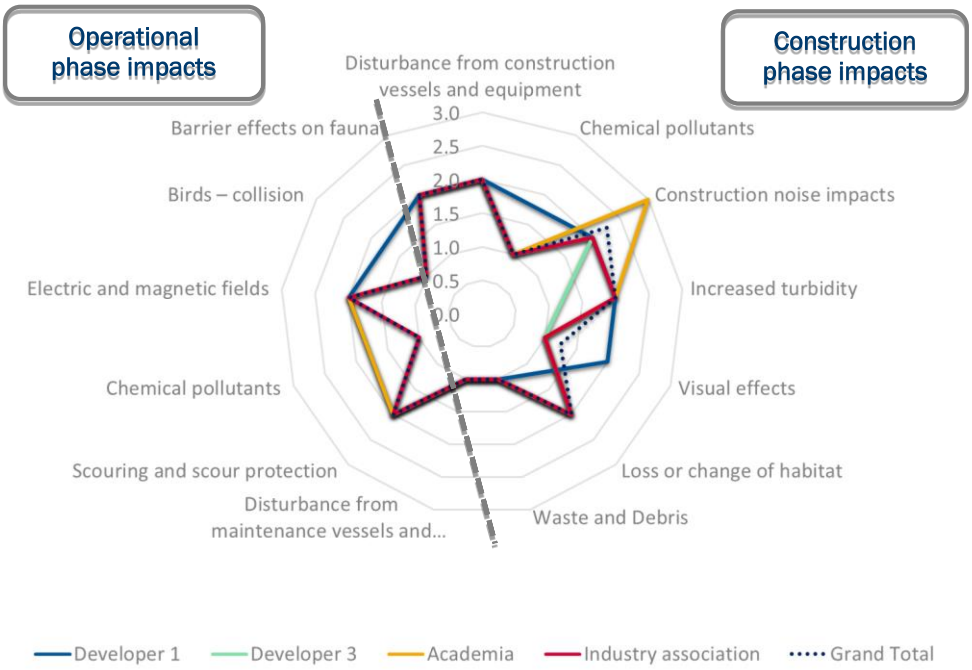
The loss change of habitat in the case of a buoyant GBF is rated by most respondents as having a negative environmental effect (-2 to -4) since it will occupy the seabed and will require seabed preparation for installation. Scouring and scour protection and was rated similarly by the respondents with grades between -3 and -4.

SIGNIFICANCE analysis:

Figure 3 below shows that most respondents have a similar opinion on the significance criteria. Turbidity increase, loss or change of habitat, scouring and scour protection, electromagnetic fields and barrier effect on fauna have a low significance impact, being considered very project specific.

One respondent that assessed the impact of construction noise from floating GBFs as attaining a regional level of impact. Even if the significance of this kind of impact is generally important, we saw in the magnitude analysis that construction noise scored well for this innovation, as it does not involve piling.

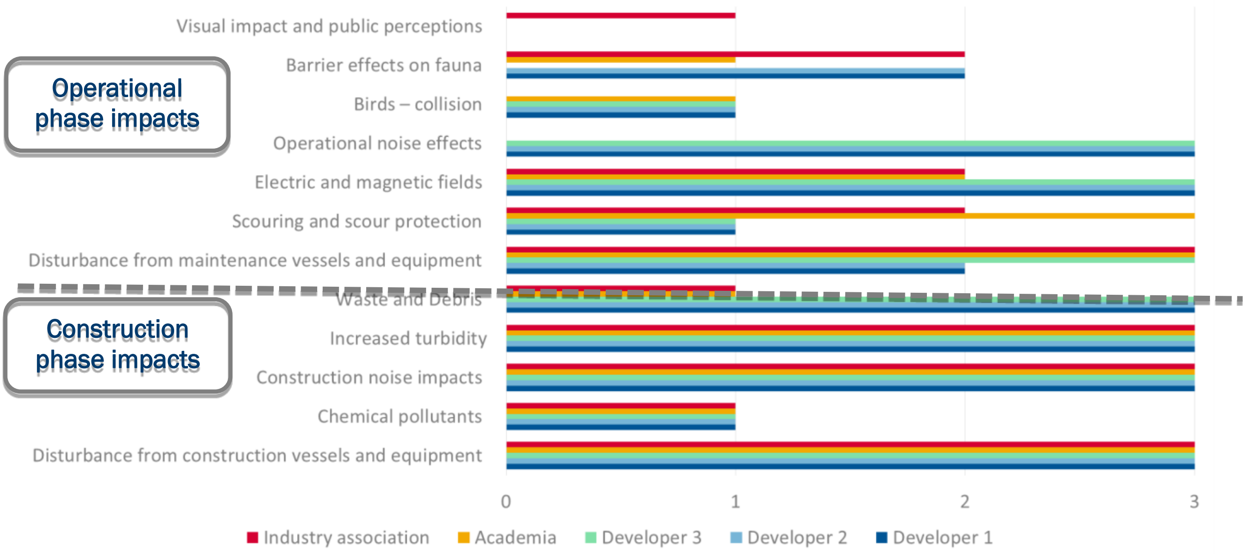
Figure 3 SIGNIFICANCE of environmental impacts of Cylindrical Caisson buoyant GBF



PROBABILITY analysis:

Figure 4 below represents the probability of environmental impacts associated with cylindrical caisson buoyant GBFs. The data shows that three impacts were rated by respondents with 1, meaning that the probability rate for them to happen is less than 50%. These impacts are: bird collisions, scouring and scour protection (highly dependent on the project location and the type of rock) and chemical pollutants during the operational phase. On the opposite side there are some impacts that will certainly occur such as environmental disturbance resulted from the installation vessels activity or O&M vessel activities, construction noise, increased turbidity or electromagnetic fields.

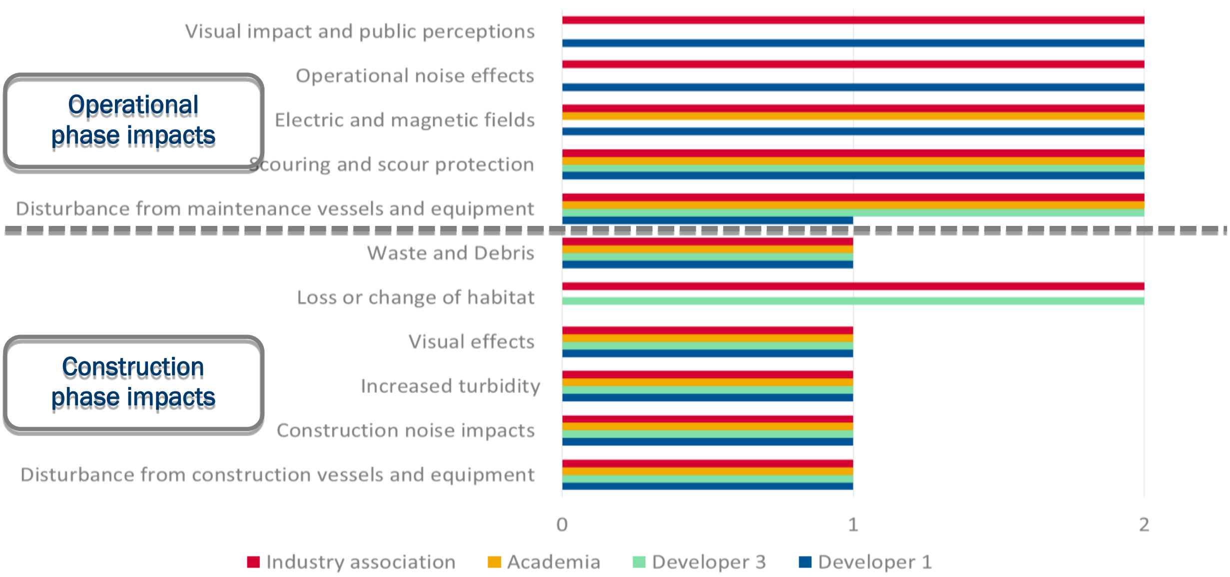
Figure 4 PROBABILITY of environmental impacts of cylindrical caisson buoyant GBF



DURATION analysis:

Figure 5 below shows that most of the construction impacts are rated to be temporary, while the environmental impacts arising in the operational phase are considered permanent. Loss or change of habitat is rated as being a permanent impact as once the GBF is installed will stay in place for the whole lifetime of a project, usually 20 to 25 years.

Figure 5 DURATION of environmental impacts of Cylindrical Caisson buoyant GBF



2.2 Design of a floating jacket

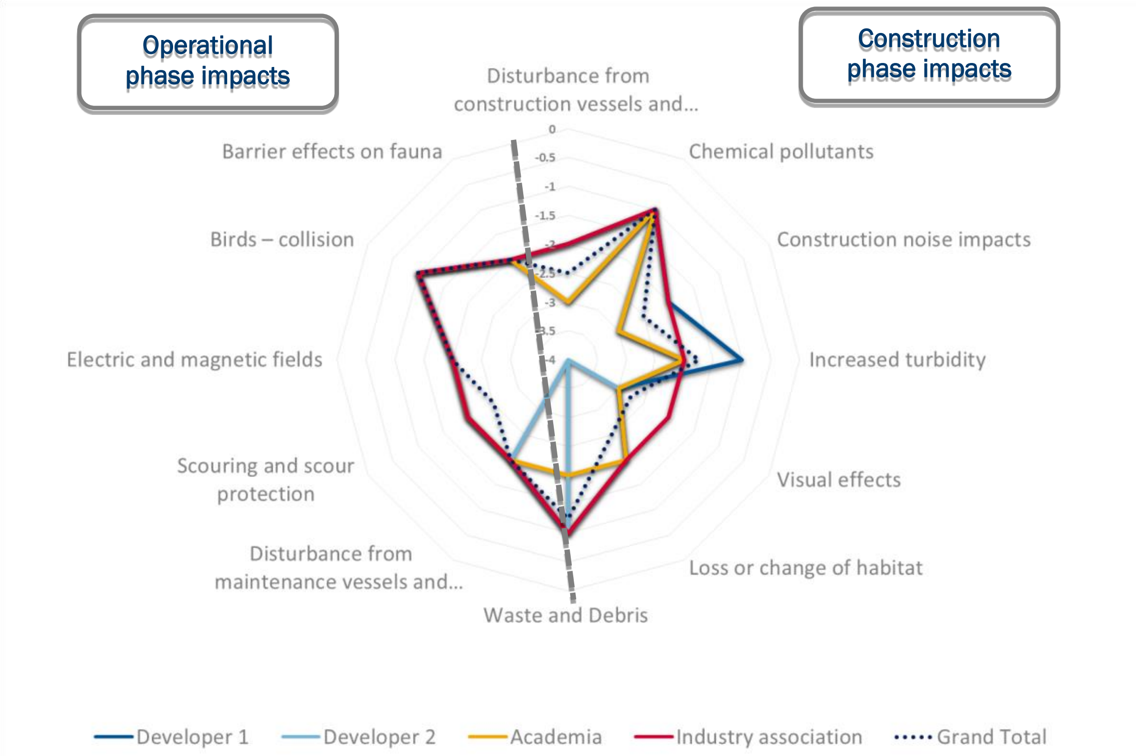
Innovation description:design and optimisation of a floating jacket foundation for the 8MW LEANWIND turbine, which can be floated to the site in a vertical position, eliminating the need for the installation vessels (see section 1.2 and 2.3). The responsible project partner is Electricité de France S.A. (EDF).

MAGNITUDE analysis:

Figure 6 below shows that chemical pollutants, increased turbidity, waste debris or bird collisions register a negligible negative impact. Disturbance from construction vessels and equipment and increased turbidity are rated as having a slight negative impact on the environment, while construction noise as having a moderate negative impact.

Respondents also rated a series of environmental impacts with a slight to major negative effect (-2 to -4), notably the loss or change of habitat and scouring and scour protection.

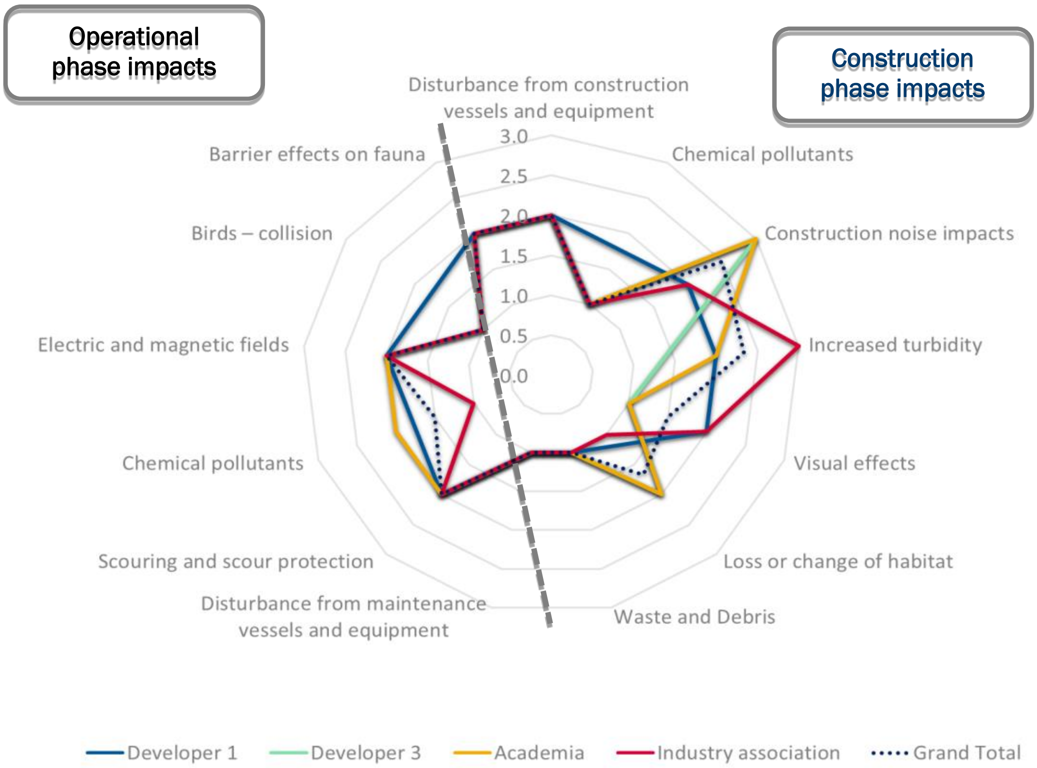
Figure 6 MAGNITUDE - environmental impacts of a floating jacket



SIGNIFICANCE analysis:

Figure 7 below shows the clear majority of environmental impacts as having either a project specific or local impact. Only two environmental indicators were rated as potentially being able to have a regional impact; these are the construction noise impact and the turbidity increase.

Figure 7 SIGNIFICANCE - environmental impacts of a floating jacket



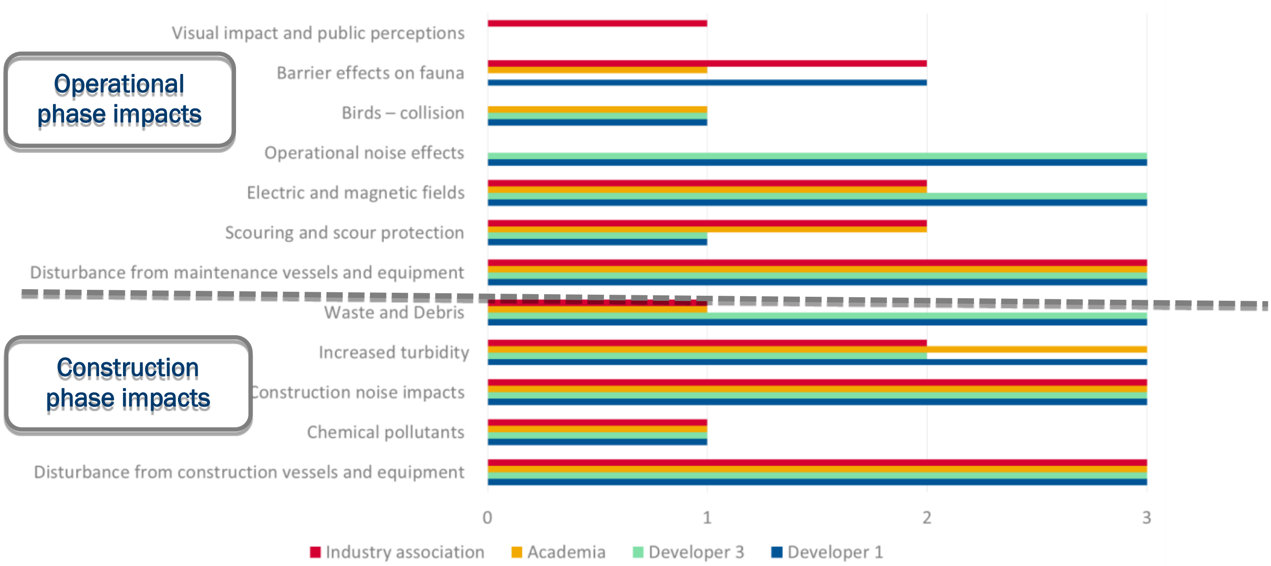
<u>PROBABILITY analysis</u>:

Figure 8 below shows the degree of probability of the environmental impacts listed.

Disturbance from construction and operational maintenance are certain. This is the case also for construction noise impacts and operational noise impacts.

Chemical pollutants, scouring and bird collisions are rated as possible with a rate of occurrence of less than 50%.

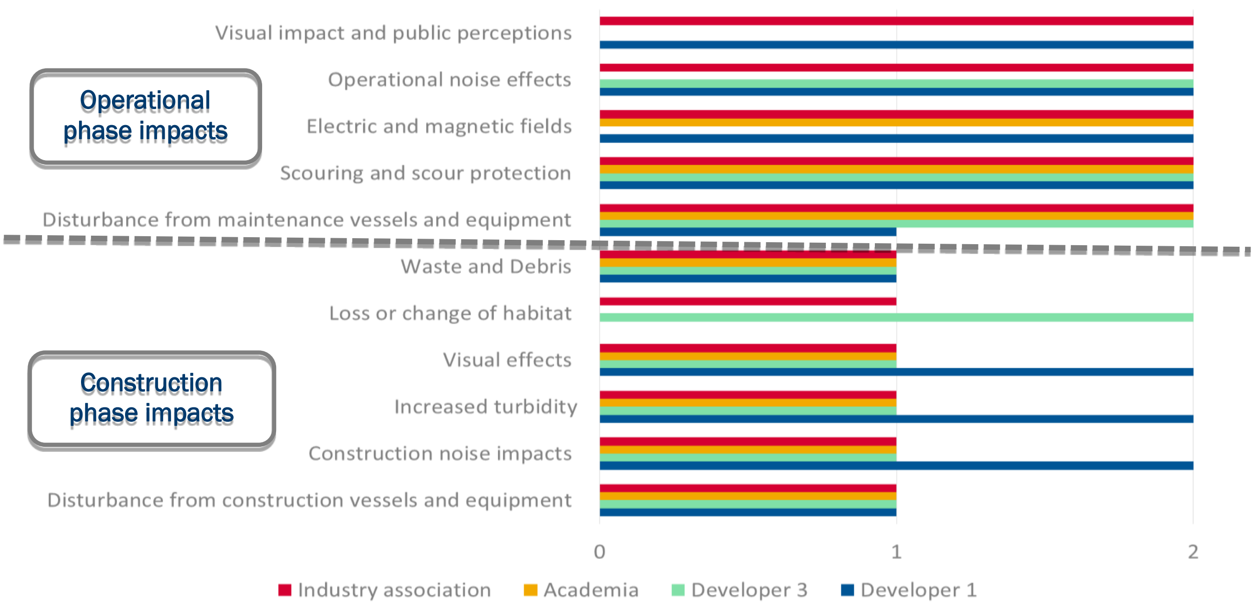
Figure 8 PROBABILITY - environmental impacts of a floating jacket



DURATION analysis:

Figure 9 below shows that all operational impacts are considered permanent, while the construction ones are considered temporary. These trends are similar to those of the cylindrical caisson buoyant GBFs.

Figure 9 DURATION - environmental impacts of a floating jacket



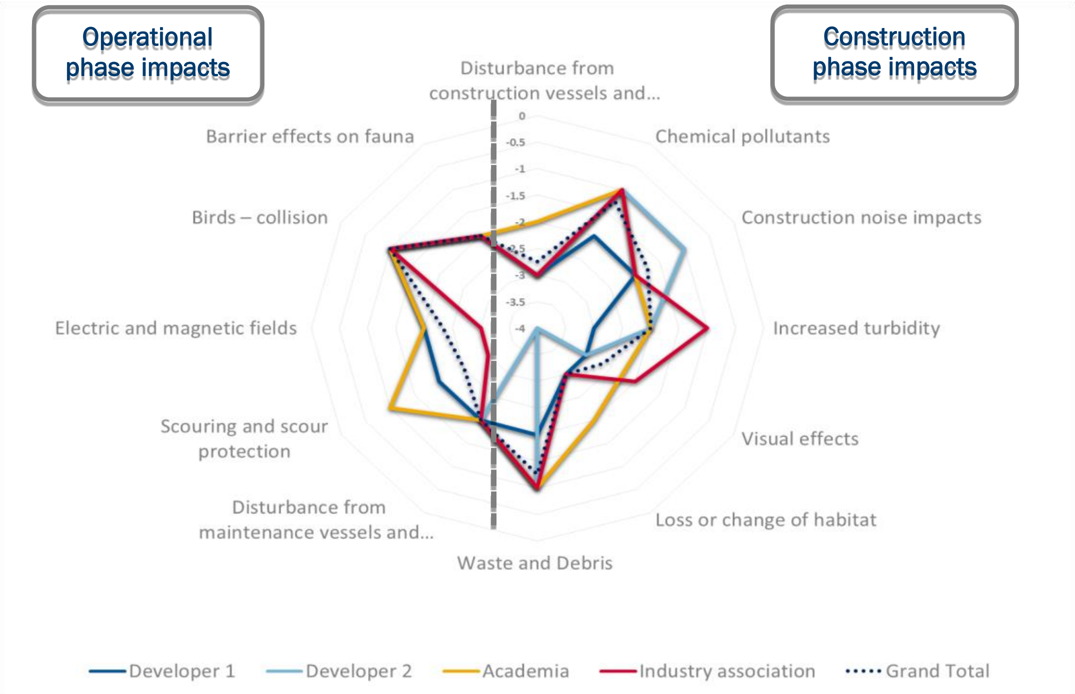
2.3 Use of suction buckets with a floating jacket

Innovation description: suction buckets used to provide the required floatability for the jacket foundation. They will allow the foundation to be towed to site and then act as anchors to fix the foundation to the seabed once installed. Unlike conventional jacket foundations, the suction buckets do not require pilling (see section 1.2).The responsible LEANWIND partners are EDF and GAVIN AND DOHERTY GEOSOLUTIONS LTD (GDG).

MAGNITUDE analysis:

Figure 10 below shows a similar environmental behaviour as for the previous floating jacket innovationwith a negligible to slight negative magnitude effect, notably on chemical pollutants, increased turbidity, waste debris and bird collisions. Disturbance from construction vessels and O&M vessels and construction noiseare considered to have a slight to moderate negative impact. Loss or change of habitat and scouring and scour protection are rated by one of the respondents as having a major negative effect as these impacts are predicted to result in a primary change to the environment with a long term effect (20 to 25 years the life time of a project).

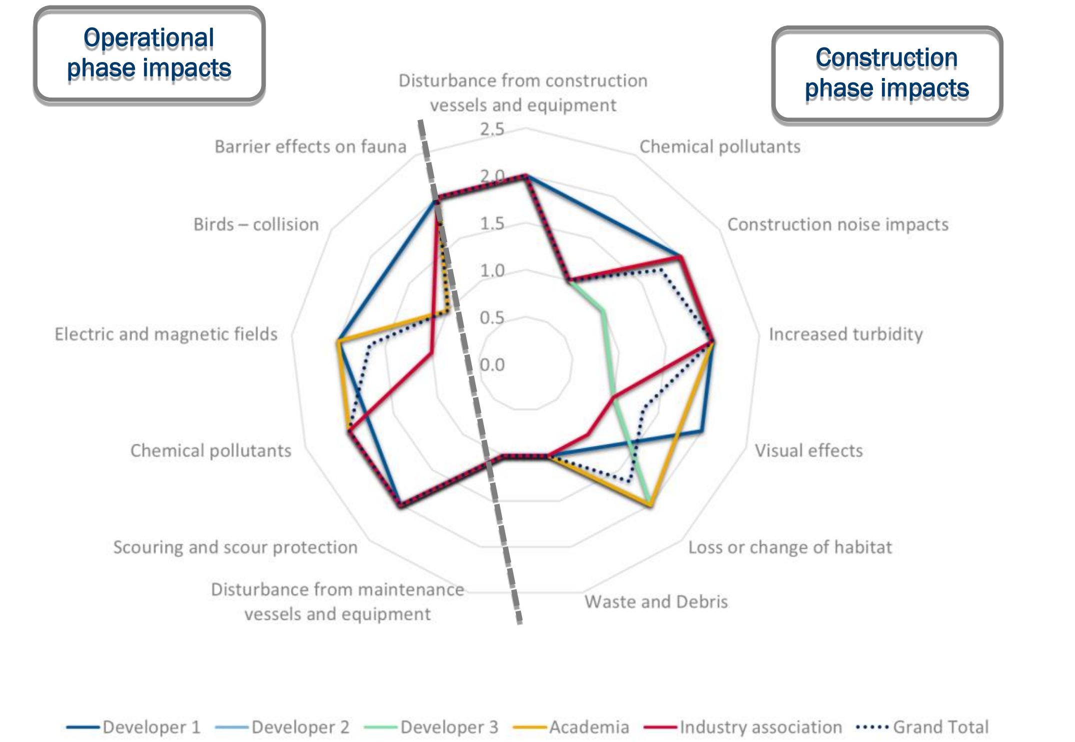
Figure 10 MAGNITUDE - environmental impacts of use of suction buckets with a floating jacket



<u>SIGNIFICANCE analysis</u>:

Figure 11 below shows the majority of the environmental impacts as having either a project specific impact or an impact on the local ecosystem.

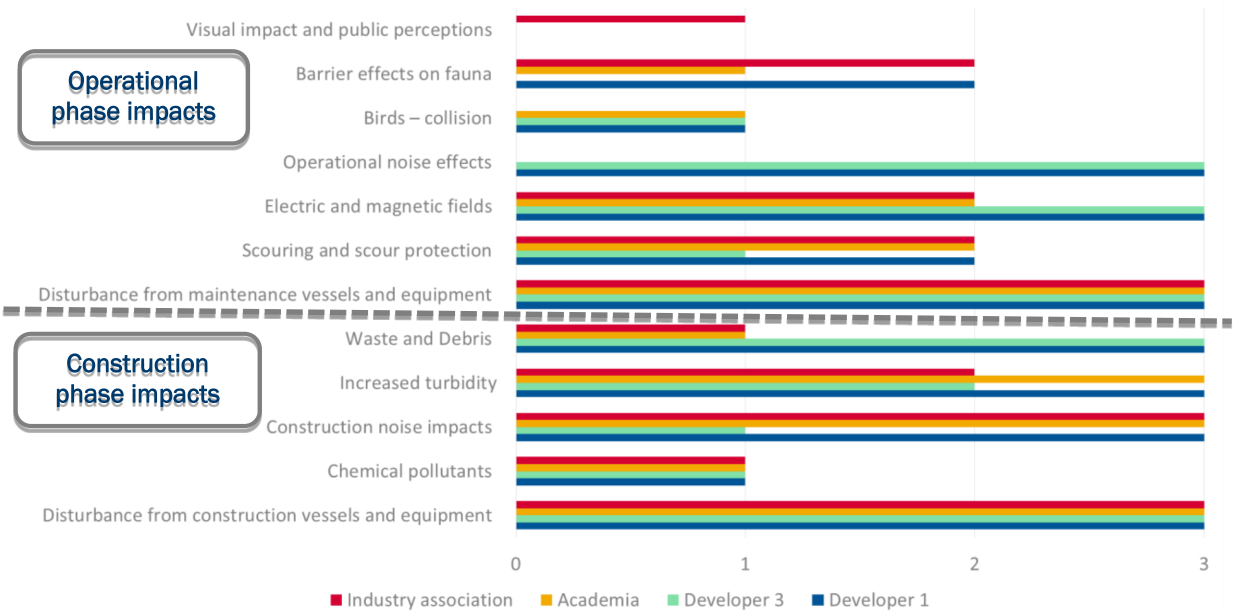
Figure 11 SIGNIFICANCE - environmental impacts of use of suction buckets with a floating jacket



PROBABILITY analysis:

Figure 12below shows the degree of probability of the listed environmental impacts. Disturbance from construction and operational maintenance are certain. This is the case also for construction noise impacts and electromagnetic fields.Chemical pollutants, scouring and birds collisions are rated as possible impacts with a rate of occurrence of less than 50%.

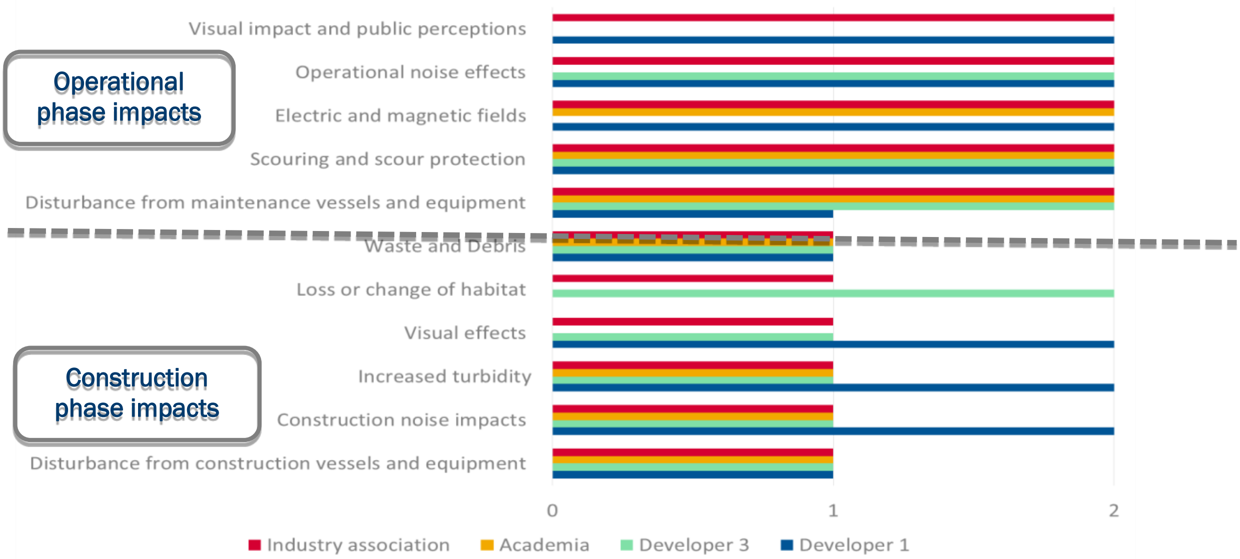
Figure 12 PROBABILITY - environmental impacts of use of suction buckets with a floating jacket



DURATION analysis:

Figure 13 below shows that all operational impacts are considered permanent, while the construction ones are considered temporary. These trends are similar with those of the cylindrical caisson buoyant GBFs.

Figure 13 DURATION - environmental impacts of use of suction buckets with a floating jacket



2.4 Design of an innovative semi-submersible platform

Innovation description:the design for the semi-submersible platform has been completed by Iberdrolaand physical scale model tests have been performed at the University College of Cork. The floating foundation can be towed to site and moored in position (see section 1.2).

MAGNITUDE analysis:

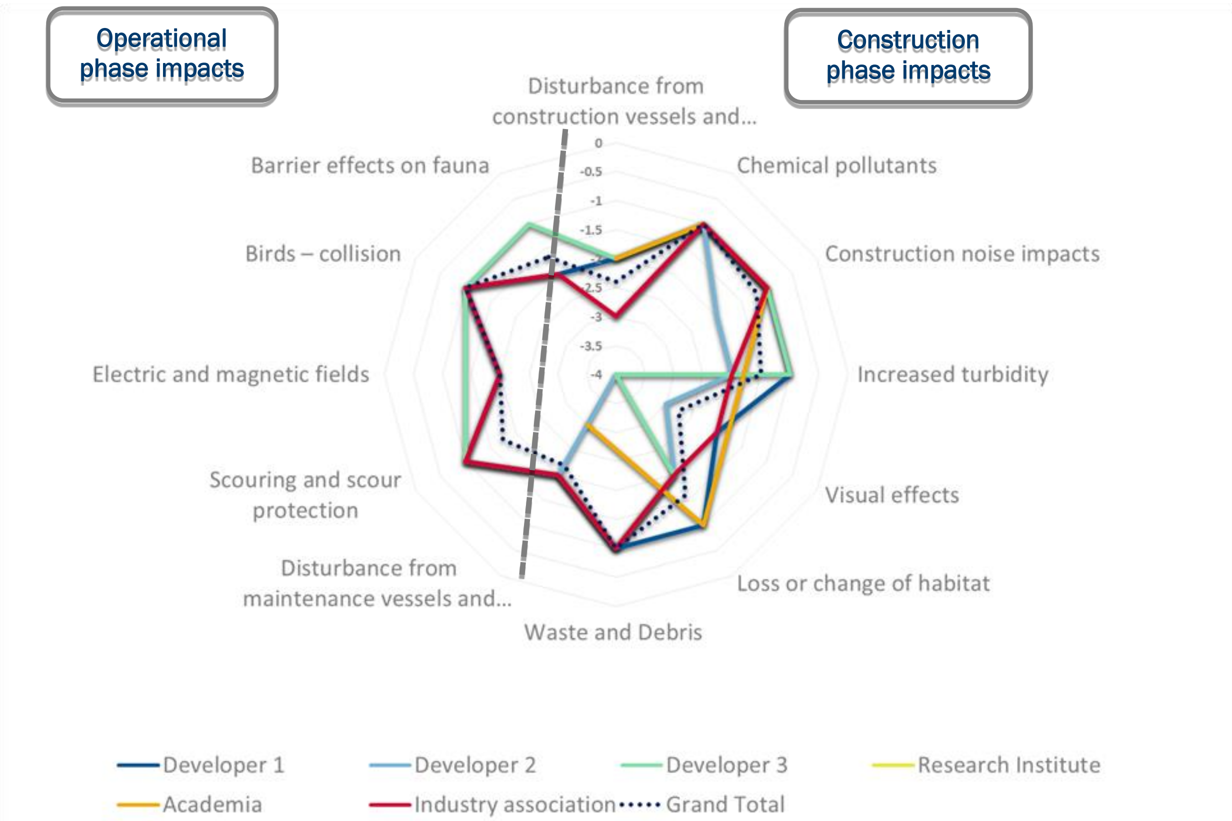
Figure 14 below shows that the semi-submersible platform scores better than the other types of substructures at almost all analysed indicators. Chemical pollutants, construction noise, waste and debris as well as bird collisions have a negligible level of impact. For example, in the case of construction noise, this is due to the fact that there is no need for piling operations for this type of foundation.

Disturbance from construction and operational maintenance vessels is considered to have a slight negative impact, as well as loss or change of habitat, most probably because this type of foundation will not occupy the seabed and will not need seabed preparation.

Scouring and scour protection also rates lower on the negative scale than for the other types of foundation as anchors are completely buried therefore not needing scour protection.

One indicator is rated by just one respondent as having a major impact on the environment: the visual effects. The rating can be explained probably by the lifetime of the project (20 to 25 years). The other ratings corresponding to this impact vary on the magnitude scale between -2 and -3.

Figure 14 MAGNITUDE - environmental impacts of an innovative semi-submersible platform

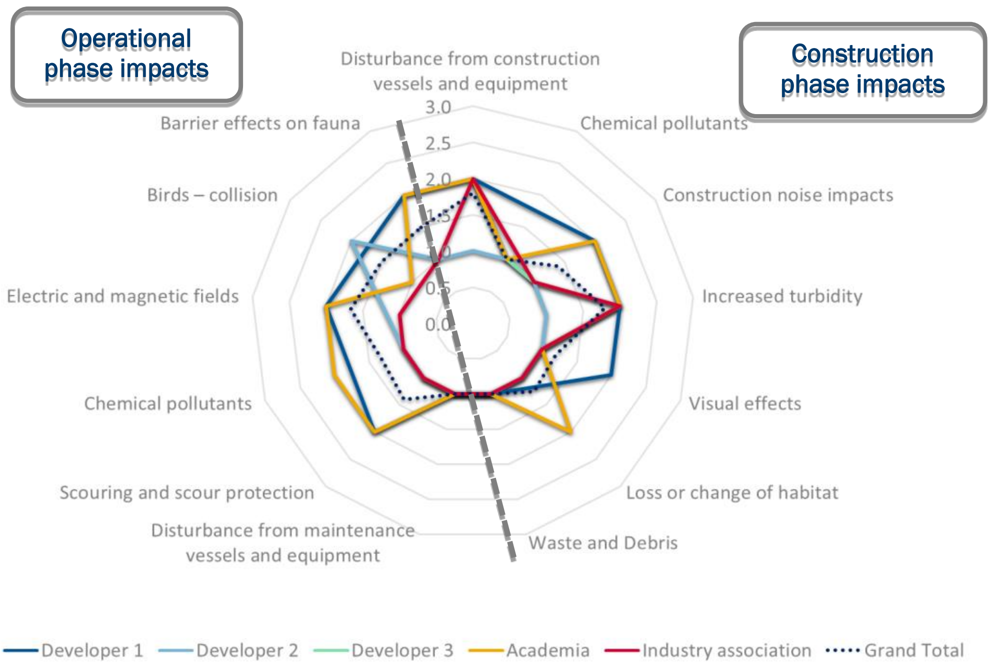


SIGNIFICANCE analysis:

Figure 15 below shows the majority of the environmental impacts as having either a project specific impact or local impact. We can list in this category the disturbance from construction vessels and equipment, increased turbidity, electromagnetic fields.

The visual effect impact, which was rated as having a slight to major level of magnitude, shows that when combined with the significance indicator the impact is mostly project specific. In many cases, for recently built offshore wind farms the distance to shore can reach on average up to 44 Km. Also taking into account the local topography we could say that the tendency of the industry is to go further offshore therefore making wind farms less visible to the surrounding coastal communities[13].

Figure 15 SIGNIFICANCE - environmental impacts of an innovative semi-submersible platform

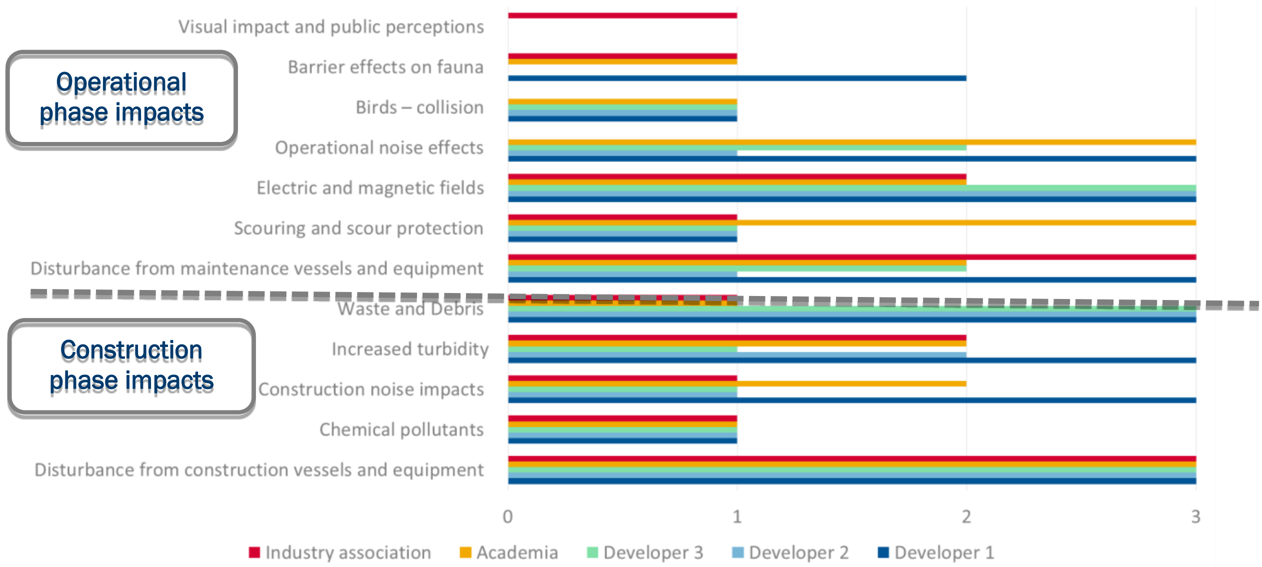


PROBABILITY analysis:

Figure 16 below shows the degree of probability of the environmental impacts listed. Disturbance from construction works and operational maintenance, as well as electromagnetic fields are certain. Increased turbidity and the barrier effect on fauna is rated as probable, meaning an occurrence rate of 50% to 100%. Chemical pollutants, scouring and bird collisions are rated as possible with a rate of occurrence of less than 50%.

Figure 16 PROBABILITY - environmental impacts of an innovative semi-submersible platform

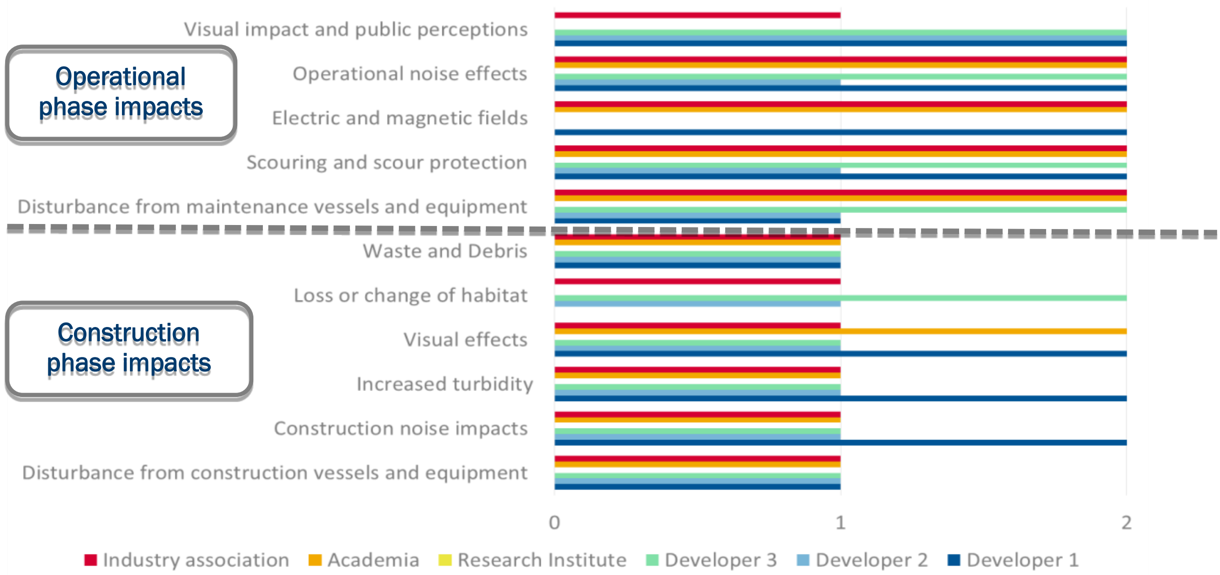
[13] Luna B. Leopold, Frank E. Clarke, Bruce B. Hanshaw, and James R. Balsley. GEOLOGICAL SURVEY CIRCULAR 645. Washington 1971.



DURATION analysis:

Figure 17 below shows that most of the operational impacts are rated as permanent, while the construction ones are considered temporary. These trends are similar to those of the cylindrical caisson buoyant GBFs, and of the floating jacket developed by EDF.

Figure 17 DURATION - environmental impacts of an innovative semi-submersible platform



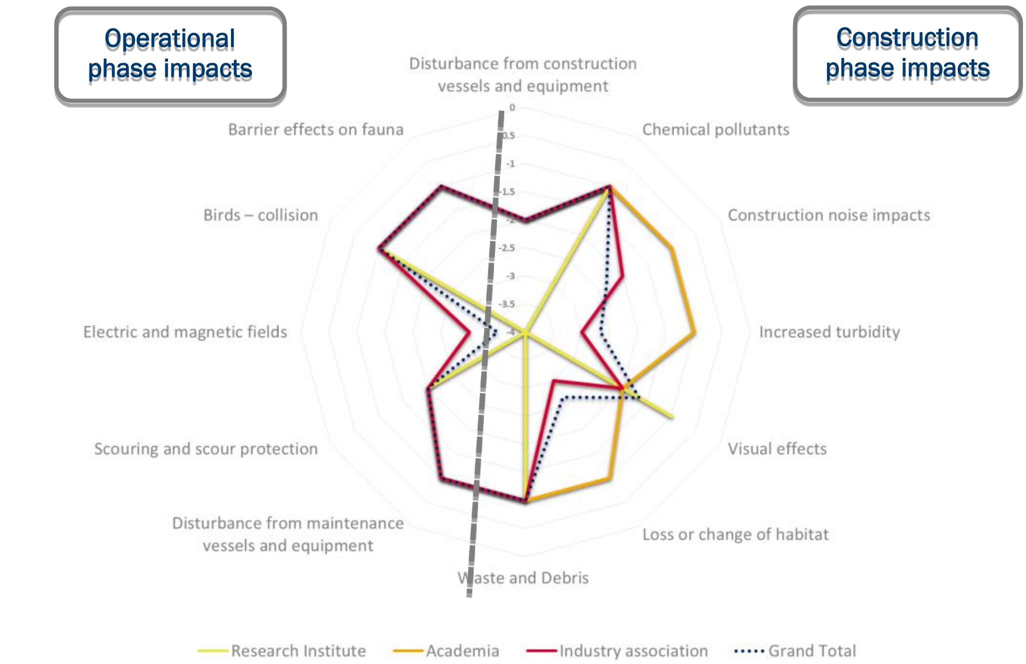
2.5 Cable laying, burial and trenching

Innovation description: the objective of this innovation is to examine the common issues and requirements related to the trenching path and burial depths of cables. The responsible LEANWIND project partner is GDG.

MAGNITUDE analysis:

Cable laying, burial and trenching are very different offshore operations compared with the installation of substructures therefore the environmental performance of the indicators scores differently. The moderate negative impacts areincreased turbidity, loss or change of habitat and the electromagnetic fields. Disturbance from construction vessels and equipment, construction noise has a slight negative impact.

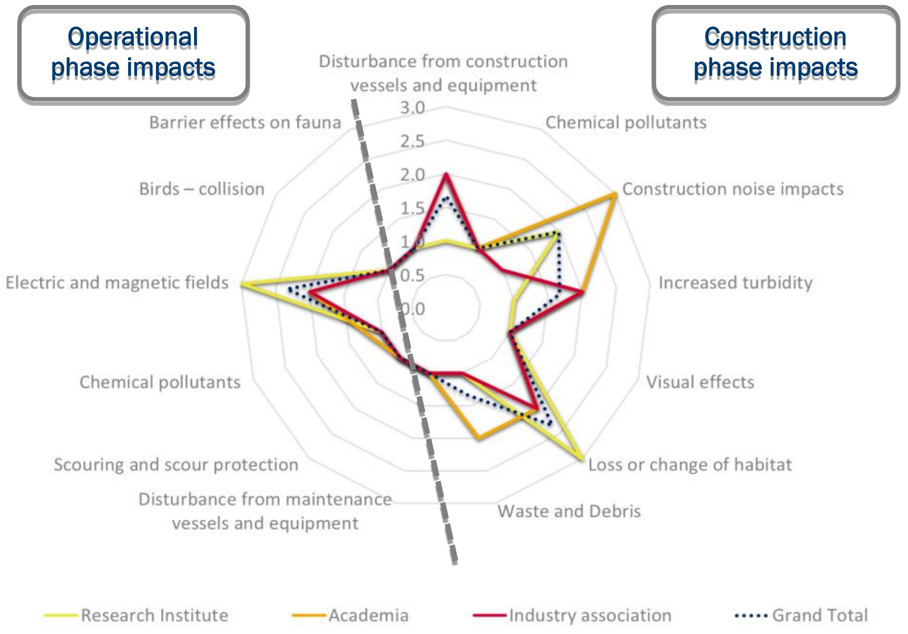
Figure 18 MAGNITUDE - environmental impacts of cable laying, burial and trenching



SIGNIFICANCE analysis:

Figure 19 below shows that the most significant impacts are associated with construction noise, increased turbidity, loss or change of habitat and electromagnetic fields.

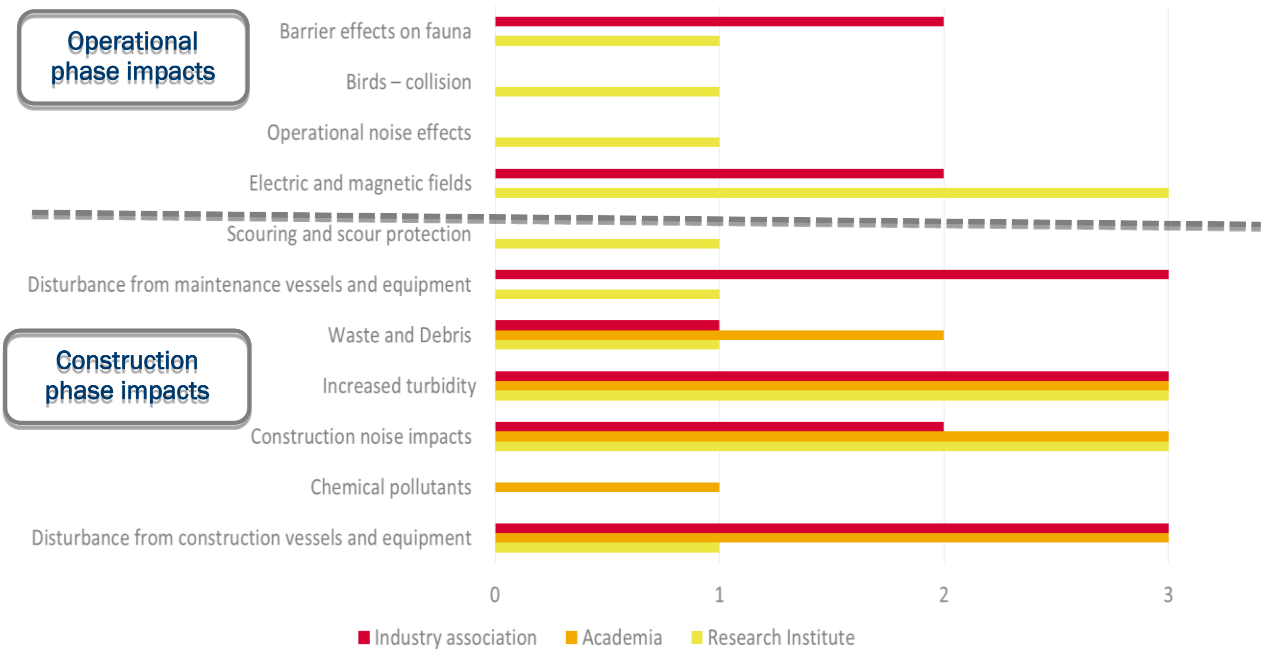
Figure 19 SIGNIFICANCE - environmental impacts of cable laying, burial and trenching



PROBABILITY analysis:

Figure 20 below represents the probability criteria. We can observe that almost all environmental impacts will produce at a probability rate higher than 50% or being certain. There are just 3 impacts that are scored as possible, these are leakage of chemical pollutants, operational noise effects and bird collisions.

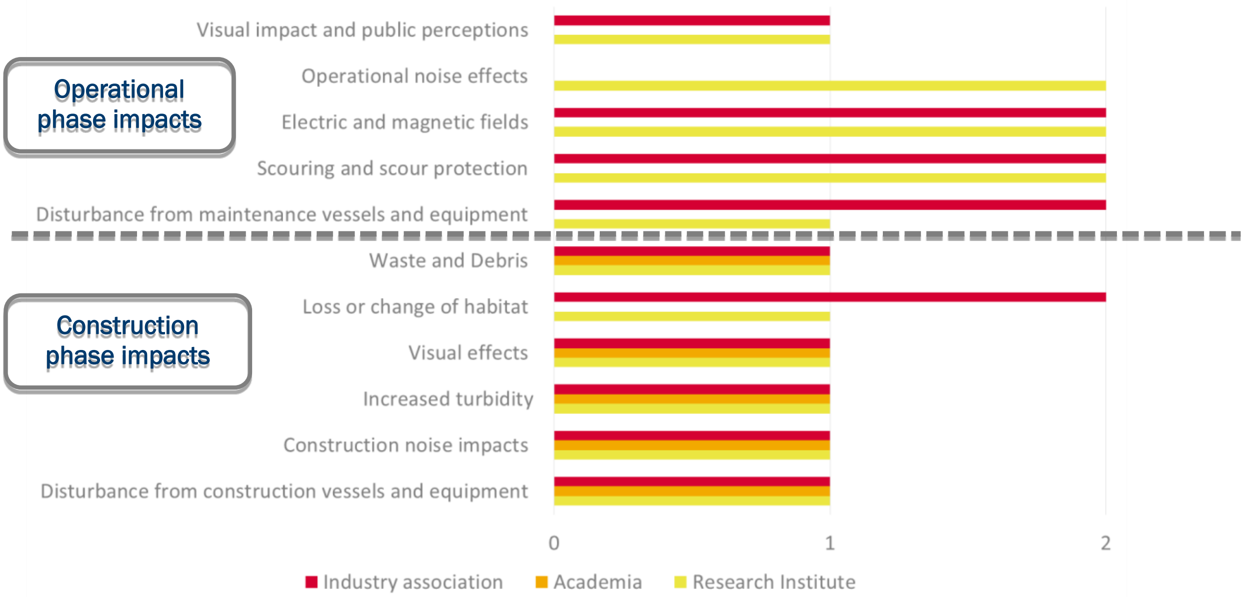
Figure 20 PROBABILITY - environmental impacts of cable laying, burial and trenching



DURATION analysis:

Figure 21 below shows that the environmental impacts occurring in the construction phase are temporary while the operational ones are almost all rated as permanent, as is the case of the previous innovations.

Figure 21 DURATION - environmental impacts of cable laying, burial and trenching



2.6 Conclusions

After applying the OSPAR environmental impacts defined in the guidelines for construction and operation of offshore wind farms to the LEANWIND innovations, we arrived at the conclusion that only a few of the interactions analysed are likely to involve impacts of such magnitude, significance/importance, probability and duration in order to deserve a comprehensive treatment in this study.

Concerning **the magnitude** and **significance** degree of impacts, we observe a different environmental performance from one type of foundation to another. The data shows for instance that the magnitude of the loss or change of habitat is negative in the case of the buoyant GBF.The explanation is that despite the innovative way of assembling the foundation (floating dock) and of transporting it to the installation site (floating) the foundation would have similar environmental impacts concerning the seabed, it will still require seabed preparation and would occupy the seabed.

The installation phase would instead have a smaller carbon footprint when compared to traditional transport (i.e. group transport in large barges or pontoons) because less fuel for transportation will be consumed in this phase. We can therefore assume that the environmental impacts of the buoyant GBF once in place would be the same as for any other project where this type of foundation is employed. The most common environmental impacts associated with the installation of GBFs are: the physical seabed footprint, meaning the exact space occupied by the foundation, the direct loss of seabed habitat and benthos[14], changes in the sediment flow, change in habitat from soft habitat to hard substratum habitat. It should be noted that all types of foundations have an environmental impact but recovery from these effects is expected within the lifespan of the windfarm project[15].

On the contrary, in the case of thesemi-submersible platform, the substructure would not sit on the seabed; it will instead float and would eliminate the need for seabed preparation.Therefore, when comparing how the semi-submersible platform scores on habitat loss or change compared with a GBF we can observe that it rates better (1.6 as impact magnitude versus 2.8 for the GBF). An important aspect of this environmental assessment of LEANWIND project innovations is that it would need to be matched also with the economic feasibility of these innovations to make it to the market. For example, we know that today only 0.02% of the installed foundations are floating concepts and that the most commonlyinstalled substructures in European waters are monopoles. The foundation choice is based on a series of factors amongst which water depths, seabed conditions and other variables[16].

The high majority of impacts discussed in the section above have a **probability**of happeningof **more than 50%or are certain,** i.e. all the construction noise impacts or the disturbance occurring in the installation and operational phase. Nonetheless, the significance criteriashowsthat their geographical extent is project specific in most cases. We have also learnt from this analysis that most of the impacts that have a negative moderate effect on the environment occur in the construction phase, which means the **duration** of the impacts is**temporary**.

From the data analysis performed above, we can focus discussion on the recurrent environmental impacts that have a negative or positive magnitude equal or higher than 2. Section 3 will present an overview of each of the following impacts: disturbance from construction vessels and O&M vessels, construction noise, loss or change of habitat, scouring and scour protection and the electromagnetic fields. This description encompasses the following aspects (where applicable): state of the art of the impact, existing mitigation techniques, and examples of best practice and/or collaborative industry projects.

3. State of the art assessment of the most significant impacts of the LEANWIND project innovations

3.1 Disturbance from construction vessels and equipment

According to OSPAR, the movements of vehicles, vessels, machinery and personnel during the construction of offshore wind farms could have a disturbing effect on the local environment (e.g. wintering/roosting, moulting and foraging birds; marine mammals). If the level of disturbance is likely to have a significant effect on birds or marine mammals,

[14] The flora and fauna found on the bottom, or in the bottom sediments, of a sea or lake.
[15] Ian Reach, M. L., "Selected Marine Environmental Consideration Associated with Gravity Based Foundations for UK Round 3", 2013
[16]WindEurope, "Annual offshore statistics", 2016

the regulating authorities may impose management rules for scheduling the timing and routes to avoid sensitive locations and times[17].

According to the Non-technical Environmental Summary of the Walney Extension Wind Farm[18], the disturbance from the construction or decommissioning phasefor this specific project include localised seabed scarring as well as jack-up vessels indentation marks on the seabed. Another impact may include disturbance of marine fauna, these impacts being very project-and species-specific. It is important to note that they are usually short-term, temporary effects and in many cases the vessels movements are unlikely to impact upon the individuals or populations.Similarly, the noise associated with vessel traffic is considered negligible. Disturbance from the operational and maintenance vessels, whilst permanent is considered to have a lower intensity than the construction vessel activity[19].

Table 4 Disturbance from construction vessels and equipment

Stakeholder	Cylindrical Caisson buoyant GBF	Design of a floated to site jacket	Suction buckets with a floated to site jacket	Innovative semi-sub platform	Cable laying, burial and trenching
Developer 1	-3	-2	-3	-2	n/a
Developer 2	-3	-3	-3	-3	n/a
Developer 3	n/a	n/a	n/a	-2	n/a
Research Institute	n/a	n/a	n/a	n/a	-2
Academia	-3	-3	-2	-2	-2
Industry association	-2	-2	-3	-3	-2
Average score	**-2.8**	**-2.5**	**-2.8**	**-2.4**	**-2.0**

In table 4 above, the first row lists the LEANWIND innovations analysed through the survey (presented in Sections 1 and 2 above), with the magnitude ratings of each respondent and the average score of all. The GBF and the use of suction buckets have the highest score of -2.8, which isalmost a moderate negative impact. The floating jacket and the semisubmersible platform are in the same range, with a score of -2.5 and -2.4 respectively.

In the case of these innovations, both the GBF and the jacket are floated to the installation site eliminating the need for using an installation vessel, such as a jack-up. This has a beneficial effect on the local environment, as it will result in less disturbance on the marine fauna and seabed, especially if we were to compare them with a regular GBF and a jacket foundation. The most common mitigation used is the careful routing of construction

[17]WindEurope, "The European offshore wind industry – key trends and statistics 2016", 2017

[18]https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010027/EN010027-000410-10.3%20Non-Technical%20Summary.pdf

[19] DONG Energy, "Burbo Bank Environmental Statement, Non-technical summary", 2013. DONG Energy, "London Array Offshore Wind Farm Environmental", 2005

vessels to minimise disturbance, particularly in relation to moulting seabirds, which can form floating rafts[20].

3.2 Construction noise

According to OSPAR, many of the human activities such asoffshore construction, sand and gravel extraction, drilling, shipping, marine piling, use of sonar, underwater explosions, seismic surveys or deterrent devices generate sound thatcontributes to the general background level of noise in the sea[21]. The noise created during the construction of offshore windfarms occurs mainly from pile driving operations necessary for foundation installation (i.e. monopoles and jackets). These offshore wind operations may have an impact on the local environment and its associated fauna.

All over Europe offshore wind farm developers mitigate the impacts that may result from pile driving during the installation of offshore wind substructures through implementation of the soft start procedure, employment of trained marine mammal observers and of acoustic monitoring devices as well as through the use of pingers and seal scarers. Moreover, activities are scheduled to avoid sensitive times for example for fish spawning or seal pupping. Other more complex mitigation techniques are applied if judged necessary by the regulating authorities.

The impact of underwater noise on marine mammals has been analysed in several studies[22].It is a complex science that examines the behaviour of marine mammals, fish and invertebrates when exposed to different sound levels. It is not in the scope of this report to enter into a detailed analysis of these effects.

As shown in Section 2 of this report, the LEANWIND innovations referring to substructures such as the buoyant GBF developed by ACCIONA, the suction bucket jacket designed by EDF and the semi-submersible platform developed by Iberdrola reduce or eliminate the use of pile driving during installation. Thus eliminating a significant source of noise pollution in the marine environment.

Table 5 Construction noise

Stakeholder	Cylindrical Caisson buoyant GBF	Design of a floated to site jacket	Suction buckets with a floated to site jacket	Innovative semi-sub platform	Cable laying, burial and trenching
Developer 1	-2	-2	-2	-1	n/a
Developer 2	-1	-3	-1	-2	n/a
Developer 3	n/a	n/a	n/a	-1	n/a
Research Institute	n/a	n/a	n/a	n/a	-4
Academia	-1	-3	-2	-1	-1

[20] Humber Gateway Offshore Wind Farm, “Non-Technical Summary of the Offshore Environmental Statement and Onshore Cable Route Environmental Statement”, 2009
[21] OSPAR inventory of measures to mitigate the emission and environmental impact of underwater noise, 2014. OSPAR, “MSFD Advice Manual and Background document on Good environmental status, Descriptor 11: Underwater noise (A living document Version 11 April 2011)”, 2012. OSPAR, “Assessment of the environmental impact of underwater noise”, 2009
[22] M. J. Brandt, A. Dragon, A. Diederichs, et al. Effects of offshore pile driving on harbour porpoise abundance in the German Bight, 2016

Industry association	-1	-2	-2	-1	-2
Average score	**-1.3**	**-2.5**	**-1.8**	**-1.2**	**-2.3**

3.3 Loss or change of habitat

According to OSPAR,consideration should be given to foundation design and scour protection that either enhance or maintain marine habitats depending on national management objectives. Where possible, the construction should be designed and planned to reduce the footprint of disturbance on the seabed, e.g. only install scour protection if the structural integrity of the foundations is at risk[23].

As mentioned already in Section 2 of this report there are a number of wind farm related activities that have the potential to cause impacts to benthic communities during the construction, operation and decommissioning phases of aproject.

According to a study financed by the German Federal Minister for Environment, Nature Conservation, Building and Nuclear Safety[24], direct effects on organisms include physical disturbance, damage, displacement and removal. Effects on the marine environment include all changes in biotope[25] characteristics. These include changes tocurrent and wave regimes, disturbance of the seabed and habitat destruction. None of these changes is reported to affect the marine environment on a large scale.

Physical disturbance and damage to benthic organisms is widely discussed in the scientific literature. Contradictory results are presented regarding the effects on benthic communities due to disturbance, but based on the results of the majority of studies changes in zoobenthic species composition, abundance or biomass are very likely to occur. Species regarded as sensitive to disturbance include the sea urchin. Other species are considered to possess either high mechanical resistance, high mobility or a high potential for regeneration, which enable them to tolerate disturbance. Recovery of disturbed communities is expected to take several years.

These impacts are very project specific. An example of mitigation arethe preconstruction surveys at the Humber Gateway Offshore Wind Farm, which identified key sensitive areas for subtidal habitats so that they could be avoided during construction. As such, only minor significant impacts occurred. In some cases there may be a net environmental benefit to the local ecosystem because the turbine structures will attract species and increase diversity[26].

Table 6 Loss or change of habitat

Stakeholder	Cylindrical Caisson buoyant GBF	Design of a floated to site jacket	Suction buckets with a floated to site jacket	Innovative semi-sub platform	Cable laying, burial and trenching
Developer 1	-2	-2	-3	-1	n/a
Developer 2	-4	-4	-4	-2	n/a

[23] OSPAR, Guidance on Environmental Considerations for Offshore Wind Farm Development, 2008
[24] https://www.bfn.de/fileadmin/MDB/documents/themen/meeresundkuestenschutz/downloads/Forschungsberichte/Ecological_Research_Offshore-Wind_Part_B_Skripten_186.pdf
25 The region of a habitat associated with a particular ecological community.
[26] Humber Gateway Offshore Wind Farm, "Non-Technical Summary of the Offshore Environmental Statement and Onshore Cable Route Environmental Statement", 2009

Developer 3	n/a	n/a	n/a	-2	n/a
Research Institute	n/a	n/a	n/a	n/a	-4
Academia	-2	-2	-2	-1	-1
Industry association	-3	-2	-3	-2	-3
Average score	-2.8	-2.5	-3.0	-1.6	-2.7

Table 6 above shows that all types of foundations have on average a moderate negative impact on the environment in the opinion of those surveyed. An exception to this is the innovative semi-submersible platform, which has a negligible to slight impact because it does not sit on the seabed compared to the GBF or the suction buckets used with the jacket.

3.4 Scouring and scour protection

Following construction there is the potential for scour to occur around the foundation structures. Scouring can have an impact on the physical processes and on the marine ecology. The scoured areas and foundations are expected to be readily colonised by species from adjacent areas and may cause a localised increase in biodiversity providing feeding opportunities and refuge habitats for a range of species.

In all offshore wind energyprojects, it is assessed whether the foundations affect the geology, bathymetry and seabed features and where necessary scourcan be mitigated by the use of scour protection. Usually the scour protection (materials placed on/in the seabed) will create new habitats potentially creating artificial reefs and increasing habitat diversity.

An assessment conducted as part of the consent application process of the Dudgeon Offshore Wind Farm looked at the impactthat the wind farm and export cable route would have on the local waves, currents, sediment distribution, sediment transport regime and features of the seabed. Dudgeon will have some localised impact in the immediate vicinity of the wind farm site, but will not have any significant impact further away from the site. There is potential for localised scour around the base of each foundation structure, although the detailed design of the foundations will take this into account. Changes due to the presence of the offshore structures are considered to be less than those due to the natural variation in both the seabed and shoreline and as such the potential impacts are considered negligible[27].

Table 7 Scouring and scour protection

Stakeholder	Cylindrical Caisson buoyant GBF	Design of a floated to site jacket	Suction buckets with a floated to site jacket	Innovative semi-sub platform	Cable laying, burial and trenching
Developer 1	-3	-2	-2	-1	n/a
Developer 2	-4	-4	-4	-4	n/a

[27] Warwick Energy, "Dudgeon offshore wind farm environmental STATEMENT Non-Technical Summary", 2009

Developer 3	n/a	n/a	n/a	-1	n/a
Research Institute	n/a	n/a	n/a	n/a	-2
Academia	-3	-2	-1	n/a	n/a
Industry association	-3	-2	-3	-1	-2
Average score	-3.3	-2.5	-2.5	-1.8	-2.0

Table 7 aboveshows the LEANWIND innovations and the related impact they have on scouring. In decreasing order of impact,they are: the cylindrical caisson buoyant GBF; the floating jacket and the use of suction buckets with the jacket;cable laying, burial and trenching; and the innovative semi-submersible platform.

3.5 Electromagnetic fields (EMF)resultingfrom cable installation

According to OSPAR the electromagnetic field (EMF) associated with offshore wind farm power cables may affect some species of fish. Research into these effects is ongoing and current mitigation measures include appropriate choice of cable types, separation and burial depths[28].

The transport of electricity through an export and inter-array power cable has the potential to emit a localised EMF, which could potentially affect the sensory mechanisms of some species of marine fauna. The degree of impact and the subsequent effect on marine communities was investigated by the Centre for Marine and Coastal studies and Cranfield University, UK, in 2003, 2005 and 2009, funded by theCollaborative Offshore Wind Research into the Environment (COWRIE). These EMF components were both within the range of detection by EM-sensitive aquatic species, such as sharks and rays[29].

Table 8 Electromagnetic fields

Stakeholder	Cylindrical Caisson buoyant GBF	Design of a floated to site jacket	Suction buckets with a floated to site jacket	Innovative semi-sub platform	Cable laying, burial and trenching
Developer 1	-2	-2	-2	-2	n/a
Developer 2	n/a	n/a	n/a	n/a	n/a
Developer 3	n/a	n/a	n/a	n/a	n/a
Research Institute	n/a	n/a	n/a	n/a	-4
Academia	-2	-2	-2	n/a	n/a
Industry association	-2	-2	-3	-2	-3
Average score	-2	-2	-2.3	-2.0	-3.5

The main sources of EMF result from a series of activities associated with the installation, O&M and decommissioning of subsea cables, namely the excavation of cable trenches in

[28] OSPAR, Guidance on Environmental Considerations for Offshore Wind Farm Development, 2008
[29] NIRAS, RGI Workshop, “Overview of the issues surrounding the environmental impacts of subsea cables”, 2015

areas with hard sea bottom, ploughing of cable trenches, cable layout, jetting, back-filling of cable trenches, protection of cables, post construction surveys and cable repair. Those may have a local and project specific impact[30].

The most common environmental impacts associated with the above-mentionedoffshore activities are the disturbance of sensitive species and habitats, seabed disturbance and the increase in turbidity. Other impacts include also thermal radiation or localised electromagnetic fields.

These impacts must be considered and analysed in the context of other influencing factors. Natural perturbations such as storm activity can have a significant effect on the structure and functioning of the seabed, as can other activities such as oil and gas exploration and infrastructure, telecommunication cable installations, certain fishing activities, aggregate extraction, and other sources of change to the physical environment. In many cases, such influencing factors may lead to related environmental impacts of greater extent, duration and significance than those observed or suspected to result from the installation of offshore wind farm cable infrastructure[31].

A study published by the UK Department for Business, Enterprise and Regulatory Reform(2008) entitled: "Review of Cabling Techniques and Environmental Effects Applicable to the Offshore Wind Farm Industry – Technical Report"[32] concluded that although cabling can cover large areas of seabed, the associated environmental impacts are highly transitory, localised in extent and temporary in duration. Although the corridor for cable installation impacts can be long, the footprint of impact is narrow, generally restricted to 2-3m width. For the majority of installation scenarios, the seabed and associated fauna and flora would be expected to return to a state similar to the pre-disturbance conditions. Exceptions could occur in hard clays and rock seabed types, where the cable trench would not naturally backfill, requiring intervention to backfill as part of construction works or else leaving permanent scarring of the seabed.

The same report gives examples of good practice measures and mitigation that could be adopted to reduce potential disturbance of cabling activities on intertidal and subtidal habitats, marine mammals, birds, fish and shellfish. They include:

- Early dialogue with the appropriate regulatory and advisory authorities;
- Sensitive timing and routing of cable installation to avoid important feeding, breeding/spawning and nursery areas and seal haul out areas especially during sensitive periods (breeding season);
- Avoidance of areas of sensitive habitat such as biogenic reef;
- Sensitive timing and routing of maintenance vessels to reduce number of trips;
- For marine mammals and birds: preparation of on-site protocol in sensitive locations as well as briefing of cable installation contractor personnel for on-site procedures and protocol; and
- Monitoring effects using a Before-After-Control-Impact (BACI) study.

4. Social acceptance and socio economic benefits of offshore wind farms

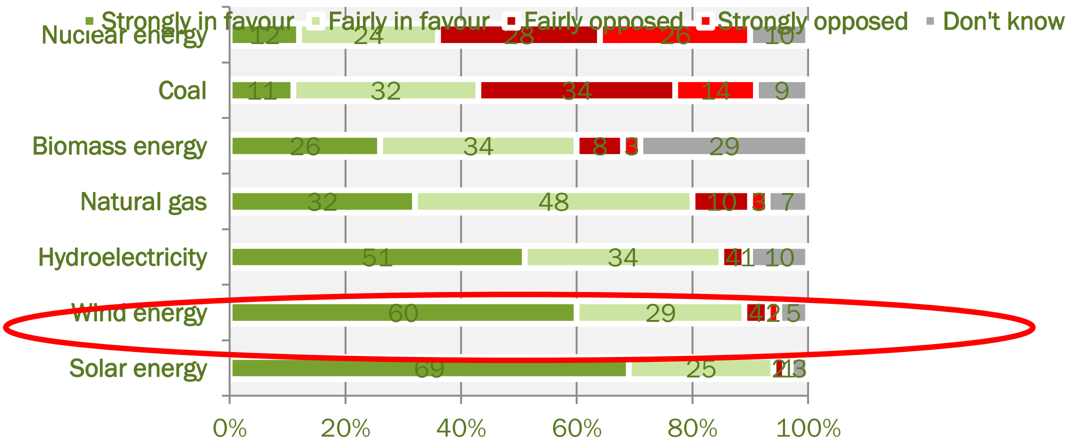
[30] NIRAS, RGI Workshop, "Overview of the issues surrounding the environmental impacts of subsea cables", 2015
[31] BERR – Department for Business Enterprise and Regulatory Reform, UK, "Review of cabling techniques and environmental effects applicable to the offshore wind farm industry", 2008
[32] Ibid.

4.1 Social acceptance

Social acceptance is multi-faceted and has aspects related tothe market, politics and community. Understanding social acceptance requires consideration of all three aspects, howeverpublic dialogue tends to focus on the community. Environmental and societal issues have become pivotal to the deployment of wind energy in many countries. Even where the economics of wind energy are favourable, deployment can only occur when the public and the planning authorities accept the technology. Community acceptance, engagement and participation in wind energy projects, both onshore and offshore, remain a key priority for all stakeholders involved in windfarm development[33].

WindEurope was the leading coordinator of WISE Power, an EU funded project that looked at how to improve local engagement and support for wind turbines, while enhancing local community participation in the planning, construction and operational phases of wind energy projects. Although the project was mainly focused on onshore wind, we believe an important number of recommendations with regard to information and engagement can also apply to offshore wind farms. Therefore, the objective of this chapter is to explore synergies between how community engagement and local participation is approached in offshore wind farm development.

Figure 22To what extent are you in favour or opposed to the use of the following energy sources?

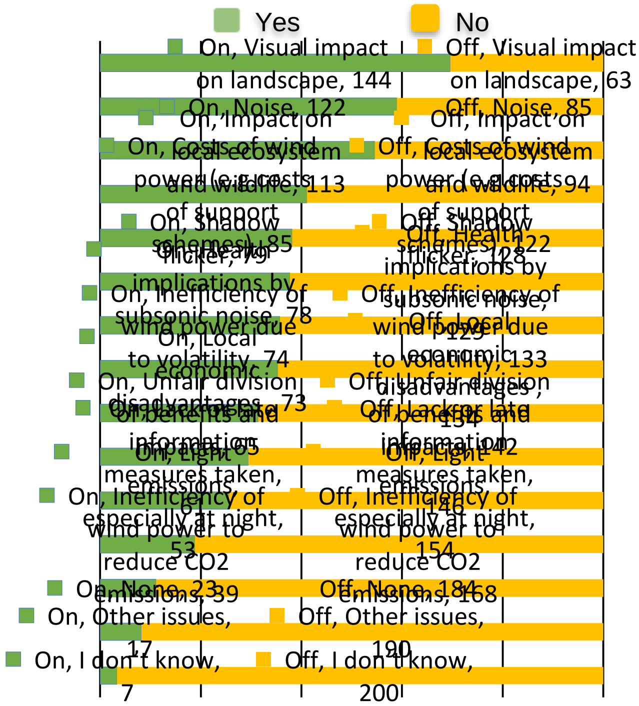


Source: European Commission Special Eurobarometer 364, 2011: Public Awareness and Acceptance of CO2 capture and storage

Wind energyis today a mainstream and competitive solution for achieving renewable energy targets and for decarbonising the economy. A European Commission 2011 survey on public awareness and acceptance of different energy technologies showed that 89% of the respondents were strongly in favour or fairly in favour of wind energy (see figure 22 above).

[33] Lantz Eric. (2015). Social Acceptance of Wind: a brief overview.

Figure 23 Negative issues raised by communities in relation to wind energyproject



Source: Stakeholders survey results, Fraunhofer ISI, WISEPower – March 2015

However, when it comes to individual developments, issues such as visual impact, noise, impact on marine life and overlapping interests with other sectors (i.e. fisheries) are often quoted as reasons for communities to oppose wind energydevelopments. Figure 23 above shows that the visual impact is considered one of the most important negative features which raises frequent opposition by members of the public.

According to a study conducted by the **Royal Belgian Institute of Natural Sciences**, expectednegative impacts on the marine environment also affect the social acceptance of offshore wind farm developments[34]. The social acceptance of offshore wind farms in Belgian waters was investigated through questionnaires in 2002 and 2009, i.e. prior to and after the first offshore wind turbines had been constructed there in 2008. The research demonstrated an increasing positive attitude towards offshore wind farms with 68% in support of the initiatives in 2009 versus 53% in 2002, and only 8% opponents in 2009 versus 21% in 2002. More than 90% of the 2009 respondents considered wind energy to be a good alternative to non-renewable energy sources. In Belgium, offshore wind farm siting is socially and environmentally more acceptable than onshore wind farms, even when the seascape is taken into account. Interestingly, beinginformed about theenvironmental impacts of offshore wind farms was valued highest by the public.

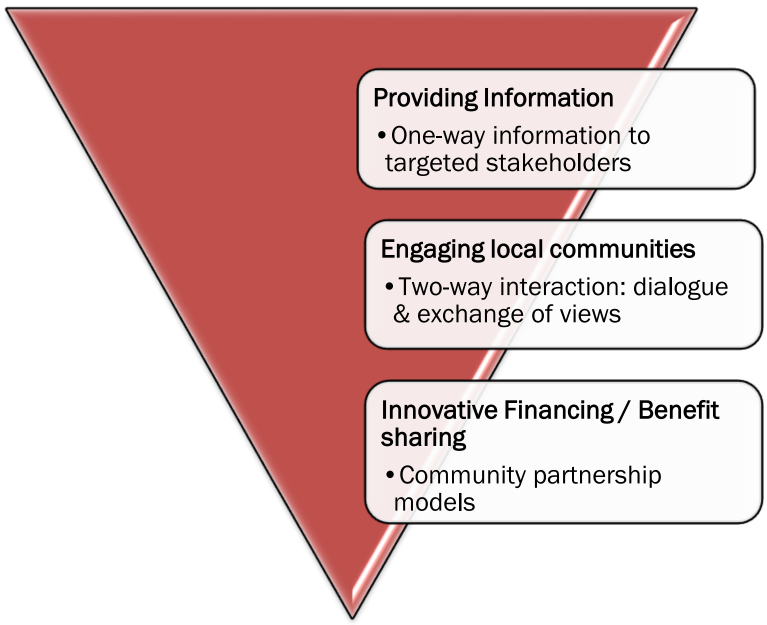
Project developers have comprehensive stakeholder engagement strategies in place in order to enhance acceptance and engage communities. These strategies identify all

[34]http://odnature.naturalsciences.be/downloads/mumm/windfarms/winmon_report_2016.pdf

relevant stakeholder groups and the specific points in the project life cycles when it is appropriate to scale up engagement with each group. This implies that the strategies put in place by project developers are tailored to specific projects and community needs.

In summer 2015 Local Energy Scotland produced a 'Good Practice Guide for Community Benefits for Offshore Renewable Energy'[35]. The guide outlines the key principles of designing and providing a community benefit package. These benefits are currently offered by project developers on a voluntary basis in Scotland and the UK. Among the benefits the following are considered as being essential when considering community benefits: scale of the project; distance of the project from shore; nature of the project (i.e. commercial development, research or trial site); and very importantly the correct identification of the beneficiary community. Figure 24 below shows the 3 core pillars of a successful stakeholder engagement strategy.

Figure 24 The 3 pillars of social acceptance (WISE Powerproject)



– **Providing information** is often seen as a prerequisite of social acceptance and community engagement strategies, but may not be sufficient to gain full community acceptance. As a good practice example in several Member States it is compulsory for project developers to publish all project documentation from application documents to environmental statements;

– **Engaging local communities** by organisingopen wind farm days, stakeholder workshops, mobile exhibitionsetc.;

– **Community ownership** is another very proactive form of engagement offered by project developers. In Denmark it is stipulated in national legislation that at least 20% of the ownership of a nearshore offshore wind farm should be offered to local communities and adjacent municipalities. In Germany, municipal utility ownership of and citizen participation in offshore wind projects is possible. Similarly, in The Netherlands, the developer of theWestermeerwind offshore wind farmallows for community buy-in.

[35] Scottish Government. "Good practice principles for Community benefits from Offshore Renewable Energy Developments", 2015

4.2 Socio economic benefits (community benefits)

Introduction

Wind energy is a reliable and affordable energy source, which benefits European electricity consumers. It already provides for decarbonisation while contributing to economic growth in many countries, proving that it will continue to be a leading solution against climate change globally.

The build-out of offshore wind farms brings a series of benefits (non-exhaustive list):

- environmental benefits, by avoiding the production of CO2 emissions or the extensive use of water in the operational phase;
- enhancement of the energy security, by avoiding the use of fossil fuels and thus decrease import dependency;
- socio-economic benefits, by providing local employment and local growth; and
- community benefits, where project developers put in place benefit-sharing mechanisms in order to engage stakeholders in the developing process of the offshore wind farms.

Community benefits – good practice examples

This section offers good practice examples in terms of stakeholder engagement and describes the associated socio-economic and community benefits at specific offshore windenergy projects.

The socioeconomic benefits of wind energyhave an increasingly important role to play at local level, being an increasingly significant source of revenue that can revitalise local economies. A good example is the case of the**Walney offshore wind farm**, approximately 15km off the Coast of Walney Island, UK. The wind farm consists of WalneyI and WalneyII each comprising 51 wind turbines with a total capacity of 367 MW. The farm brings thefollowing advantages to the surrounding communities:

- Approximately £1 million per month contributed to the local economy during the construction of Walney I and II, comprised of salaries, local contracts, accommodation and services;
- 5,697 people worked on Walney I and II during theirconstruction and it is estimated that for the Walney Extension Project, the project developer could createup to 185 full-time jobs annually throughout the estimated 25-year operational lifespan of the wind farm.

In the case of the **Walney Extension**,the developer has committed to a Community Benefit Fund[36] worth up to £660,000 peryear.GrantScape[37] has been appointed by the project developer to undertake a consultation exercise to gather views from local people on how this money for the community should be allocated.

[36] According to DECC, UK a community fund is a voluntary monetary payments from an onshore wind developer to the community, usually provided via an annual cash sum.
[37]GrantScape is a charity specialised in grant management, providing grant-making solutions in the delivery of top quality, cost-effective grant programmes

The Walney Extension offshore wind farm,located in the Irish Sea approximately 19 kilometres off the coast of Cumbria,is currently in the construction phase. This project will have a generation capacity of 659 MW and is expected to be fully commissioned in 2018, at which time it will be the biggest offshore wind farm in the world. The project will produce enough power for 460,000 UK homes a year[38].

Another example of socio- economic benefit for the communities located in the vicinity of offshore wind farms is the **West of Duddon Sands offshore wind farm**, UK, which was officially inaugurated in autumn 2014 after construction finished ahead of schedule[39]. It comprises 108 turbines with a total capacity of 389MW, providing power for over 270,000homes a year. A total of 1,000 peoplewerefully employed during the 2 years of construction. 35 people are employed by the project developerfor operation and maintenance services.

Besides the local employment created, one of the biggest benefits for the community was the construction of theoffshore wind farm terminal at Belfast Harbour, worth £50m.The terminal is the first purpose-built offshore wind installation and pre-assembly harbour in the UK and Ireland, and has createdup to 300 permanent jobs. The size and scale of the harbour allows for continual delivery of turbine components and round-the-clock operations[40].

The third example of socio-economic benefits generated for the local communities is the **London Array offshore wind farm**, UK. London Array is the largest operational offshore wind farm in the world, comprising 175wind turbines of 3.6MW of capacity each. Its total capacity of630 MW can deliver sufficient electricity to meet the needs of nearly half a million UK homes a year.

An £850,000 community benefit fund was established when the onshore substation was built,and thispaid for the following community projects:

- £200,000 for nature conservation, donated to and handled by Kent Wildlife Trust;
- £300,000 for community benefits, donated to and handled by the specially establishedGraveney and Goodnestone Trust;
- A new car park and road crossing for Graveney Primary School;
- £2,000 a year each for three local schools to spend on extra-curricular activities (with a linkto sustainability, environment, engineering etc.); and
- A 10-year university bursary scheme to help fund one local student a year through university.

4.3 Stakeholder engagement strategy - recommendations

Engaging local communities

Early and thorough engagement with local communities should be a first step inassessing the needs and concerns of communities, discussing appropriate and desired benefit models, and determining potential beneficiary communities. Local authorities can play a useful rolein linking the needs of communities with the project developers in discussing potential benefits[41].

Shorter and smoother administrative procedures through local community engagement

[38] DONG Energy, "Walney Extension – Community Benefits", 2015
[39] DONG Energy, "West of Duddon Sands Offshore Wind Fram", 2015
[40] DONG Energy, "West of Duddon Sands Offshore Wind Fram", 2015
[41] David Rudolph, Claire Haggett, Mhairi Aitken, "Community Benefits from Offshore Renewables: Good Practice Review, Climate Exchange, University of Edinburgh, 2015

According to the main findings of the WISEPower project, acceptance of offshore wind energyprojects by local communities could, in theory, contribute to faster permitting procedures and thereby a faster and wider deployment of wind energyacross Europe. The best practice for encouraging community acceptance of wind farms is for relevant groups to be regularly and openly informed, engaged and consulted. To date it is considered challenging to establish a quantitative correlation between the numbers of wind energy projects consented relative to the proactive engagement ofcommunities. Nonetheless, from interviews with specialists there is indication of a potential positive correlation at least in the case of onshore wind energy projects.

Explore the possibility of a potential financial partnership

Developers and transmission system operators may wish to consider how to provide information to communities, how to facilitate engagement and dialogue, and how to explore the potential for a financial partnership with a community organisation. Co-ownership of offshore wind energy projects bycoastal communities, co-operatives or non-local energy utilities remains rare.

Currently, there is insufficient information to allow a thorough assessment of how to involve communities as financial partners in offshore wind energy projects. It may also be that this is less feasible in offshore as compared to onshore wind energy projects due to the high investment needsin these large,capital-intensive projects.

5. Life-cycle analysis of LEANWIND foundations

5.1 Introduction

This section describes the findings of an analysis of the environmental impacts during the lifecycle of the innovative steel foundations that have been developed for the LEANWIND project. The first of these is the floating jacket foundation, which is similar to a conventional jacket foundation but can be towed to site before sinking, and instead of piles it is fixed to the seabed with suction buckets. The second is a floating foundation that is towed to site and moored. It can also easily be towed back to shore for maintenance. The third is a gravity base foundation that is also designed to float for transport to site before sinking for installation on the seabed (a more comprehensive description of the foundations types was provided in section 1.2).

The purpose of the analysis presented in this sectionis to use life-cycle analysis (LCA) to examine the environmental impacts of these new foundation designs over their full life cycle.This complements the analysis presented in Section 3 by concentrating on impacts that can be objectively quantified, allowing the performance of the three foundations to be compared to each other and to existing solutions. This analysis also allows the key areas that contribute to the environmental impacts to be identified such that they can be further refined in future design iterations and the environmental impacts minimised.

5.2 Life-cycle assessment

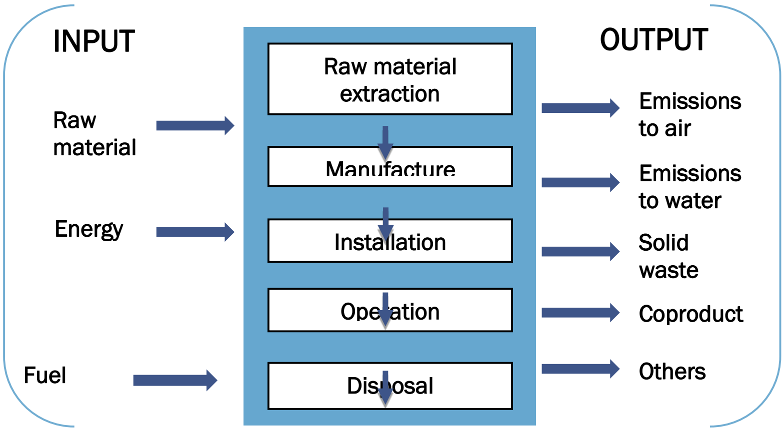
5.2.1 Overview

Life-cycle assessment (LCA) is a methodology for quantifying the environmental impacts of a product or service over its whole lifetime[42], from the extraction of raw materials, through transportation, manufacture and operation, to disposal of waste materials at the end-of-life, as illustrated in

Figure 25 below. The stages of the life cycle are considered interdependent, with one operation leading to the next, allowing the cumulative environmental impacts to be calculated. Thus LCA provides a complete view of the environmental aspects of the product or process.

Figure 25 Life cycle stages, resource use and pollutant emissions

[42] ISO, "BS EN ISO 14040 - Environmental management - Life cycle assessment - Principles and framework," British Standards Institute, 2006. ISO, "BS EN ISO 14044 - Environmental management - Life cycle assessment - Requirements and guidelines," British Standards Institute, 2006.



5.2.2 Standards and technical documentation

In the late 1990s, ISO (International Standards Organisation) created the Technical Committee TC207 to establish environmental standardisation tools and these generated the ISO 14040 series of standards that govern LCA. There are currently two key standards that apply the analysis presented here:

- ISO 14040 (2006) specifies the general framework, principles and basic needs for conducting a LCA study[43].
- ISO 14044 (2006) specifies the requirements and guidelines for Life-Cycle Assessment (LCA)[44].

Further technical documentation also applies:

- ISO/CD TR 14048 (2002) provides information regardingthe data used in a LCA study[45].
- ISO/TR 14049 (2012) provides examples of practices in carrying out a life-cycle inventory analysis (LCI) as a means of satisfying certainprovisions of ISO 14044:2006[46].
- ISO TR 14047 (2012) provides illustrative examples on how to apply ISO 14044 to impact assessment situations[47].

5.2.3 Analysis process and tools

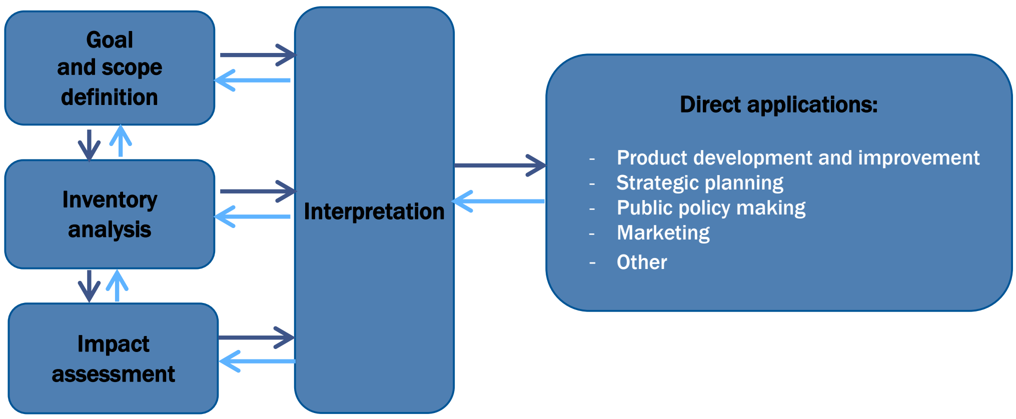
LCA involves four key stages (

[43] ISO, "BS EN ISO 14040 - Environmental management - Life cycle assessment - Principles and framework," British Standards Institute, 2006.
[44] ISO, "BS EN ISO 14044 - Environmental management - Life cycle assessment - Requirements and guidelines," British Standards Institute, 2006.
[45] ISO, "ISO/TS 14048 – Environmental management – Life cycle assessment – Data documentation format," International Organisation for Standardisation, 2002.
[46] ISO, "ISO/TR 14049 - Environmental management – Life cycle assessment – Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis," International Organisation for Standardisation, 2012.
[47] ISO, "ISO TR 14047 - Environmental management – Life cycle assessment – Illustrative examples on how to apply ISO 14044 to impact assessment situations," International Organisation for Standardisation, 2012.

Figure 26):

- Definition of the goal and scope, including a description of the product, process or activity being studied and establishing the context and boundaries of the evaluation;
- Creating an inventory of all raw materials, energy flows and pollutant emissions to the environment (life cycle inventory or LCI);
- Evaluating the possible environmental impacts associated with these inputs and outputs by classifying and characterising these resources and pollutants according to their human or ecological effects in terms of environmental impact factors (life cycle impact assessment or LCIA); and
- Interpreting the results to inform environmental decisions.

Figure 26 Life-cycle assessment framework[48]



When a number of different impact categories are being considered it is common to employ life-cycle assessment software. The two leading LCA software tools are GaBi and SimaPro. These have a number of life-cycle inventory databases built into them containing data on the cradle-to-gate, gate-to-gate or gate-to-grave resource use and pollutant emissions of a wide range of standard materials, processes and waste treatments. A number of standard impact assessment methods are also available, containing detailed characterisation factors for a wide range of resources and pollutants, sothat the environmental impacts can be calculated.

5.2.4 Advantages

The main advantage of LCA is that it allows the environmental impacts and sustainability of any innovative construction process to be evaluated and compared to conventional technologies. As the competition between companies of any sector in the economy gets

[48] OSPAR, Guidance on Environmental Considerations for Offshore Wind Farm Development, 2008

stronger, cost minimisation is becoming a necessity, not an option, and environmental costs (energy, materials and water use) play an important role from an accounting and business strategy point of view.

The real value of LCA is the articulation between life-cycle environmental criteria, company strategies and planning to achieve commercial benefits. LCA can provide a company with valuable internal information about the efficiency of the use of resources of a production system, waste management, etc. It can also help the company to gain competitive advantages through cost savings, increased profits and improved image (of the company or a particular product). It also brings knowledge about the negative aspects of a process/product, allowing the adoption of new, more environmentally sustainable techniques. Thus, this analysis provides the company with relevant knowledge about the stage of the LCA of a product/process that is most sensitive to modifications or improvements to increase the sustainability of the overall process. In addition, LCA tool bring the possibility of comparing the environmental impacts of different materials/systems used for the same purpose in order to determine the economic and environmental optimum.

In summary, LCA is an environmental and business management tool that provides the following competitive advantages:

- evaluation and reduction of potential risks;
- identification of 'hot spots' in the life cycle of a product;
- product comparison;
- evaluation and improvement of environmental programmes;
- prevention of pollution;
- development of market strategies;
- strategic planning; and
- development of policies and regulations.

5.2.5 Limitations

While LCA is a powerful tool, one of the challenges of comparing the results of different published studies is that inconsistencies can arise in the analysis methodology. The methodology is very broad and therefore there is significant scope for variation in results due to different choices made by the LCA practitioner. One key example of this is in the treatment of recycling of metals; even when considering a renewable energy converter, it is possible to double-count the benefit of recycling metal if the credit is allocated to that converter for both using recycled material in the initial manufacture, and also crediting the same device if the material is recycled at the end-of-life. Other discrepancies can arise from variations in the LCI databases, different characterisation factors, and in neglecting to include all components and processes in the life cycle of the device being studied.

One of the ways of avoiding these challenges is to conduct a comparative LCA study, where one person or team analyses several different devices, making the same assumptions, allowing the results to be compared. This has an additional benefit in that the results only need to be reported relative to each other, and therefore common parts of the LCA can be omitted (such as the wind turbine, when doing a comparative LCA of foundations). The analysis presented in this report, however, is not strictly a comparative LCA, as one of the three foundations was designed for a different sized wind turbine (although some attempt has been made to normalise for this), and two different software tools (GaBi and SimaPro) and different life-cycle inventory databases have been used. For these reasons, the analyses presented here are of three independent LCA studies of three different foundations.

Despite its limitations, LCA remains a valuable tool for estimating the environmental impacts of renewable energy converters, allowing designs to be refined to minimise these, and demonstrating how well they perform in comparison with other types of generation.

5.3 Goal and scope

The goal of this analysis is to provide information on the environmental impacts of the foundations that have been developed during the LEANWIND project. The studies focus solely on the foundations, and therefore do not include the turbine, cables, or any transition piece for mounting the turbine. Every stage of the foundation life cycle is considered: from materials extraction, through manufacture, assembly, installation and maintenance to decommissioning and disposal.

The case study under consideration is for installation at West Gabbard, off the UK coast. This has a depth of 33m (the GBF is designed for a depth of 40m, while the jacket is designed for a modified water depth of 60m, and the floating foundation 100m), and the seabed is shallow bedrock/medium dense sand. It is 30 km from shore and the nearest port is 100 km away. The design life of the foundations is expected to be 20 years and a conservative capacity factor of 40% has been selected to estimate the energy output of the turbines, corresponding to a lifetime energy output of 561 GWh for an 8MW turbine, and 350 GWh for a 5MW turbine. The results have all been normalised per unit of energy output in order to facilitate comparison with other published studies.

As the analysis was carried out by teams at both the University of Edinburgh and ACCIONA, two different sets of software, databases and impact assessment methods were used. The impacts of the two steel foundations were analysed with SimaPro v8.3 PhD software[49], with data mostly sourced from the Ecoinvent 3 database[50], the most commonly used database in Europe, except where otherwise stated. The results for these foundations are presented for the impacts characterised by the CML-IA baseline methodology, 2013[51], and the cumulative energy demand method[52]. The impacts of the GBF were analysed using GaBi 6 software[53], with the most reliable European databases (Ecoinvent, ELCD, GaBi Databases) updated in 2016[54]. Here the impacts arepresented in terms of in use of resources (materials and energy) as well as the impact categories included in the CML 2001 methodology[55], and the primary energy demand.

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[49] PRe Consultants, "SimaPro PhD v8.3," 2016.
[50] Ecoinvent, "Ecoinvent database v3.1," Swiss Centre for Life Cycle Inventories, 2014.
[51] CML - Department of Industrial Ecology, "CML-IA baseline methodology", Universiteit Leiden, http://www.cml.leiden.edu/software/data-cmlia.html, 2013
[52] [30] Pre Consultants, "SimaPro Database Manual - Methods Library", https://www.pre-sustainability.com/download/DatabaseManualMethods.pdf, 2016
[53] European Commission, "European Life Cycle Database (ELCD)", http://eplca.jrc.ec.europa.eu/ELCD3/
[54] Ecoinvent, "Ecoinvent database v3.1," Swiss Centre for Life Cycle Inventories, 2014. European Commission, "European Life Cycle Database (ELCD)", http://eplca.jrc.ec.europa.eu/ELCD3/. European Commission, "European Life Cycle Database (ELCD)", http://eplca.jrc.ec.europa.eu/ELCD3/
[55] Guinée et al., "CML 2001 methodology," Leiden University - Institute of Environmental Sciences, 2002

5.4 Analysis inputs for the steel foundations

5.4.1 Jacket life cycle

The life cycle of the LEANWIND jacket foundation is illustrated inFigure 27below, which shows the principal components, materials and processes. The main input was 1,230 tonnes of steel, as detailed in the report “Fixed Platform Design Framework”, with the surface area and lengths of welds and cuts estimated from the associated sketches. It is assumed that the foundation is constructed from steel sheet rolled and welded into pipes, with 8 cross-braces at the top and 8 cross-braces further down. The top third of the structure is assumed to be sandblasted and painted with marine-grade glass-flake paint, using the same analysis methodology detailed in[56], withthe remainder is protected by aluminium alloy sacrificial anodes, estimated from details in DNV-RP-B401[57]to be 37 tonnes. A total of 300 tonnes of concrete ballast (as detailed in Deliverable 2.3), and an estimated 5,000 tonnes of gravel for scour protection are also included.

It is assumed that the foundation is towed to site by a single large tugboat with a bollard pull of 40 tonnes. This may be a significant under- or over-estimate, as the installation requirements have yet to be detailed. An allowance is also made for one construction support vessel to travel to site for each foundation installation. A factor of 10% is added to all journey times to allow for delays due to weather or sea state - this could be further refined following outputs of other parts of the LEANWIND project. A side stone dumping vessel is used to install the scour protection. Details of the impacts of these sea vessels are given in Section 5.4.3.

It is assumed that routine maintenance of the foundation will take place alongside that of the turbine, so in order to estimate the impacts of maintaining the foundation alone, a single maintenance visit has been considered. It is assumed that this will be carried out with a construction support vessel. No allowance has been made for replacement of the sacrificial anodes, as they have been sized for the full lifetime of the foundations.

As no information is currently available on the decommissioning of this foundation, it is assumed that this will be achieved using the same processes as installation, although the scour protection will be left on the seabed.

It is assumed that 90% of all waste metals will be recycled, with the remaining waste going to landfill at the end-of-life. In order to avoid double-counting, the average world mix of recycled and virgin materials isused at the manufacturing stage and therefore no recycling credit is considered at the end-of-life; instead the recycled material appears only as an avoided impact as only 10% of the waste metals go to landfill.

Note that no allowance is made for transporting materials and components to the port,asno detailed information about a supply chain is available at this stage.

[56] R. C. Thomson, “Carbon and Energy Payback of Variable Renewable Generation,” School of Engineering, University of Edinburgh, Edinburgh, 2014.
[57] DNV, “DNV-RP-B401 Cathodic Protection Design,” Det Norske Veritas, 2010.

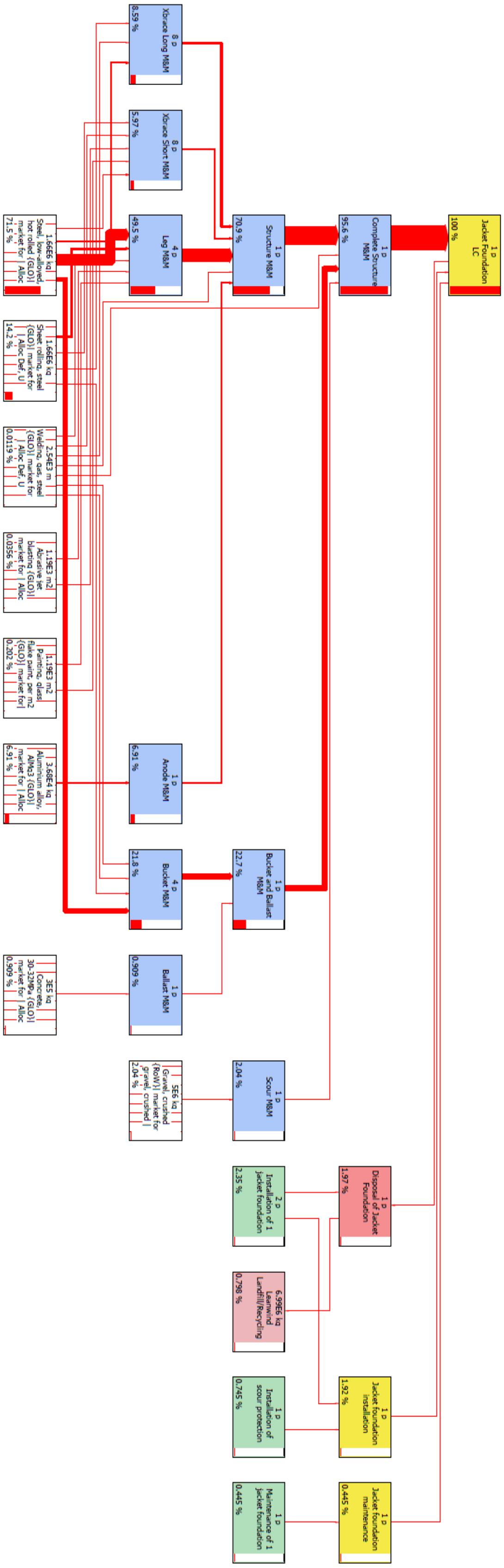


Figure 27 Life cycle of the jacket foundation showing climate change impacts

5.4.2 Floating foundation life cycle

The life cycle of the LEANWIND floating foundation is illustrated in Figure 28below. It comprises 1,700 tonnes of steel, which is assumed to be folded into sections, and sandblasted and painted as perthe jacket foundation. Estimates of surface area, cut lengths and lengths of weld were taken from information provided by LEANWIND partners. The ballast is seawater, so no impacts are considered. No allowance has been made for sacrificial anodes, as (unlike the jacket foundation) the whole structure is painted and it is assumed that this will be sufficient protection from corrosion.

The mooring system is a 3-catenary-line system, with the 895 m long lines formed from 60 mm diameter marine-grade steel chains (approximated by stainless steel, cut and welded into a chain). The anchors are taken to be 15 tonnes of steel, with no further processing considered.

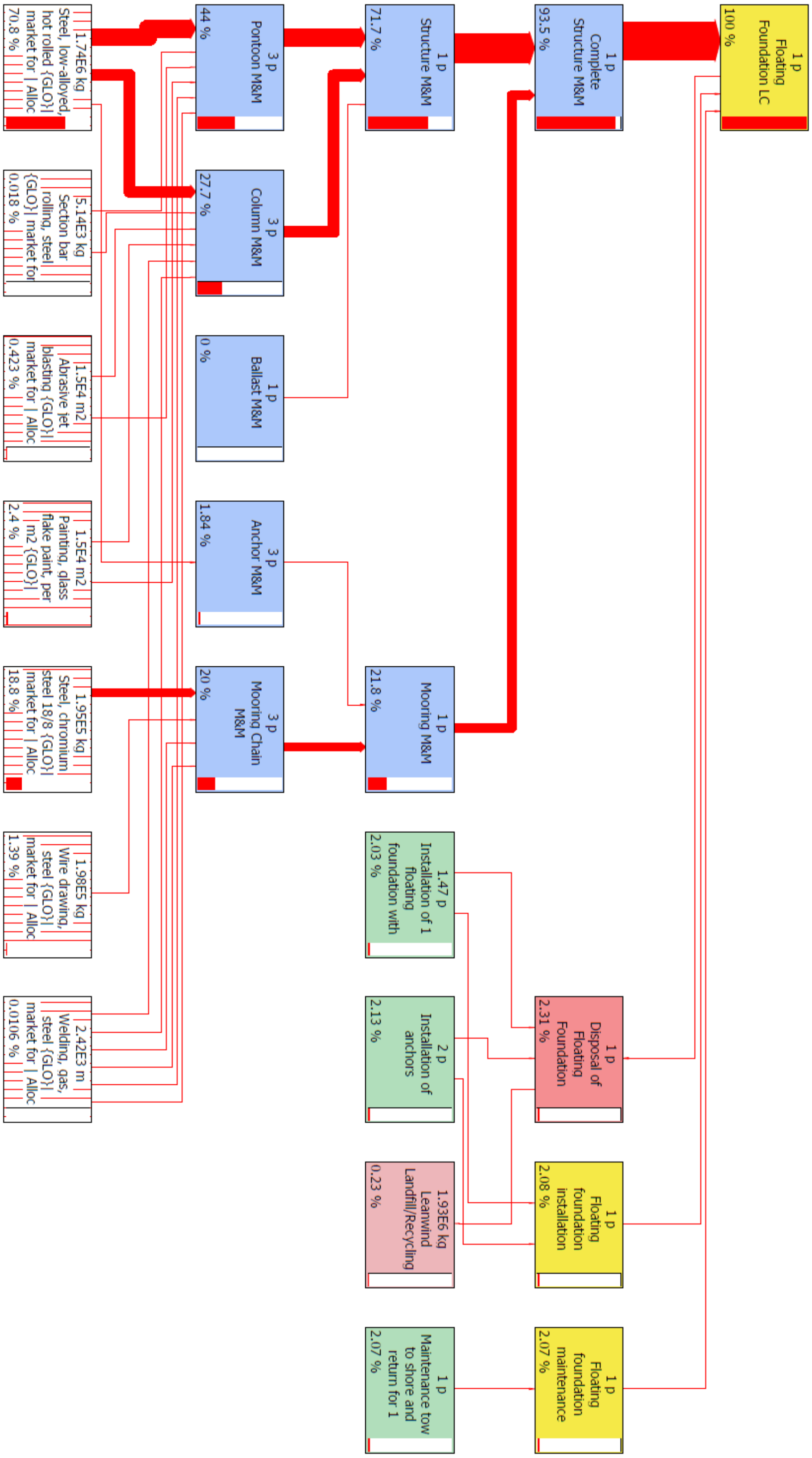
The foundation is transported to site with the turbine preinstalled, so it has been estimated that two large tugboats will be required. The impacts of this process have been allocated according to mass, with the NREL 5MW turbine being 697 tonnes. A further anchor handling tug support vessel is expected to be used to install the mooring system, which is estimated to take 9 hours.

As with the jacket foundation, maintenance is estimated to be equivalent to one maintenance trip in the lifetime of the foundation. The impacts of this have been approximated as one round trip from the wind farm to shore and back.

Decommissioning of the foundation is expected to be the same as installation, in reverse. As with the jacket foundation, 90% of the waste metal is expected to be recycled at the end-of-life, with the remainder of the waste materials going to landfill; however, no recycling credit is given at this stage due to the consideration of recycled materials during manufacture.

Again, a factor of 10% is added to all sea vessel journey times to allow for delays due to weather or sea state, and no other transportation has been considered.

Figure 28 Life cycle of the floating foundation showing climate change impacts



5.4.3 Sea vessels

The main life-cycle inventory databases do not contain detailed information on the resource use and emissions of operating small sea vessels for wind farm installation and maintenance activities. Therefore, considerable use was made of theDTOcean sea vessels database[58], and the impacts of sea vessels were approximated by adjusting those of a transoceanic freight ship for the fuel consumption of these vessels. The environmental impacts of the sea vessels that were used as inputs to the LCA of the steel foundations are summarised in Table 9.

Table 9Operational impacts of sea vessels for use in LCA study

Impact category	Unit	Large tugboat, towing	Large tugboat, transit	Side stone dumping vessel	Anchor handling tug support	Construction support vessel
Speed	m/s	2.5	5.6	6.68	5	5.68
Dumping rate	t/h			2,000		
Abiotic depletion	$\times 10^{-4}$ kg Sb eq/h	1.48	1.11	2.07	1.76	1.37
Abiotic depletion (fossil fuels)	$\times 10^{4}$ MJ/h	3.10	2.33	4.33	3.69	2.86
Global warming (GWP100a)	$\times 10^{3}$ kg CO_2eq/h	2.03	1.52	2.83	2.41	1.87
Ozone layer depletion (ODP)	$\times 10^{-4}$ kg CFC-11 eq/h	3.76	2.82	5.24	4.46	3.47
Human toxicity	kg 1,4-DB eq/h	619	465	864	736	571
Fresh water aquatic ecotoxicity	kg 1,4-DB eq/h	45.9	34.5	64.0	54.5	42.3
Marine aquatic ecotoxicity	$\times 10^{5}$ kg 1,4-DB eq/h	3.23	2.43	4.51	3.83	2.98
Terrestrial ecotoxicity	kg 1,4-DB eq/h	2.38	1.79	3.33	2.83	2.20
Photochemical oxidation	kg C_2H_4eq/h	1.59	1.20	2.22	1.89	1.47
Acidification	kg SO_2eq/h	50.4	37.9	70.4	59.9	46.5
Eutrophication	kg PO4--- eq/h	4.41	3.31	6.15	5.24	4.07
Cumulative Energy Demand	$\times 10^{4}$ MJ/h	3.13	2.35	4.37	3.72	2.89

5.5 Analysis inputs for the gravity base foundation

5.5.1 Life-cycle inventory

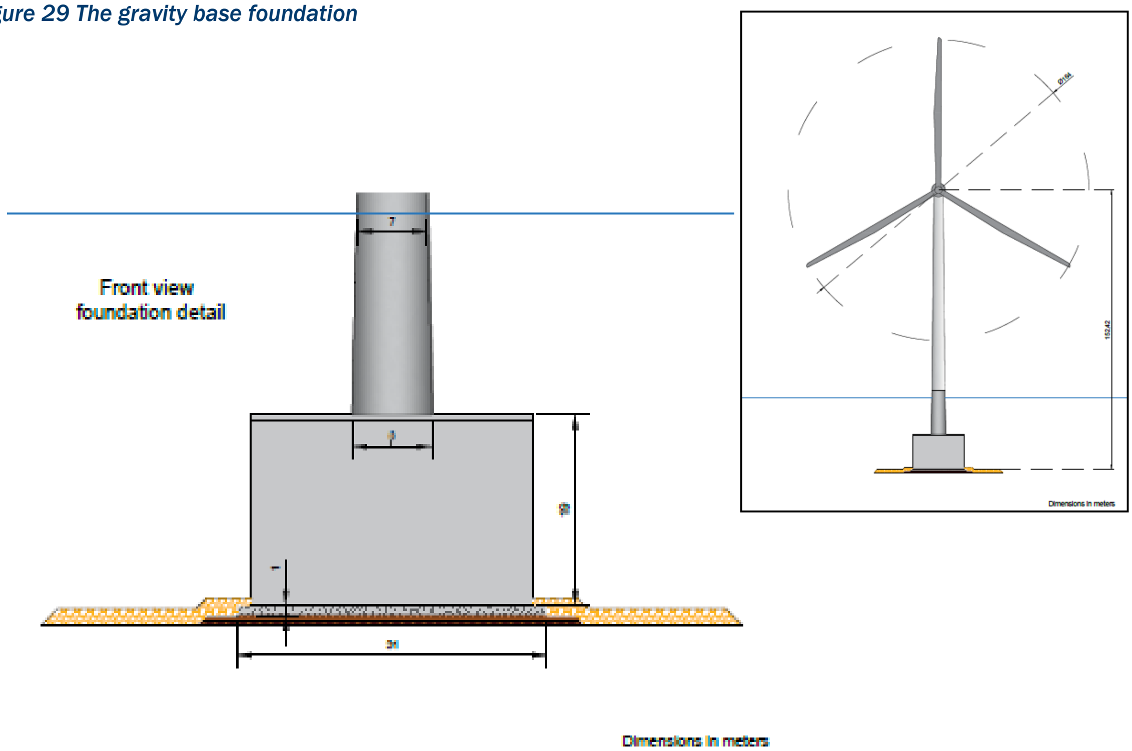
The collection of the necessary data for the environmental impact study was carried out through a questionnaire among ACCIONA structures design group knowledge and experience. The information compiled is described below:

5.5.2 Product

Reinforced concrete caisson (gravity base foundation, GBF) for the support of an 8 MW Wind Turbine (Figure 29).

[58] DT Ocean, “Design and Optimisation Tool for Ocean Arrays,” European Commission, 2016.

Figure 29 The gravity base foundation



5.5.3 Composition

<u>Specifications and regulations</u>
A reinforced concrete caisson with the following geometric data (See D2.4):

- bottom slab: 28 m Ø
- shaft: 20 m height
- footing: 31 m Ø; 1 m height
- transition piece: 24 m height; 8 m Ø

<u>Materials used for the process (specify type and quantity)</u>
The cement content for the concrete is approximately 380 kg/m^3. The maximum water-cement ratio will be 0.45 in all cases (see D2.4).

The passive reinforcement steel used on site is corrugated, with a tensile limit of 500 N/mm^2, and of natural hardness, corresponding to the designation B500S of EHE 08 Structural Concrete Instruction [38].

- concrete HA-35/B or F/IIIc+Qb+E: 3,498.33 m^3
- B500S steel: 524,749.5 kg

<u>Equipment</u>

- caisson dock
- tower crane
- concrete and aggregate plant: 150 m3/h
- pumping equipment

- concrete trucks: the period of time between the truck load and the unloading of the concrete on site is less than three quarters of an hour (3/4 h) and during the transport and unloading period the agitation system shall be constantly operated.

Consumption (energy, water, heat, compressed air, etc.)
- 1 concrete plant
- 370 trucks
- 1 caisson dock
- 2 concrete pumps
- 2 generating sets (400-500 kVAs)
- 1 tower crane
- worksite facilities (site huts, toilets, etc.)
- 1 tug boat
- stockpile area

Providers and transport
For the transport of materials and equipment it is necessary to use trucks.

5.5.4 Process

Production rate
The manufacture of a caisson with the caisson dock methodology can be carried out in 7-15 days working continuously in a double turn:
- average concreting speed: 45 m^3/h;
- average sliding speed: 4.2 m/day.

Production process description
Caissons are manufactured sheltered from the surge in a floating dock, which is specifically designed for the construction of reinforced concrete maritime caissons. The floating dock is basically a metal pontoon flanked by metallic turrets. It performs immersion and re-floating manoeuvres with ballasting and deballasting tanks that allow launching operations of concrete caissons built on its deck to be performed. It has auxiliary elements that allow to perform this operation, in particular:
- structures for supporting formwork;
- formworks;
- sliding equipment;
- concrete distribution equipment;
- ballasting equipment; and
- work platforms.

The assembly of the bottom slab reinforcement is performed on a barge ready for this purpose, which allows the assembly independently of the caisson construction. Once the reinforcement of the bottom slab has been prepared and assembly on the auxiliary pontoon, it is moved to the dock, previously submerged, where the reinforcement grid is suspended from the structure through steel wires, removing then the auxiliary pontoon and proceeding to the grid descent and placement at the base of the floating dock.

When the reinforcement of the bottom slab has been moved to the dock proceeds the placement of the formwork of the bottom slab of the caisson and the concreting of it.

After the concreting operation of the bottom slab, it proceeds to the placement of the first section of the shaft reinforcement and the descent of the sliding-formwork supporting structure for continue with concreting of the rest of the caisson.

The sliding formwork consists of metal sheets and form the horizontal section of the shaft of the caisson. The inner cells formworks are attached to the adjacent cells formworks and, in necessary, to the outer formworks by yokes (special pieces that maintain the separation between various panels while rigidifying the assembly). These yokes are suspended from the structure by cables and therefore they move jointly. The sliding equipment consists of a series of hydraulic jacks that move upwards along metal bars arranged for this purpose by jaws, dragging in its movement the structure and the formwork hanging from it.

Usually the concrete plant is located at the working site, although it can also be a short distance away, making it necessary to use concrete trucks to transport the material. In the present case study, the concrete plant will be considered at a distance of 1 km.

The concrete distribution equipment allows the pumping of the concrete from the ground, through a system of flexible pipes adaptable to the tidal race. In order to carry out the distribution of the concrete during the construction of the caisson, these pipes are connected to the distribution nibs, installed in the superstructure of the floating dock. In a complementary way, the supply of the steelwork to the auxiliary pontoon and to the floating dock is carried out thanks to a tower crane.

In the present study, it will be considered that the time required for the construction of a caisson is 9 days. The scope of the same will finish with the sinking of the caisson into the chosen scenario.

Table 10 Scenario details

Location	Water depth (m)	Distance to Port (km)	Ground conditions	Foundation type	Foundation installation	Foundation installation vessel	Turbine installation	Turbine installation vessel	Turbine Installation method
West Gabbard	40	30	Shallow bedrock	Gravity base	Float-out	2 tugs + 1 AHTS + 1 multicat	Installed separately	Jack-up	Bunny ears with 2 part tower

5.5.5 Transport

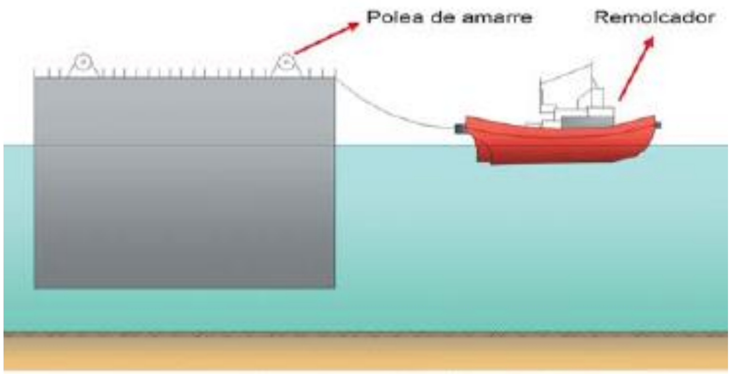
Transport of concrete: 1 km approx. from the concrete plant to the work site

5.5.6 Installation

Once the caisson is fully assembled, it is ready to be transported from the place of its construction to its final location where it is sunk. The sinking place is about 30 km from the coast with 40 m depth.

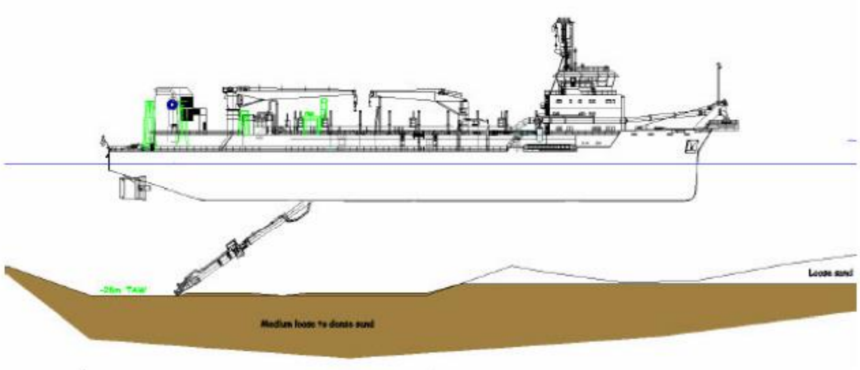
For this purpose, installing berth devices are required and the caisson is partially ballasted. Then one tug towsit to the installation place.

Figure 30 Installation of the GBF



Prior to the arrival of the foundation to the final location, certain actions on the seabed must be carried outto ensure that it is flatand homogeneous. Depending on the status of the soil, the upper layer of the seabed will have to be dredged. All dredged material will be disposed of around the site or saved for later ballasting if thatis the case.

Figure 31Seabed preparation



After dredging, a bedding layer slightly wider than the foundation is installed over the preparedsurface. This bedding layer will transfer forcesevenly to the subsoil. It normally consists of gravel. Once the bedding layer is prepared and the caisson sunk it is essentialto protect it against scouring.

Finally, once the caisson is towed to its final location, the sinking process starts by ballasting the interior cells of the caisson with water. The ballasting of the cells is performed by valves and groups of cells.

<u>Equipment</u>

- dredger vessel
- fall pipe vessel
- tugs

- anchor handling tug supply vessel
- multicatvessel
- generating set

Production rate

Taking into account the information available from technical specifications sheets for each vessel (cargo capacity, propulsion, endurance, etc.), the installation of the caisson will last approximately 7 days considering the operation time required for each vessel and operation:

- transport from port and sinking operation: 2 days
- dredging operation: 2 days
- bedding layer construction: 1 day
- scour protection construction: 2 days

The departure place of each vessel has not been considered because it is a great impact for just considering the construction of one caisson, which also it is not a real situation. The application of this data will make sense when a windfarm with a specificnumber of wind turbines is considered. Then it would be possible to allocate the impact between the number of structures.

Materials used for the process (specify type and quantity)

The bedding layer consists of two layers of material: a first filter layer of crushed gravel (diameters between 10-150 mm) supporting a secondlayer of gravel (diameters up to 63 mm).

The scour protection consists of a layer of crushed rock ofweight ranging from 10 to 200 kg.

Consumption (energy, water, heat, compressed air, etc.)

- 1 dredger vessel
- 1 fall pipe vessel
- 3 tugs
- 1 anchor handling tug supply vessel
- 1 multicatvessel
- 1 generating set (30 KVAs)

5.5.7 Waste management

Energy companies that operate offshore are obligated to remove all structures, clear the site, and verify clearance upon lease termination. All facilities, including pipelines, cable, and other structures and obstructions must be removed when they are no longer used for operations but no later than 2 years after the termination of the lease.

Requirements for facility removal are described in 285.910 (30 CFR)[59]:

- All facilities must be removed to a depth of 5 m below the mudline

[59] US Government Publishing Office, “Code of Federal Regulations (CFR)”, Title 30 – Chapter II – Subchapter B – Part 285 – Subpart I – Section 285.910, 2011

- Within 60 days after a facility is removed, the site must be cleared and clearance must be verified.

Waste management is not considered for the LCA of the GBF.

5.5.8 LCI details

The findings of the LCI of the gravity base foundation are summarised in Table 11, Table 12 and Table 13.

Table 11 Life cycle Inventory - Stage 1Installation and mobilisation of equipment

LIFE CYCLE INVENTORY (LCI)					
Inputs	Stage 1. Installation and mobilisation of equipment				
Description	Installation of construction equipment, berth devices for the caisson dock, installation of concrete pumps, installation of tower crane, material stockpile (steel)				
Raw materials (kg)	Material				Total (m3)
Energy consumption (equipment,machinery,etc.) (Kwh)	Service	KW	hours	% demand	Total (Kw*h)
Transport (km) or fuel/diesel consumption (Kwh)	Transport service	No. Vehicles	km		Total km
	Transport Crane Tower 1,000 kg (rush hour)	4	20		80
	Transport construction equipment (MAW approx. 12,000 Kg)	8	20		160
	Transport concrete pumps (MAW approx. 12,000 Kg)	2	20		40
	Transport for stockpile area (MAW approx. 12,000 Kg)	15	20		300
Waste (kg)	Material				
Products (kg)	Material				Total (kg)

Table 12Life Cycle Inventory - Stage 2 Caisson construction

LIFE CYCLE INVENTORY (LCI)					
Inputs	Stage 2. Caisson construction				
Description	Caisson construction within 9 days (216 hours) in 3 shifts				
Raw materials (kg)	Material				Total (m3)
	Concrete C30/37				3,498.33
	Concrete C20/25				1,107.42
	Steel B500S (kg)				524,749.5
	Release agent				3
	Water				10
Energy consumption (equipment, machinery, etc) (Kwh)	Service	KW	hours	% demand	Total (Kw*h)
	General operation caisson dock	101	216	0,95	20,725.2
	Manoeuvre operation caisson dock	567.4	216	0,05	6,127.92
	Concrete plant				
	1 Crane tower	12	108		1,296
	1 Tug	8,000	6	1	48,000
	Worksite facilities				2,160
Transport (km) or fuel/diesel consumption (Kwh)	Transport service	No. Vehicles	km		Total km
	Concrete mixer truck - outward journey (8-9 m3)	370	1		370
	Concrete mixer truck - return journey (8-9 m3)	370	1		370
Waste (kg)	Material				
	Concrete C30/37			0,07	579,000
	Steel B500S (kg)			0,1	52,474.95
Products (kg)	Material				Total without ballast (kg)
	Caisson - GBF				9,439,963.57

Table 13Life Cycle Inventory - Stage 3 Caisson installation

LIFE CYCLE INVENTORY (LCI)					
Inputs	Stage 3. Caisson installation				
Description	Caisson installation within 7 days including: transport from port and sinking operation (2 days), dredging operation (2 days), bedding layer construction (1 day), scour protection construction (2 days)				
Raw materials (kg)	Material				Total (m3)
	Crushing gravel				1,075
	Crushed rock				5,550
Energy consumption (equipment,machinery,etc) (Kwh)	Service	KW	hours	% demand	Total (Kw*h)
	1 Generating Set	22	4,6	0,75	75,9
Transport (km) or fuel/diesel consumption (Kwh)	Transport service	No. Vehicles	km	Total km	Fuel consumption (kg)
	Dredger vessel	1			8,68E+05
	Fall pipe vessel	1			452,800
	Tug	3			121.2
	Anchor Handling Tug Supply vessel	1			3,88E+03
	Multicat vessel	1			941
Waste (kg)	Material				
Products (kg)	Material				Total (kg)

5.5.9 Analysis of the GBF life cycle

The results of the analysis for each stage are collected using GaBi life-cycle analysis software.

Stages 1, 2 and 3 of the construction and installation of the gravity base foundation have been analysed separately to evaluate the impacts of each of the stages without distinction.

Figure 32Analysis in GaBi of "Stage I: Installation and mobilisation of equipment"

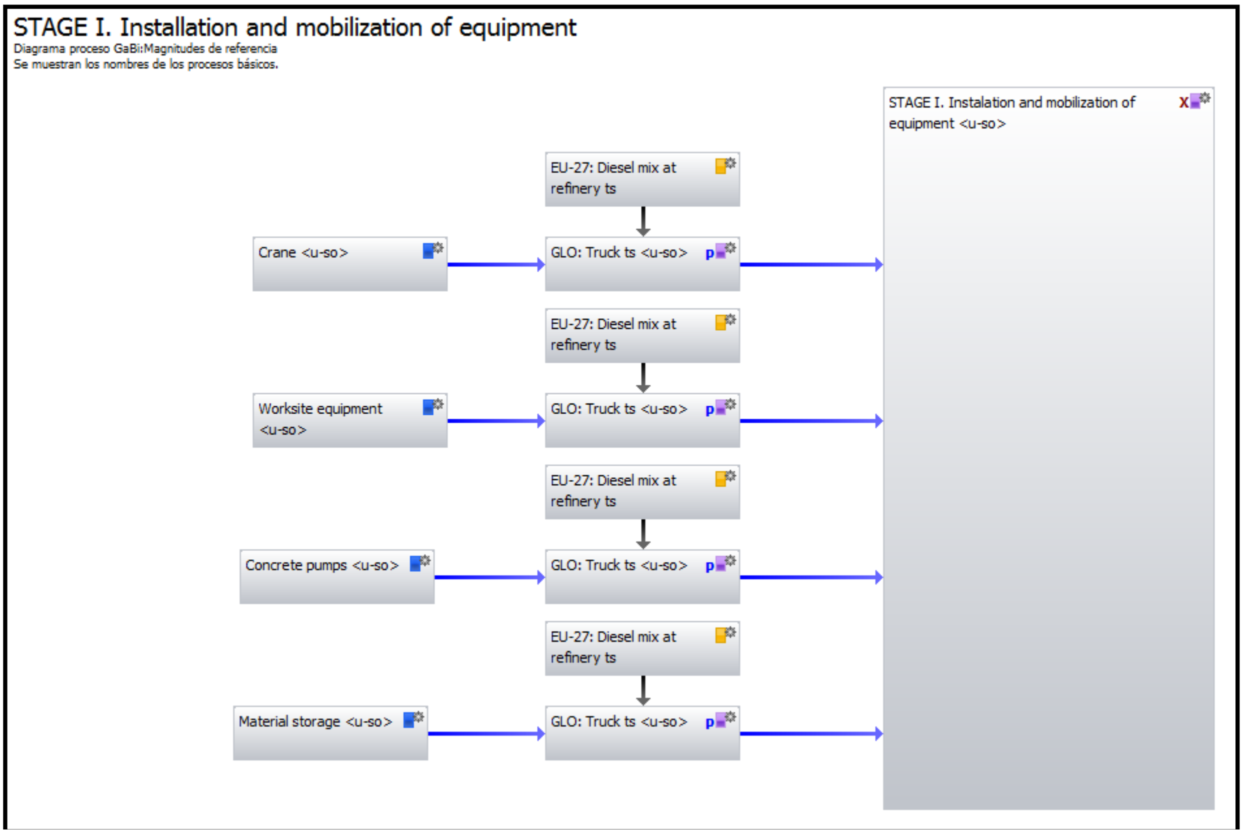


Figure 33Analysis in Gabi of 'Stage II: Caisson construction'

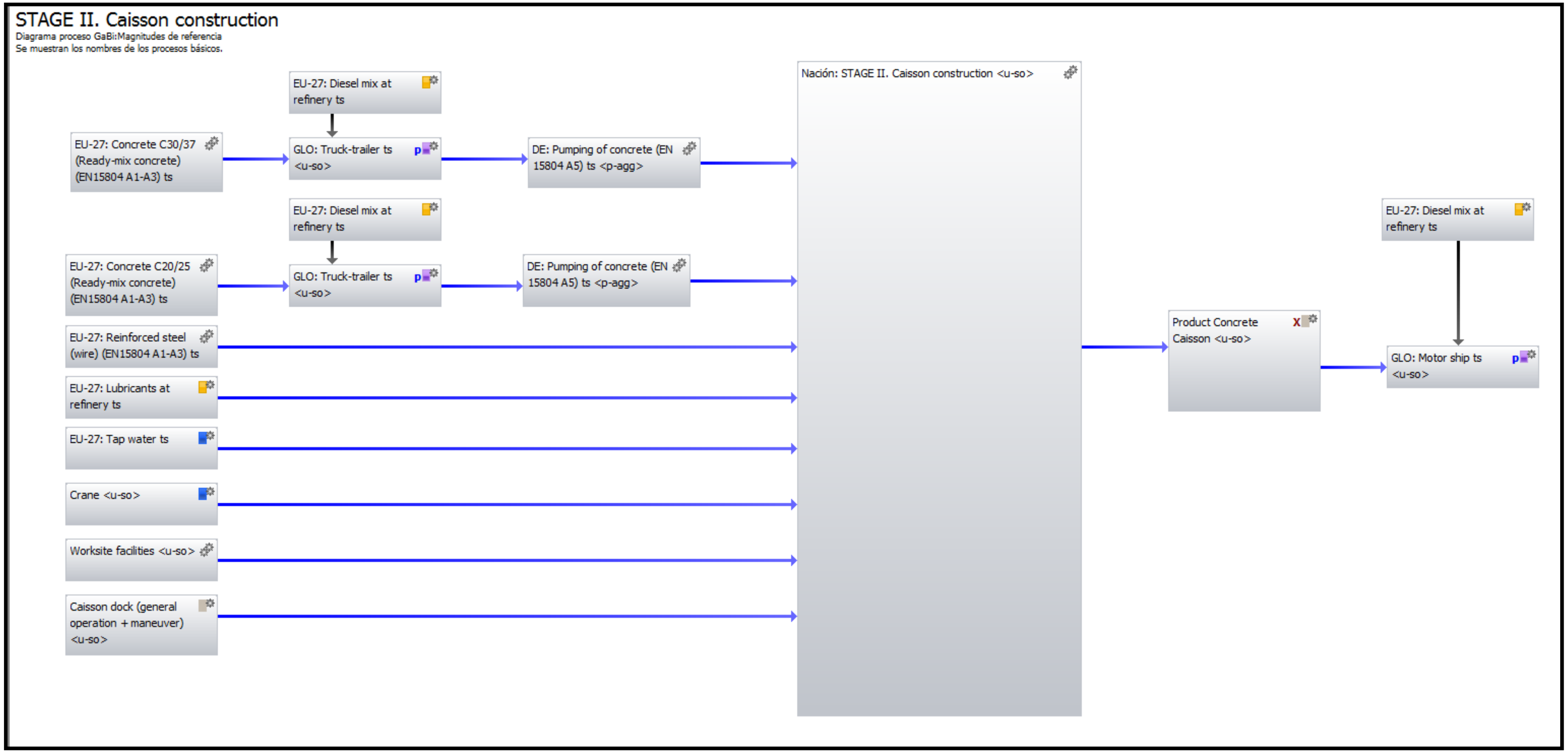


Figure 34Analysis in Gabi of 'Stage III: Caisson installation' (Part 1)

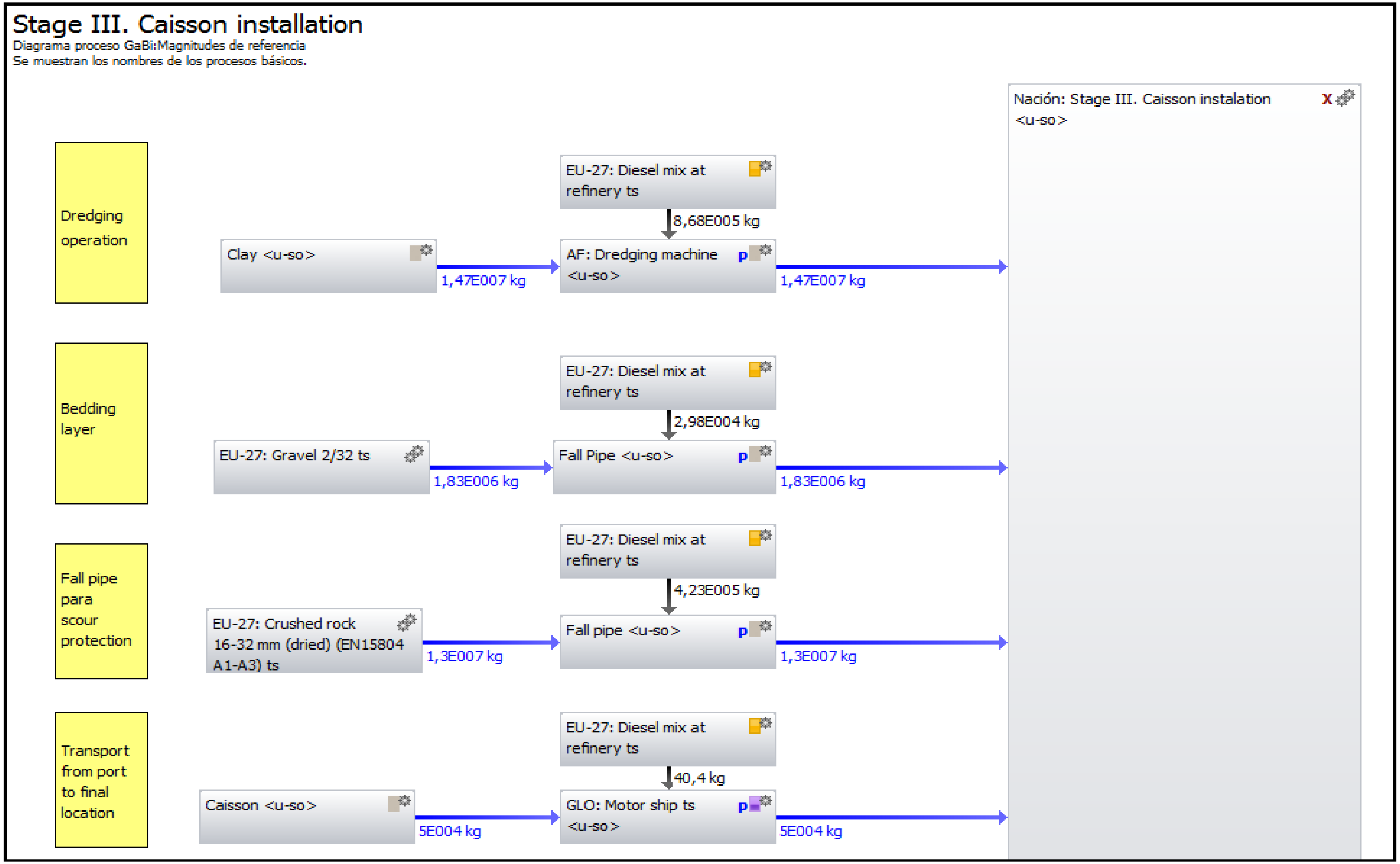
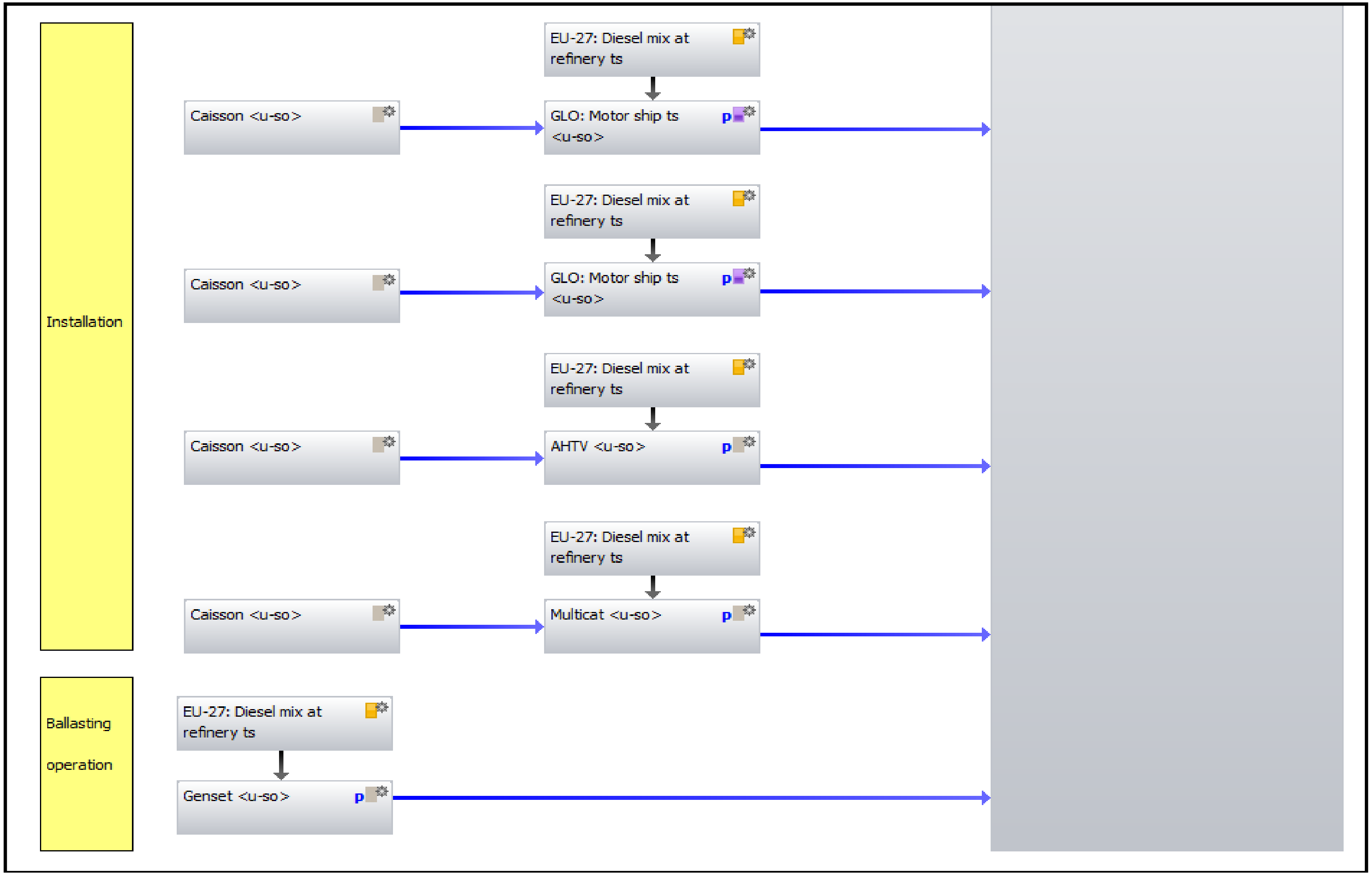


Figure 35Analysis in Gabi of 'Stage III: Caisson installation' (Part 2)



5.6 Evaluation of life-cycle assessment results

The life cycle impact assessment (LCIA) stage is aimed at assessing the importance of potential environmental impacts using the results of the life cycle inventory analysis. In general, this process indicates the association between inventory data with specific environmental impacts in order to value those impacts. Once obtained the data inventories associated with the life-cycle analysis of the materials and processes are interpreted, where raw materials and energy input flows are a consequence of the manufacturing process. Thus, from the initial data set it is possible to define the degree of environmental impact associated to each system.

This interpretation must be done in a structured way to classify, categorise and assess the contribution to the environmental damage of the different data derived from the life cycle of the material. Therefore, the results from the environmental performance of these systems are expressed in use of resources (materials and energy) as well as considering the environmental impacts proposed by the CML methodology, which quantifies the environmental impacts in equivalents units of a substance that is taken as a reference of the damage (e.g. global warming potential, kg CO_2 equivalent).

The CML methodology considers the following impact categories to be of crucial importance, which are also considered standard and representative according to the 15804 sustainability standard for construction materials[60]:

Global warming potential (100 years)
The calculation of this impact category is carried out taking into account the greenhouse gases that contribute to modify the energy balance between the earth and the atmosphere. To determine their value, the Global Warming Potentials (GWP) of greenhouse gases are used. These potentials express the relationship between increased infrared absorption due to the instantaneous emission of 1 kg of one of these gases and due to an equal emission of carbon dioxide, integrated both over time. Global warming potentials are published periodically by the Intergovernmental Panel on Climate Change experts (IPCC). The result of the calculation is expressed in kg of CO_2-equivalents.

Acidification potential
Acidification consists on the deposition of acids resulting from the release of nitrogen oxides and sulphur into the atmosphere, soil and water, where the acidity of the medium can vary. The calculation of this value is carried out considering the importance of the gases with acidifying capacity in relation to the reference substance, sulphur dioxide (SO_2). The result of the calculation is expressed in kg SO_2-equivalents.

Ozone depletion potential
The ozone layer is present in the stratosphere and acts as a filter by absorbing UV radiation. Most chlorides and bromides, from fluorocarbon compounds, CFCs and other sources react in the presence of polar stratospheric clouds emitting active chlorides and bromides that, under the catalytic action of UV, cause the

[60] European Standards, "EN 15804 - Sustainability of construction works – Environmental Product Declaration – Code rules of the product category of construction products", 2012

decomposition of ozone. The ozone layer depletion potential is defined as the ratio between ozone decomposition at steady state due to annual emissions by a destructive substance and the ozone decomposition at steady state due to an equal amount of CFC-11 (R-11). The result of the calculation is expressed in kg of R11-equivalents.

Photochemical ozone creation potential (photochemical smog processes)
This indicator defines the potential creation of ozone at the tropospheric level due to the reaction, in the presence of sunlight, of certain atmospheric pollutants, such as nitrogen oxides and volatile organic compounds (VOCs). The creation of ozone in the troposphere, where it acts as a photo-oxidant together with other pollutants, leads to the phenomenon known as smog. This can be detrimental to human health and ecosystems, as well as causing damage to materials. The photochemical oxidant creation potential is defined as the ratio between the change in ozone concentration due to a change in the emission of a VOC and the change in that concentration due to a change in the emission of ethene (one of the substances, belonging to the group of the volatile organic compounds, more reactive in the creation of ozone in the troposphere). The result of the calculation is expressed in kg of ethene-equivalents.

All of the results are presented as a total value per foundation, but also normalised per unit of energy produced by the wind turbine mounted on top. The latter value implies that the impacts are proportional to the size of the corresponding turbine, which is unlikely to be the case, but allows comparison between foundations designed for different sizes of turbine. Note that these values are NOT directly comparable with those that have been published for offshore wind energy, as these studies only consider the impacts of the foundations themselves.

5.6.1 Jacket foundation

The life-cycle impacts of the jacket foundation are summarised in Table 14 below, broken down by life-cycle stage, with the impacts normalised per unit of energy produced by the wind turbine in Table 15. The global warming potential and cumulative energy demand are highlighted, as these two impact categories are the two of most interest for renewable generators. It can be seen that the impacts of the materials and manufacturing stage dominate in all categories, contributing over 80% to all but freshwater aquatic ecotoxicity. In the latter, the disposal stage is also significant, due to the impacts of disposing in landfill.

Table 14Life cycle environmental impacts of the LEANWIND jacket foundation

Impact category	Unit	Total	Materials & Manufacture	Installation	Maintenance	Decommissioning & Disposal

Global warming (GWP100a)	**kt CO_2eq**	**4.52**	**4.32**	**0.087**	**0.020**	**0.089**
Ozone layer depletion (ODP)	kg CFC-11 eq	0.34	0.30	0.016	0.004	0.019
Acidification	t SO_2eq	25.24	21.16	2.16	0.50	1.41
Eutrophication	t PO4--- eq	12.46	11.94	0.19	0.044	0.29
Photochemical oxidation	t C_2H_4eq	2.18	2.04	0.068	0.016	0.052
Abiotic depletion	kg Sb eq	59.12	58.94	0.006	0.001	0.18
Abiotic depletion (fossil fuels)	TJ	49.06	46.36	1.33	0.31	1.06
Human toxicity	kt 1,4-DB eq	12.81	12.62	0.027	0.006	0.15
Fresh water aquatic ecotox.	kt 1,4-DB eq	8.77	5.43	0.002	0.000	3.33
Marine aquatic ecotoxicity	Mt 1,4-DB eq	12.02	10.94	0.014	0.003	1.06
Terrestrial ecotoxicity	t 1,4-DB eq	65.54	64.59	0.10	0.024	0.82
Cumulative Energy Demand	**TJ**	**58.39**	**55.48**	**1.34**	**0.31**	**1.26**

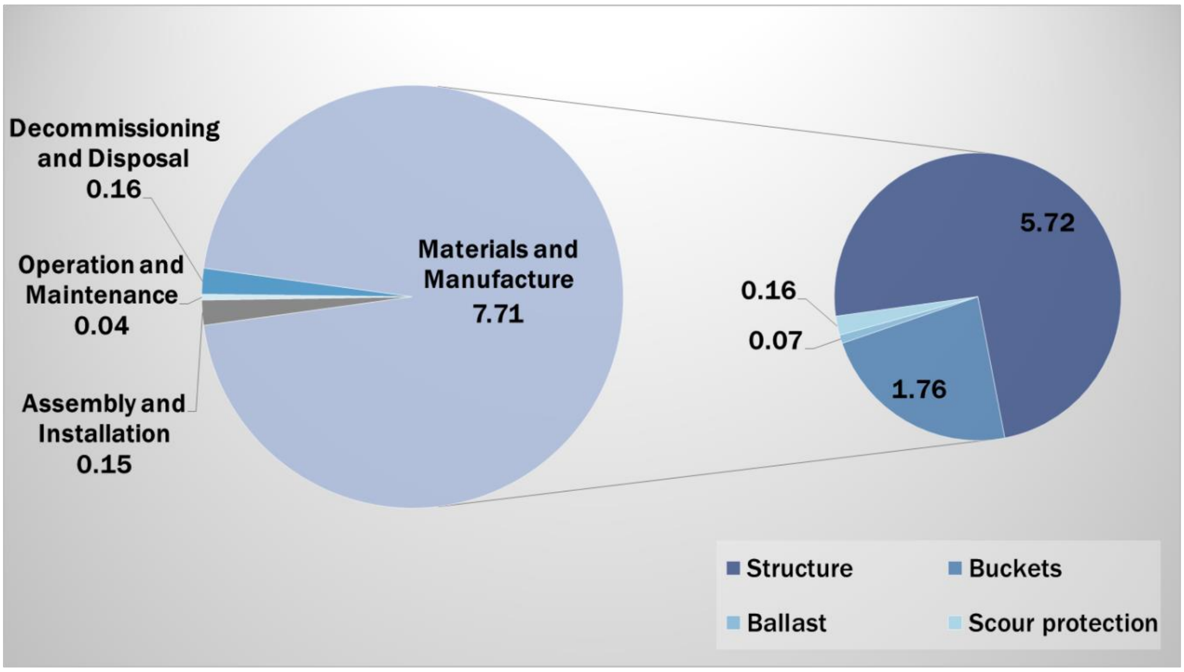
Table 15Normalised impacts of the LEANWIND jacket foundation

Impact category	Unit	Total	Materials & Manufacture	Installation	Maintenance	Decommissioning & Disposal
Global warming (GWP100a)	**g CO_2eq/kWh**	**8.06**	**7.71**	**0.15**	**0.04**	**0.16**
Ozone layer depletion (ODP)	x10^{-9} g CFC-11 eq/kWh	**610**	540	28.7	6.65	34.1
Acidification	x10^{-3} g SO_2eq/kWh	**45.0**	37.7	3.85	0.893	2.52
Eutrophication	x10^{-3} g PO4--- eq/kWh	**22.2**	21.3	0.337	0.078	0.513
Photochemical oxidation	x10^{-3} g C_2H_4eq/kWh	**3.88**	3.64	0.122	0.028	0.092 4
Abiotic depletion	x10^{-6} g Sb eq/kWh	**105**	105	0.011	0.003	0.317
Abiotic depletion (fossil fuels)	kJ/kWh	**87.51**	82.70	2.37	0.55	1.89
Human toxicity	g 1,4-DB eq/kWh	**22.84**	22.51	0.05	0.01	0.28

Fresh water aquatic ecotox.	g 1,4-DB eq/kWh	**15.64**	9.69	0.00	0.00	5.95
Marine aquatic ecotoxicity	kg 1,4-DB eq/kWh	**21.44**	19.52	0.02	0.01	1.89
Terrestrial ecotoxicity	x10^{-3} g 1,4-DB eq/kWh	**117**	115	0.182	0.042	1.46
Cumulative Energy Demand	**kJ/kWh**	**104.2**	**99.0**	**2.24**	**0.55**	**2.39**

Figure 36below shows how the global warming potential is broken down by life cycle stage and component, and it can be seen that it is the impacts of the steel components that dominate - similar results are also found for the other impact categories. The greatest opportunity in reducing all environmental impacts lies in reducing the mass of steel required for the foundation structure.

Figure 36 Global warming potential (g CO2eq/kWh) of the jacket foundation per life cycle stage



5.6.2 Floating foundation

The life-cycle impacts of the floating foundation are summarised in Table 16 below, with the impacts normalised per unit of energy presented in Table 17. Again, it can be seen that the impacts of the materials and manufacturing stage dominate in all categories, contributing over 75% to all but freshwater aquatic ecotoxicity. As with the jacket foundation, the disposal stage is also significant in the freshwater aquatic ecotoxicity category, due to the impacts of disposing in landfill.

Table 16Life cycle environmental impacts of the LEANWIND floating foundation

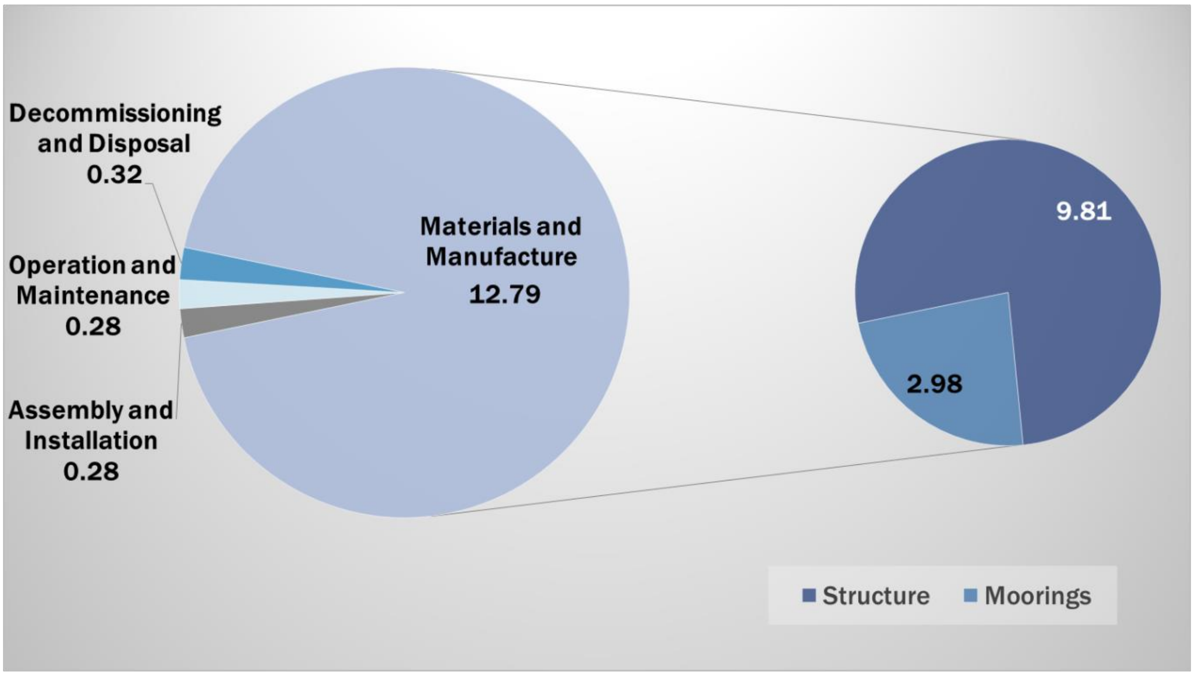
Impact category	Unit	Total	Materials & Manufacture	Installation	Maintenance	Decommissioning & Disposal
Global warming (GWP100a)	**kt CO_2eq**	**4.79**	**4.48**	**0.10**	**0.099**	**0.11**
Ozone layer depletion (ODP)	kg CFC-11 eq	0.32	0.25	0.018	0.018	0.028
Acidification	t SO_2eq	30.16	22.65	2.48	2.46	2.56
Eutrophication	t PO4--- eq	13.07	12.39	0.22	0.22	0.25
Photochemical oxidation	t C_2H_4eq	2.29	2.06	0.078	0.078	0.083
Abiotic depletion	kg Sb eq	66.09	65.87	0.007	0.007	0.20
Abiotic depletion (fossil fuels)	TJ	51.56	46.83	1.53	1.52	1.69
Human toxicity	kt 1,4-DB eq	27.48	27.27	0.031	0.030	0.16
Fresh water aquatic ecotox.	kt 1,4-DB eq	11.35	7.60	0.002	0.002	3.75
Marine aquatic ecotoxicity	Mt 1,4-DB eq	13.13	11.96	0.016	0.016	1.14
Terrestrial ecotoxicity	t 1,4-DB eq	83.85	82.68	0.12	0.12	0.93
Cumulative Energy Demand	**TJ**	**61.55**	**56.56**	**1.54**	**1.53**	**1.92**

Table 17Normalised impacts of the LEANWIND floating foundation

Impact category	Unit	Total	Materials & Manufacture	Installation	Maintenance	Decommissioning & Disposal
Global warming (GWP100a)	**g CO_2eq/kWh**	**13.68**	**12.79**	**0.28**	**0.28**	**0.32**
Ozone layer depletion (ODP)	$x10^{-9}$ g CFC-11 eq/kWh	**906**	721	52.8	52.4	79.7
Acidification	$x10^{-3}$ g SO_2eq/kWh	**86.1**	64.6	7.09	7.03	7.30
Eutrophication	$x10^{-3}$ g PO4--- eq/kWh	**37.3**	35.4	0.620	0.615	0.702
Photochemical oxidation	$x10^{-3}$ g C_2H_4eq/kWh	**6.55**	5.87	0.224	0.222	0.236
Abiotic depletion	$x10^{-6}$ g Sb eq/kWh	**189**	188	0.021	0.021	0.579
Abiotic depletion (fossil fuels)	kJ/kWh	**147.2**	133.6	4.36	4.33	4.82
Human toxicity	g 1,4-DB eq/kWh	**78.43**	77.81	0.09	0.09	0.44
Fresh water aquatic ecotox.	g 1,4-DB eq/kWh	**32.38**	21.68	0.01	0.01	10.69
Marine aquatic ecotoxicity	kg 1,4-DB eq/kWh	**37.46**	34.12	0.05	0.05	3.25
Terrestrial ecotoxicity	$x10^{-3}$ g 1,4-DB eq/kWh	**239**	236	0.335	0.333	2.66
Cumulative Energy Demand	**kJ/kWh**	**175.7**	**161.4**	**5.47**	**4.37**	**4.40**

Figure 37 shows how the global warming potential is broken down by life cycle stage and component, and here it can be seen that a significant contribution is from the moorings, including line and anchors. These are of particular significance, as the mooring lines have been approximated as 18/8 chromium steel, which has a much higher impact in the human toxicity category than mild steel. There is, therefore, the potential to reduce significantly the impacts of the floating foundation by both optimising the mass of steel required in the structure and reducing the length of the mooring lines; for example by sharing moorings between multiple turbines if possible.

Figure 37 Global warming potential (g CO2eq/kWh) of the floating foundation per life cycle stage



5.6.3 Gravity base foundation

The life-cycle impacts of the floating foundation are summarised in Table 18 below, with the impacts normalised per unit of energy presented in Table 19.

Table 18Life cycle environmental impacts of the LEANWIND gravity base foundation (CML 2001 - Apr 2015)

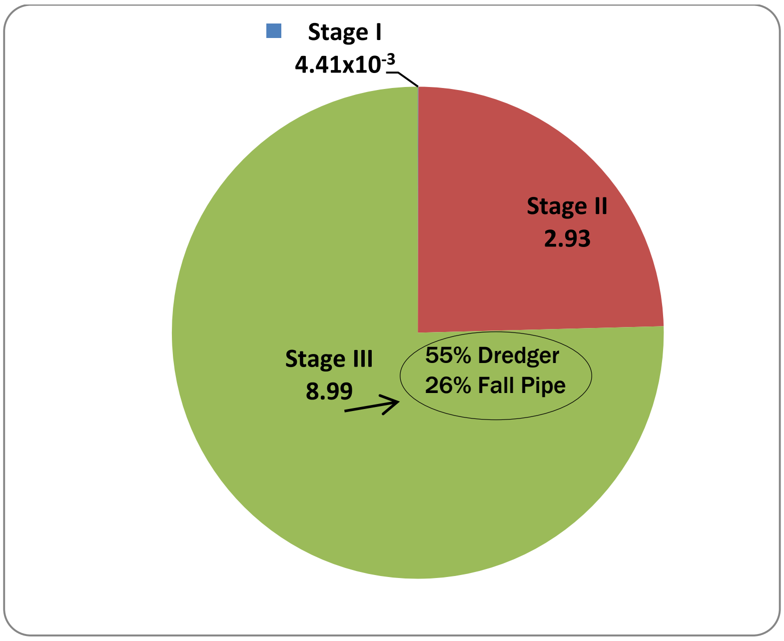
Impact category	Unit	Stage I	Stage II	Stage III	Total
Global warming potential (100 years)	kg CO_2eq	$2.47x10^3$	$1.64x10^6$	$5.04x10^6$	$6.68x10^6$
Ozone depletion potential	kg R-11 eq	$1.12x10^{-8}$	**0.000185**	0.000112	$2.97x10^{-4}$
Acidification potential	kg SO_2eq	3.59	$3.27x10^3$	$3.27x10^4$	$3.60x10^4$
Eutrophication potential	kg PO4--- eq	0.785	452	$8.04x10^3$	$8.49x10^3$
Photochemical ozone creation potential	kg C_2H_4eq	-0.372	201	$4.93x10^3$	$5.13x10^3$
Depletion of abiotic resources (elements)	kg Sb eq	0.000162	**1.97**	0.362	2.33
Depletion of abiotic resources (fossil)	MJ	$3.35x10^4$	$1.12x10^7$	$6.97x10^7$	$8.09x10^7$
Human Toxicity Potential	kg DCB eq	61.2	$3.77x10^5$	$2.45x10^5$	$6.22x10^5$
Freshwater Aquatic Ecotoxicity Pot.	kg DCB eq	14.3	$3.46x10^3$	$2.81x10^4$	$3.16x10^4$
Marine Aquatic Ecotoxicity Pot.	kg DCB eq	$3.14x10^4$	$6.46x10^7$	$7.46x10^7$	$1.39x10^8$
Terrestrial Ecotoxicity Potential	kg DCB eq	5.52	$3.43x10^3$	$1.09x10^4$	$1.43x10^4$
Primary energy demand from renewable and non-renewable. resources (net cal. value)	MJ	$3.56x10^4$	$1.45x10^7$	$7.51x10^7$	$8.96x10^7$
Primary energy from non-renewable resources (net cal. value)	MJ	$3.36x10^4$	$1.29x10^7$	$7.08x10^7$	$8.37x10^7$
Primary energy from renewable resources (net cal. value)	MJ	$1.91x10^3$	$1.52x10^6$	$4.29x10^6$	$5.81x10^6$

Table 19Normalised impacts of the LEANWIND gravity base foundation (CML 2001 - Apr 2015)

Impact category	Unit	Stage I	Stage II	Stage III	Total
Global warming potential (100 years)	g CO_2eq/kWh	$4.41\text{x}10^{-3}$	2.93	8.99	11.9
Ozone depletion potential	g R-11 eq/kWh	$2.00\text{x}10^{-14}$	$3.30\text{x}10^{-10}$	$2.00\text{x}10^{-10}$	$5.30\text{x}10^{-10}$
Acidification potential	g SO_2eq/kWh	$6.40\text{x}10^{-6}$	$5.83\text{x}10^{-3}$	$5.83\text{x}10^{-2}$	$6.42\text{x}10^{-2}$
Eutrophication potential	g PO4--- eq/kWh	$1.40\text{x}10^{-6}$	$8.06\text{x}10^{-4}$	$1.43\text{x}10^{-2}$	$1.51\text{x}10^{-2}$
Photochemical ozone creation potential	g C_2H_4eq/kWh	$-6.64\text{x}10^{-7}$	$3.59\text{x}10^{-4}$	$8.79\text{x}10^{-3}$	$9.15\text{x}10^{-3}$
Depletion of abiotic resources (elements)	g Sb eq/kWh	$2.89\text{x}10^{-10}$	$3.51\text{x}10^{-6}$	$6.46\text{x}10^{-7}$	$4.16\text{x}10^{-6}$
Depletion of abiotic resources (fossil)	kJ/kWh	$5.98\text{x}10^{-2}$	20.0	$1.24\text{x}10^{2}$	$1.44\text{x}10^{2}$
Human Toxicity Potential	g DCB eq/kWh	$1.09\text{x}10^{-4}$	$6.72\text{x}10^{-1}$	$4.37\text{x}10^{-1}$	1.11
Freshwater Aquatic Ecotoxicity Pot.	g DCB eq/kWh	$2.55\text{x}10^{-5}$	$6.17\text{x}10^{-3}$	$5.01\text{x}10^{-2}$	$5.63\text{x}10^{-2}$
Marine Aquatic Ecotoxicity Pot.	g DCB eq/kWh	$5.60\text{x}10^{-2}$	$1.15\text{x}10^{2}$	$1.33\text{x}10^{2}$	$2.48\text{x}10^{2}$
Terrestrial Ecotoxicity Potential	g DCB eq/kWh	$9.85\text{x}10^{-6}$	$6.12\text{x}10^{-3}$	$1.94\text{x}10^{-2}$	$2.56\text{x}10^{-2}$
Primary energy demand from renewable and non-renewable resources (net cal. value)	kJ/kWh	$6.35\text{x}10^{-2}$	25.9	$1.34\text{x}10^{2}$	$1.60\text{x}10^{2}$
Primary energy from non-renewable resources (net cal. value)	kJ/kWh	$5.99\text{x}10^{-2}$	23.0	$1.26\text{x}10^{2}$	$1.49\text{x}10^{2}$
Primary energy from renewable resources (net cal. value)	kJ/kWh	$3.41\text{x}10^{-3}$	2.71	7.65	10.4

As can be concluded from the tables, Stage III (caisson installation) is the stage that contributes most to the impacts generated during the life of the infrastructure. Figure 38below shows how each stage contributes to global warming potential, with the bigger impact of Stage IIIagain being remarkable. Within this stage of caisson installation, the factors that contributes most to GWP are dredging and fall pipe vessels.

Figure 38 Global warming potential (g CO2eq/kWh) of the GBF per life cycle stage



However, there are two indicators that behave in a different way and in Stage II they are higher than in Stage III. The first one is ozone depletion potential due to a chlorofluorocarbon (CFC) present in the reinforced steel. It is dichlorotetrafluoroethane (R-114) and it is listed on the Intergovernmental Panel on Climate Change's list of ozone depleting substances. The second one is abiotic depletion potential (elements). One of the constituents of cement is calcium sulphate, which is included in cement in form of gypsum and anhydrite. In this case, the large influence of gypsum on the parameter ADP (elements) is caused by the relative scarcity of sulphur in the Earth's crust.

It is important to highlight the fact that a comparison is not made between the impacts that are most important, since they are different concepts, measured in different units and therefore, the ultimate aim is to give absolute values and be able to ensure that these impacts are evaluated and quantified but not compared between them.

5.6.4 Comparison of foundations

The results for the three foundations are compared in Table 20 below, and it can be seen that the floating foundation has significantly higher impacts in most categories. This is likely to be because of the high quantity of steel used in this foundation. The GBF is largely formed from reinforced concrete and the jacket foundation is constructed from 1,650 tonnes of mild steel, while the floating foundation (including anchors) has a total of 1,755 tonnes of mild steel, with a further 193 tonnes of marine-grade steel for the mooring lines.

As the last is also designed for a smaller 5 MW turbine, this means that it requires 90% more steel than the jacket foundation when compared per unit of energy generated.

This accounts for much of the discrepancy shown in Table 20, with some variation where impact categories are less affected by steel production, and instead by other processes, such as concrete manufacture or sea vessel operation. The large difference in the human toxicity category is due to the significant impact of the marine-grade steel (approximated as 18/8 chromium steel) used for the mooring lines of the floating foundation.

Table 20Comparison of impacts from LEANWIND foundations (difference from jacket foundation shown in brackets)

Impact category	Unit	Jacket foundation	Gravity base foundation	Floating foundation
Global warming (GWP100a)	g CO_2eq/kWh	**8.06**	**11.9 (+48%)**	**13.7 (+70%)**
Ozone layer depletion (ODP)	x10^{-9} g CFC-11 eq/kWh	610	53.0 (-91%)	906 (+49%)
Acidification	x10^{-3} g SO_2eq/kWh	45.0	64.2 (+43%)	86.1 (+91%)
Eutrophication	x10^{-3} g PO4--- eq/kWh	22.2	15.1 (-32%)	37.3 (+68%)
Photochemical oxidation	x10^{-3} g C_2H_4eq/kWh	3.88	9.15 (+136%)	6.55 (+69%)
Abiotic depletion	x10^{-6} g Sb eq/kWh	105	4.16 (-96%)	189 (+80%)
Abiotic depletion (fossil fuels)	kJ/kWh	87.51	144 (+65%)	147 (+68%)
Human toxicity	g 1,4-DB eq/kWh	22.84	1.11 (-95%)	78.4 (+243%)
Fresh water aquatic ecotox.	g 1,4-DB eq/kWh	15.64	0.056 (-100%)	32.4 (+107%)
Marine aquatic ecotoxicity	kg 1,4-DB eq/kWh	21.44	0.25 (-99%)	37.5 (+75%)
Terrestrial ecotoxicity	x10^{-3} g 1,4-DB eq/kWh	117	25.5 (-78%)	239 (+104%)
Cumulative Energy Demand/ Primary Energy Demand	**kJ/kWh**	**104**	**160 (+54%)**	**176 (+69%)**

There are some limitations to comparing the three foundations in this way, however. Normalising per unit of energy produced by the corresponding turbine assumes that there is a linear relationship between all of the impacts and the size of the turbine (and corresponding energy production), which is unlikely to be the case. Therefore, the impacts of a floating foundation for an 8MW turbine may well be lower than the values suggested by this analysis. Furthermore, the analysis of the GBF did not include any maintenance or decommissioning impacts, although these are expected to be relatively small.

It is also important to note that despite its higher environmental impacts, the floating foundation has much greater flexibility of installation location, and remains a viable technical solution.

The gravity base foundation has lower impacts than the jacket foundation, including categories considered to be of crucial importance and representative according to the standards[61](global warming potential, acidification potential, ozone depletion potential and photochemical oxidation/ozone creation potential). It also performs betterin the embodied energy category, which is of particular interest for renewable energy converters. The GBF would therefore appear to perform better than the jacket foundation at first glance, largely due to the differences in the principal materials used; steel with aluminium sacrificial anodes in the case of the jacket foundation, and concrete for the GBF. The GBF has lower impacts than the jacket foundation mostly due to greater emissions of ozone depleting and eutrophying pollutants from the smelting of iron ore and refining of molybdenite for steel production, along with a larger consumption of abiotic resources such as chromium, cadmium, lead and molybdenum for the steel and aluminium alloys.

It is unclear whether the lower toxicity potential of the GBF is due to the different materials or a fundamental change in the calculation of toxicity potential between the two different LCIA methods employed in this analysis (CML 2001 for the GBF and CML 2013) for the jacket and floating foundations[62]. The calculation of toxicity potentials is very complicated, and therefore the characterisation factors are often adjusted significantly when impact assessment methods are updated.

In the case of photochemical oxidation/ozone creation potential, the particularly high impacts for the GBF are due to emissions from the operation of the dredging vessel (56.5%) and the fall pipe vessel (27.5%).

Although the GBF performs better than the jacket foundation in all categories, it is important to notethat these foundations are not directly comparable, as the floating foundation was designed for a water depth of 100m, the jacket foundation for 60m and the GBF only 40m. It is likely that the jacket foundation would need considerably less material at a depth of 40m, and the floating foundation would have much shorter mooring lines which would be expected to significantly reduce the environmental impacts and provide a much better performance at a shallower depth. In contrast,however, the LEANWIND GBF requires minimal changes for use at a depth of 60m, suggesting that the GBF compares much more favourably with the jacket foundation at deeper sites.

[61] US Government Publishing Office, “Code of Federal Regulations (CFR)”, Title 30 – Chapter II – Subchapter B – Part 285 – Subpart I – Section 285.910, 2011
[62] CML - Department of Industrial Ecology, “CML-IA baseline methodology”, Universiteit Leiden, http://www.cml.leiden.edu/software/data-cmlia.html, 2013. Guinée et al., “CML 2001 methodology,” Leiden University - Institute of Environmental Sciences, 2002

5.6.5 Impact of LEANWIND innovations

In order to assess the impact of the LEANWIND innovations on the environmental impacts of the foundations, the results for global warming potential have been compared to those from a number of other published studies. This factor has been chosen as it is the most widely studied for offshore wind farms.

All of the studies considered in this section have included the turbine as well as the foundation; however, in all but one[63], the contribution of the foundations to the materials and manufacturing stage has been reported. The full life-cycle impacts of the foundations have therefore been estimated by assuming that the contribution of the foundations to the impacts of all life-cycle stages is the same as for the materials and manufacturing stage. (For the study by Weinzettel et al.[64], it has been assumed that the foundations contribute 68% to the total life-cycle impacts, as this is the mean of the contributions found by Raadal et al.[65] for other types of floating foundation.) This is a pessimistic assumption, as it is likely that the maintenance impacts of the foundation will be disproportionately lower than for the moving parts of the turbine.

As all different studies also estimate different capacity factors and design lives, the global warming potential has also been adjusted for the same capacity factor (40%) and design life (20 years) used in this analysis.

Finally, the global warming potential per tonne of material has also been calculated where possible. Figure 39below shows how the global warming potential of the LEANWIND jacket foundation compares with estimates from other published studies. It can be seen that it is slightly lower than the median of the adjusted values, which is particularly positive when it is considered that all but one of these studies[66] is considering installation in a water depth of only 25 - 30 m (compared to the 60 m design depth of the LEANWIND foundation). Raadal et al.[67]examined the life-cycle impacts of a jacket foundation in a water depth of 50m, and estimate the impacts to be 60% higher than the LEANWIND solution. This difference may be due to the lower impacts of the floating/suction bucket design used for the LEANWIND foundation, in place of more conventional piles. It is worth noting, however, that the GWP per unit mass of the LEANWIND foundation is estimated to be significantly lower than in other analyses, and this could indicate that the impacts of maintenance and decommissioning stages have been underestimated.

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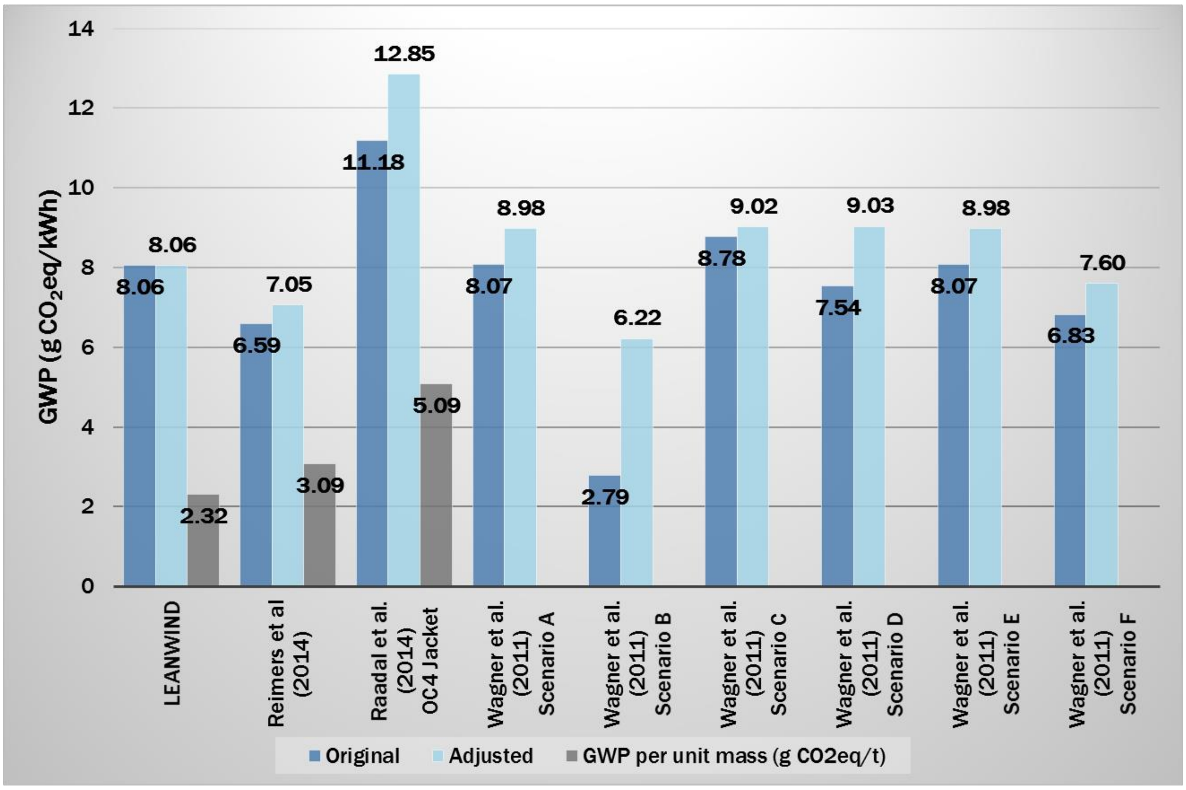
[63] J. Weinzettel, M. Reenaas, C. Solli, and E. G. Hertwich, "Life cycle assessment of a floating offshore wind turbine," Renewable Energy, vol. 34, no. 3, pp. 742-747, Mar, 2009.
[64] H. L. Raadal, B. I. Vold, A. Myhr, and T. A. Nygaard, "GHG emissions and energy performance of offshore wind power," Renewable Energy, vol. 66, pp. 314-324, 2014.
[65] Ibid.
[66] Ibid.
[67] Ibid.

Figure 39 Comparison of LEANWIND jacket foundation with results from other published studies[68]



The global warming potential of the LEANWIND floating foundation is compared with those for other floating foundations in Figure 40 below. Again, the impacts are slightly lower than the median impacts found by[69] and[70], suggesting that the floating foundation performs[71] comparably with its competitors. It is also worth noting that the study by Weinzettel et al. does not include the mooring lines, which have been shown to have a significant impact, and therefore may be overly optimistic. Conversely, the lower impact of the LEANWIND floating foundation per unit of mass may be of concern, as this suggests that the study presented here may have been overly optimistic in analysing the maintenance and decommissioning impacts of the foundation.

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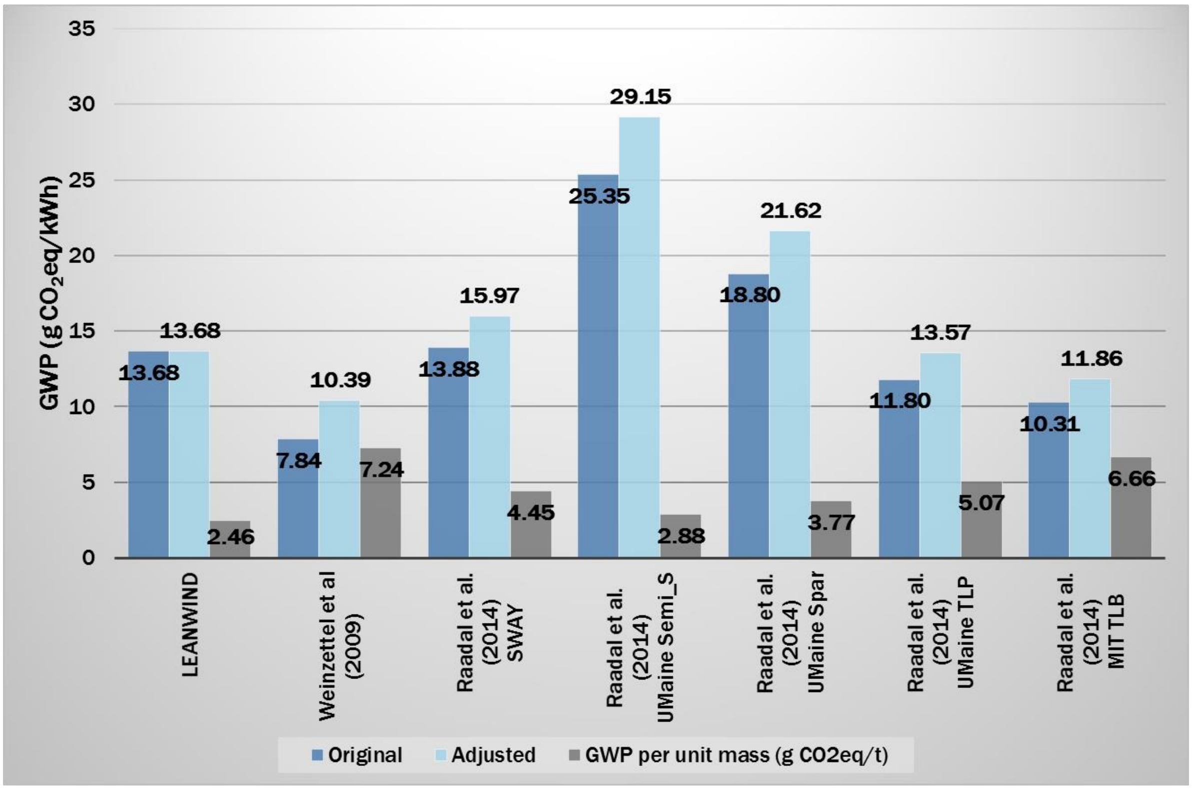
[68] David Rudolph, Claire Haggett, Mhairi Aitken, "Community Benefits from Offshore Renewables: Good Practice Review, Climate Exchange, University of Edinburgh, 2015. ISO, "BS EN ISO 14040 - Environmental management - Life cycle assessment - Principles and framework," British Standards Institute, 2006.ISO, "BS EN ISO 14044 - Environmental management - Life cycle assessment - Requirements and guidelines," British Standards Institute, 2006.
[69] J. Weinzettel, M. Reenaas, C. Solli, and E. G. Hertwich, "Life cycle assessment of a floating offshore wind turbine," Renewable Energy, vol. 34, no. 3, pp. 742-747, Mar, 2009.
[70] H. L. Raadal, B. I. Vold, A. Myhr, and T. A. Nygaard, "GHG emissions and energy performance of offshore wind power," Renewable Energy, vol. 66, pp. 314-324, 2014.
[71] J. Weinzettel, M. Reenaas, C. Solli, and E. G. Hertwich, "Life cycle assessment of a floating offshore wind turbine," Renewable Energy, vol. 34, no. 3, pp. 742-747, Mar, 2009.

Figure 40 Comparison of LEANWIND floating foundation with results from other studies[72]



Only one published study was identified that has reported the impactsof a gravity base foundation[73], and the comparison of the global warming potential of the LEANWIND GBF with this is shown in Figure 41below(the two sets of results from[74]represent the results from two different scenarios, with 20 and 25 year lifetimes). The impact of the LEANWIND GBF is found to be much lower than the adjusted values estimated by Arvesen et al.[75] but the impacts per unit of mass are much higher for the LEANWIND foundation, which is half the total mass of that studied by Arvesen et al.

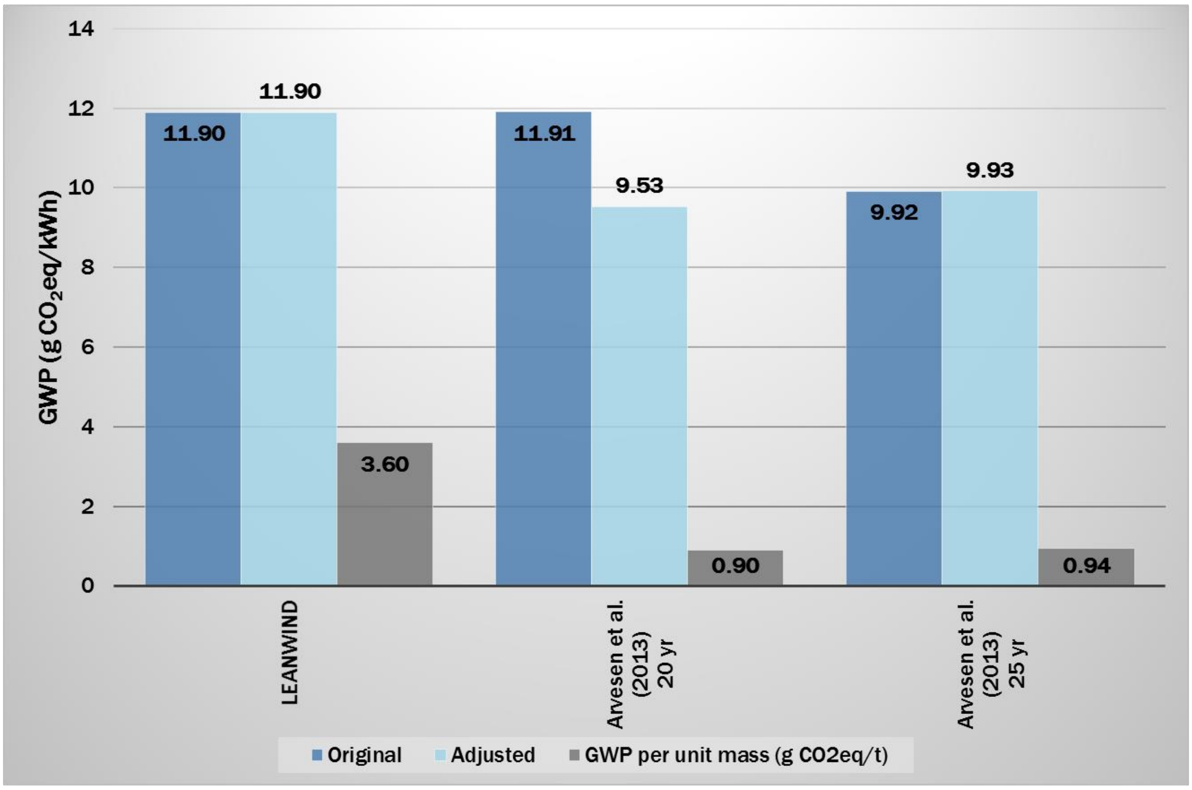
[72] Scottish Government. “Good practice principles for Community benefits from Offshore Renewable Energy Developments”, 2015. David Rudolph, Claire Haggett, Mhairi Aitken, “Community Benefits from Offshore Renewables: Good Practice Review, Climate Exchange, University of Edinburgh, 2015

[73] B. Reimers, B. Özdirik, and M. Kaltschmitt, “Greenhouse gas emissions from electricity generated by offshore wind farms,” Renewable Energy, vol. 72, pp. 428-438, 2014.

[74] Ibid.

[75] Ibid.

Figure 41 Comparison of LEANWIND gravity base foundation with results from another study[76]



The mass breakdown of the two foundations is shown in Table 21 below, and it can be seen that the LEANWIND foundation does have a higher proportion of reinforcing steel, which may account for the higher impacts per unit mass. The lower overall impacts of the LEANWIND foundation are likely attributable to the innovative floating assembly and installation strategy.

Table 21 Comparison of mass of materials in different GBFs[77]

Studied foundation	Concrete (t)	Reinforcing steel (t)	Total
LEANWIND	1,329	525	1,854
Arvesen et al. (2013)	3,146	560	3,706

[76] ISO, "ISO/TS 14048 – Environmental management – Life cycle assessment – Data documentation format," International Organisation for Standardisation, 2002.
[77] ISO, "ISO/TS 14048 – Environmental management – Life cycle assessment – Data documentation format," International Organisation for Standardisation, 2002.

5.7 Conclusions

This analysis aims to examine the life-cycle environmental impacts of the innovative foundations that have been developed as part of the LEANWIND project: a jacket foundation with an innovative floating deployment/suction bucket seabed attachment design, a floating foundation, and a gravity base foundation (GBF) constructed with the caisson dock methodology. All of these foundations have been designed for installation at West Gabbard, for a sea depth of up to 60m. Note that the impacts of the turbine itself have not been considered in this study.

The analysis employed life-cycle assessment (LCA) methodology, using two different software tools: Sima Pro PhD v8.3 with the Ecoinvent database, and GaBi 6 with the PE-International database. The analysis of the GBF focussed on three key life-cycle stages or construction phases: the installation and mobilisation of equipment, the construction of the caisson itself (including the impacts of extracting raw materials) and final installation on the seabed. All life-cycle stages of the steel foundations were considered, including extraction of raw materials, manufacture, maintenance, decommissioning and disposal. Environmental impacts were assessed according to the CML 2001 and 2013 standard impact assessment methods, and all results are presented.

The analysis found that the environmental impacts of the floating foundation are generally higher than for both other types of foundation, due to the greater use of steel per unit of energy produced, but it is important to note that there is much more flexibility over the choice of installation location for this type of foundation.

The GBF was found to have the lowest impacts in all of the studied impact categories, suggesting that it is be the better option in terms of environmental impacts. The higher impacts of the jacket foundation are largely due to the manufacturing processes and materials used for the manufacture of steel for the main structure and aluminium alloy for the sacrificial anodes. The highest impacts for the GBF were from the installation vessels.

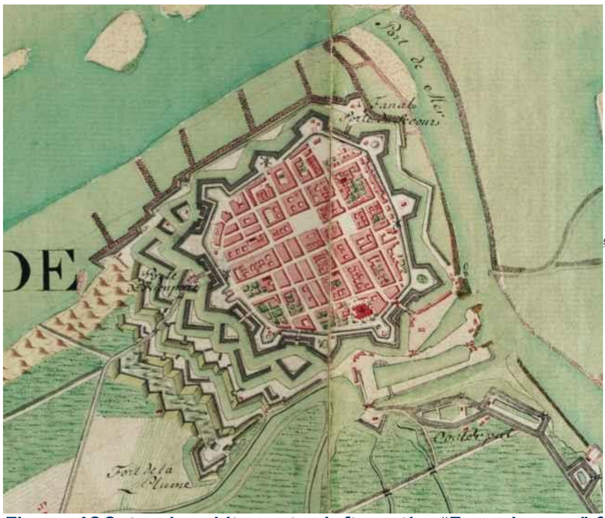
When one key impact, the global warming potential, is compared to that in other published studies, it is found that theLEANWIND solutions perform well relative to their competitors. In the case of both the jacket foundation and GBF, their impacts are found to be considerably lower than those for a similar sized foundation for a similar water depth, probably due to the lower impacts of the floater/suction bucket design and innovative caisson dock construction methodology.

The analysis has also highlighted the key areas for potentially reducing the environmental impacts of these foundations, principally in minimising sea vessel fuel consumption and optimising the design of the steel foundations for minimal use of steel; in the case of the floating foundation, reducing the length of the mooring lines per turbine or sharing mooring lines should be investigated.

6. Case study of the Port of Oostende becoming established as a base for Offshore Wind

Introduction

The port and city of Ostend[78] on the Belgian North Sea coast dates back at least to 1265. It has seen many ups and downs in its history and been destroyed on several occasions. Nevertheless, throughout the centuries, the port has remained an essential asset of the city, which since the 1970's has had a stable resident population of c.70.000 (145.000 including its closest surroundings). Ostend lies in West Flanders province (1.17 million inhabitants, capital: Bruges) within the Flemish Region & Community of federal Belgium.



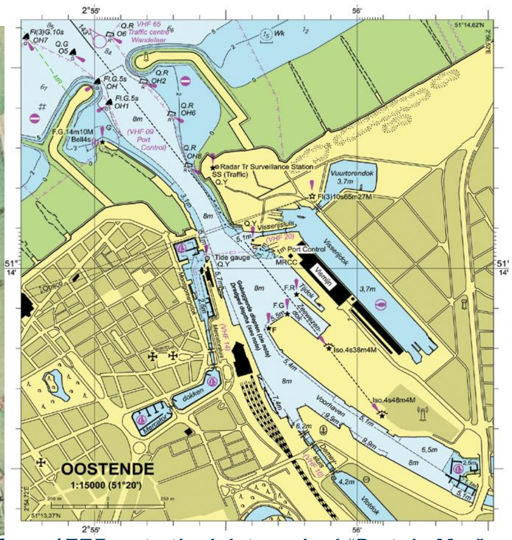


Figure 42Ostend and its port – left: on the "Ferraris map" from 1775, note the inlet marked "Port de Mer", and right: today. Sources: Royal Library of Belgium and Port of Oostende.

6.1 General Background

Ostend is an established tourist destination on the Belgian coast, its tourism heritage goes back to the 1830's. However, other sectors of its economy have been struggling, and unemployment is higher than the national average.[79]

Ports are very important to the Belgian economy (the EU's 9th largest) although Belgium has only 67 km of coastline. It has six international ports: Antwerp, on the river Schelde, is Europe's 2nd largest port. According to statistics from the National Bank of Belgium [80], the port of Antwerp creates €11 bn direct value added annually, 2% of the country's GDP, and 60,000 direct jobs.

Ostend, a smaller port engaged in fisheries, ro-ro ferries, containers and bulk goods, has seen a decline in its traditional businesses in the last decades. Such declines are often

[78] Throughout this report, the spelling **Ostend** is used, being the accepted English orthography (French and German: **Ostende**) except in referring to specific organisations or terms that incorporate official spelling in Dutch, **Oostende**.

[79] Official statistics: statbel.fgov.be/,

[80] National Bank of Belgium "Economic importance of Belgian ports" 2016-06-26. These statistics include both the maritime and "non-maritime" economic clusters associated with the ports.

interpreted in the concept of "life-cycle of ports" by Roger H. Charlier, *emeritus* professor at ULB, the Free University of Brussels.[81] In this life-cycle approach, ports since Antiquity have gone through periods of development, growth and bloom, followed by obsolescence, but renaissance also occurs. Charlier points out that when ports fade to oblivion, their cities also do, citing Bruges as a prototype example.[82]

The present study is motivated by the fact that Ostend today has become a main hub for offshore wind, an industry unknown in Belgium only 10 years ago. How did this happen? According to Charlier, renaissance cycles occur by adaptation to new external conditions. It has been pointed out by Stubbe[83] that conventional economics, where a port's significance is calculated purely on basis of "the number of boxes handled", cannot fully explain the turn-around observed. Stubbe remarks that ports are about much more than cargo traffic. In the North Sea region, the growth of offshore wind has been spectacular, and the role of ports is relatively little studied, compared to other ports businesses and also much less than wind power industry offshore.

After a modest start in shallow waters off the Danish coast from 1991, offshore wind is today the prime renewable energy supply source in the EU.[84] A much less well-known fact is its adoption in Belgium, with the second-smallest coastline of all EU coastal states. In 2015, Belgium installed the EU's 4th highest capacity after the UK, Denmark and Germany (5th in the world). At the end of 2016, Belgium is ranked 4th in the world in cumulative installed capacity per inhabitant.Offshore wind is thus a key contributing factor to reaching Belgium's national renewables target of 13% [85], equalling a 21% share of RES electricity. The 2020 offshore wind target is2 292 MW from all the nine concessions, around 450 turbines to deliver an annual output of around 8.5 TWh [Elia 2015-25][86] and NREAP [87]. There are ambitions for as much as 4000 MW by 2030.

For the LEANWIND project, which has as one of its aims to promote sustainable growth of offshore wind, both from a technical and socio-economic perspective, it is of interest to chart and analyse why it was Ostend, not its bigger and more established competitors in Antwerp and Zeebrugge, or Dutch ports such as Rotterdam and Vlissingen, that took the lead role in developing the Belgian offshore wind industry.

Belgium is a regionalised state, with only its territorial waters and its EEZ under federal jurisdiction. In 2003-4, the federal government implemented a structured plan process

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[81]Charlier 2005, PIANC Seminar on life cycle approach in port infrastructure, reducing financial risks and achieving cost savings", Brussels Belgium February 2, 2005.
[82]Charlier 2013, "Life cycle of Ports", Int. J. of Env. Studies Vol. 70, Issue 4, pp. 594-602.
[83] Stubbe 2016, The port of Oostende - Home for the Blue Growth cluster in the Southern North Sea, European Energy Innovation, Winter 2016 issue, published by http://www.europeanenergyinnovation.eu/Latest-Research/Winter-2016/
[84] AVG 2017, Unleashing Europe's offshore wind potential A new resource assessment Report by AVG for Wind Europe June 2017.
[85] NREAP for the Kingdom of Belgium, as described in the Appendices to Directive 28/2009/EC.
[86] Website www.elia.be
[87]In its NREAP Belgium did not provide the breakdown into on- and off-shore wind as prescribed by the Commission, however, EWEA estimates from 2011 [EWEA, EU Energy Policy to 2050, section "Belgium", , European Wind Energy Association (now Wind Europe) Brussels 2011] indicate that the plan was consistent with a 2 GW offshore target for 2020.

that led to the award of 9 offshore concessions between 21 and 52 km from shore, at depths of 12 to 42 m. Construction of the first wind park, C-Power, started in May 2017. Ostend port, which as mentioned had seen its traditional business drop, took on its first role hosting the construction of six huge gravity-based foundations for C-Power Phase 1 [Mengé and Gunst 2008].[88] It soon became evident that this new economic activity, today known as a key part of "Blue Growth", needed special infrastructure and space in order to be able to realize further constructions. Thus, in 2009, the Port decided to rethink its infrastructure strategy so as to handle supply, installation and maintenance for further offshore wind parks. This resulted in setting up the dedicated Public-Private partnership "REBO" (Renewable Energy Base Oostende) N.V. in October 2010. It was owned 55% by the Port andthe public investment *ParticipatiemaatschappijVlaanderen,* PMV, and 45% private construction, marine contracting, offshore maintenance and logistics companies. REBO aims to be an efficient and cost-effective offshore terminal to handle, lift, store, assemble and transport offshore components. It has invested or co-invested more than €15 million in reinforcing the infrastructure, 15 hectares terminal surfaces with heavy lift capacity quay (up to 20 t/m^2), 120 ha dedicated areas for wind farm logistics, office and storage space to attract service providers in the offshore industry.

This is the key background for the present study, performed to assess, as far as can be done by qualitative data and methods, the success of Ostend realising its "renaissance" as a port for the offshore wind industry. The emphasis is on societal impacts, essentially defined as the contributions the offshore wind industry makes to the local community, in this context the city and port of Ostend. Quantitative socio-economic data do not exist at the local level but only at the national level.[89]

It is not the purpose of this study to provide a comprehensive description of Ostend port and of its offshore wind oriented industry cluster. Detailed information as well as lists of the wind farms constructed and/or serviced from Ostend is provided by the referenced works of Stubbe and Timmermans.

6.2 Methodology background

The interviews were structured according to accepted methods of qualitative research, following the approaches of Kvale[90] and Dunn[91]. Using closed formulations, or "opinion statements", was selected rather than open-ended questions so as to obtain greater precision in the analysis of responses. The interviews in the present study were interactive and not based on pre-filled forms, with the majority done face to face (only a few by phone). They were of a conversational nature rather than interrogatory. Therefore, it was possible to assist interviewees avoiding to select "neutral" if they were not in fact neutral to the statements given. The order of questions was fixed.

[88] Mengé and Gunst: "Gravity Base Foundations for the Wind Turbines on the Thorntonbank, Belgium", paper presented at 15th Innovatieforum Geotechniek, Antwerpen 8 Oct 2008.
[89]Breyer et al. 2017: "The socio-economic impact of the Belgian offshore wind industry, Report by CLIMACT commissioned by the Belgian offshore Platform, March 2017.
[90]Kvale 1996: Interiews: an introduction to qualitative research interviewing, Sage Publications, Thousand Oaks, California 1996, The University of Michigan, ISBN 0803958196
[91] Dunn "Interviewing", Ch. 6 in Qualitative Research in Human Geography, ed. Hay, Oxford University press 2000, ISBN 0195430158

Qualitative research interviews seek to describe and probe the opinions on key themes in the mind of the subjects. The main task in interviewing is to understand the meaning of what the interviewees say. Qualitative research interviews seek to cover "factual" as well as "opinion" levels, the latter the more challenging.[92] Interviews are particularly useful for getting the story behind participants' experiences. The interviewer can pursue in-depth information on and around the topic. Interviews are a much more personal form of collecting information than questionnaires, because the interviewer works directly with the respondent. Unlike (e-) mail surveys, the interviewer has the opportunity to probe or ask follow up questions. Interviews are generally easier for respondents (interviewees), especially if what is sought is opinions or impressions. Interviews are however time consuming and can be resource intensive. Interviews are completed and results analysed by the interviewer based on what the respondent says.

In this study, the conversational style of the interviews meant that some subjects that most or all respondents were familiar with were not formally requested as an opinion. One example is referring to the Ostend offshore wind industry as a "cluster" (see remark under "Executive Summary".

However, as some questions (statements) could relate to competitive business strategy, two aspects were clarified before starting each interview:

1. interviewees were asked to express their personal opinions
2. their identity would not be revealed; only statistical trends would be reported.

No potential interviewees declined to be interviewed, but two (from large organisations) requested a short waiting period to decide before they accepted to be interviewed.

6.3 The interview results

This section describes the response to the questions covered in the interviews. In order to get results that were both consistent and manageable to analyse, the questions were formulated as statements to which each interviewee was asked to state his degree of disagreement/agreement, using a scale in line with good practice according to Dunn and Kvale.

6.3.1 Affiliation

Interviewees were asked to self-identify their affiliation to each of ten defined categories:

1.	Public administration	*city, provincial or other public agency*
2.	Port & Base	*port or offshore base management*
3.	Offshore developer	*developers / owners of offshore wind farms*
4.	OEM representative	*original equipment manufacturers,such as WT's*
5.	Tier 1+2 suppliers	*supplier of major sub-systems to the OEM's*
6.	Supplier/Sub-supplier	*lower tier suppliers of products and services*
7.	Logistics operator	*vessels and other logistical equipment and services*
8.	O&M operator	*operations & maintenance contractors and suppliers*
9.	Civil society	*including NGO's, campaign groups and citizens*
10.	R&D/Other	*academic researchers / consultants*

[92]Kvale 1996: Interiews: an introduction to qualitative research interviewing, Sage Publications, Thousand Oaks, California 1996, The University of Michigan, ISBN 0803958196

Multiple answers were not allowed. In cases of doubt, the interviewer helped explain the definitions. Respondents who had changed jobs were asked to choose the one that was considered most relevant to the study. The distribution in categories are shown below.

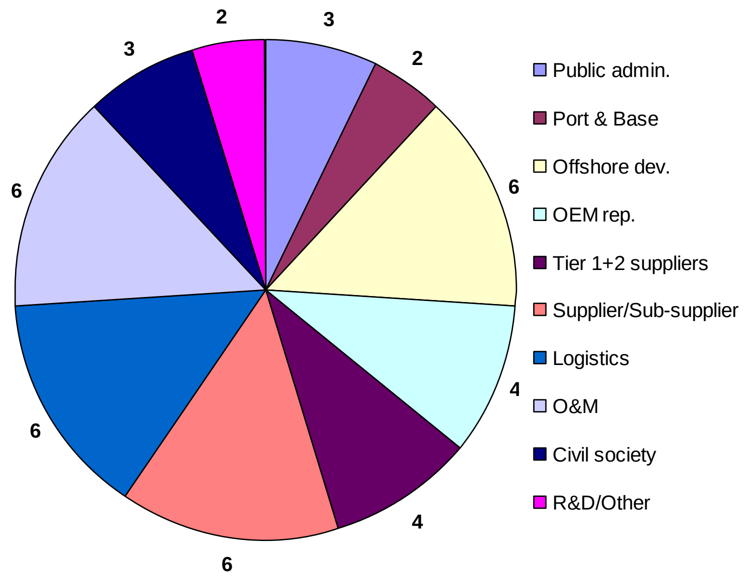


Figure 43 Affiliation of the interviewees

The total number of respondents was 42. Industry participants (32) are more than 75%, however the 10 others make the group comprehensive and diverse. 8 respondents were female. No category was represented by only one person. As to seniority, self-declared functions and/or titles on business card indicate the majority to be of medium or higher seniority, with a preponderance of technical-managerial jobs. No age data was collected.

6.3.2 Time frame of involvement

Each interviewee was asked to describe his establishment in Oostende on a time scale as follows:

"I am / We are / Our company is established in the Ostend area since…"

In cases (3) where respondents had changed jobs/roles whilst working in the area they were asked to choose the one they considered to be most relevant to the study.

2009 or earlier	2010 -12	2013-15	2015-	Not (yet) present
6	8	11	10	7

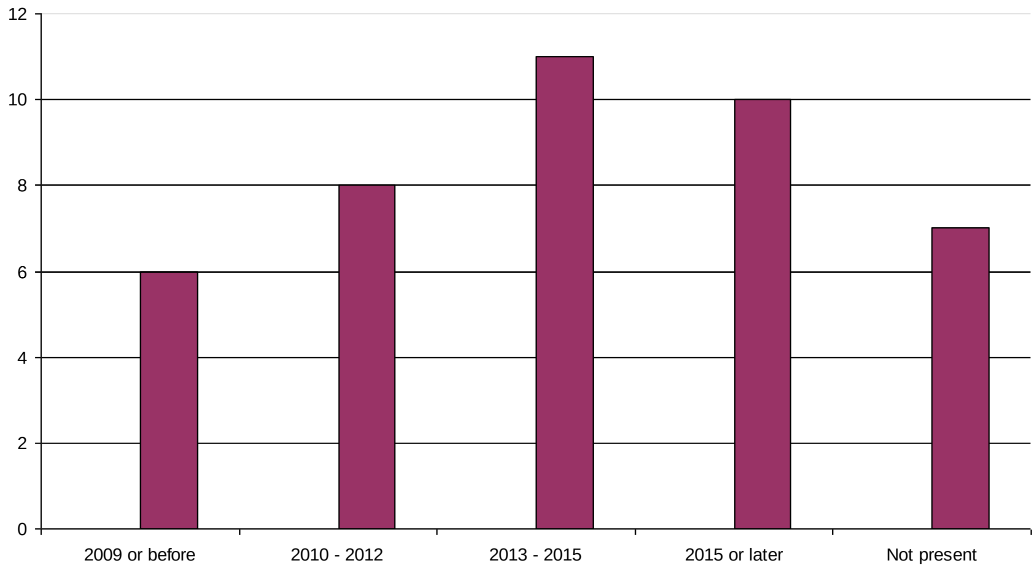


Figure 44Year of establishment of the interviewees' companies / organisations in Oostende community.

The six respondents established for the longest time came from the construction and shipping industries. The seven not established in Ostend were from other ports or port cities, or companies established elsewhere. They are included in the present study since their opinions were considered to be relevant. Because all interviews were carried out in Ostend, or in immediate connection with industry events there, the seven non-local interviewees were also assumed to possess knowledge of, or specific interest in, the port and local community.
An informal review of the responses of "non-locals" showed no significant deviation from this assumption, *e.g.* industries based in other ports did not seem to give widely different responses to those of locally based industry representatives, one Port representative not from Ostend was in close agreement with another, etc.

The responses show that a large fraction, 25 of 42, nearly 60%, have been present for a relatively long time (3 years or more) whilst 10 of the 35 are more recent arrivals. This is thought to reflect well the growth and development of activity over the years and thereby indicates that the selection of interviewees is representative.

6.3.3 The opinion statements

Following the introduction, the interviewees were asked to express their opinions about the subject of the study. The interviewees response to the ten (later 11) pre-formulated opinion statements, were scored on the following scale:

Strongly disagree	Disagree	Neutral	Agree	Strongly agree	No answer

In order to facilitate statistical analysis, numbers were assigned to responses as follows:

-2 for "Strongly disagree"
-1 for "Disagree"
0 for Neutral, interpreted as "Neither agree nor disagree"

+1 for "Agree"
+2 for "Strongly agree"

This type of scoring allows easy quantification of results and comparing across themes. An "average" response is readily calculated and immediately comparable to individual responses quickly seeing the opinion of an individual versus the "average". The average responses were calculated without taking into account blank ("No answer") responses.

The Opinion Statements were presented always and consistently in the same order that also is the order in which the results are given below. All statements – except for the 11th which was added later – had been formulated together in pairs, which was an attempt to frame and strengthen trends in the opinions.

The following section presents the results graphically with both paired statements shown together on one page. The response data are also included in tabular form in Table 1.

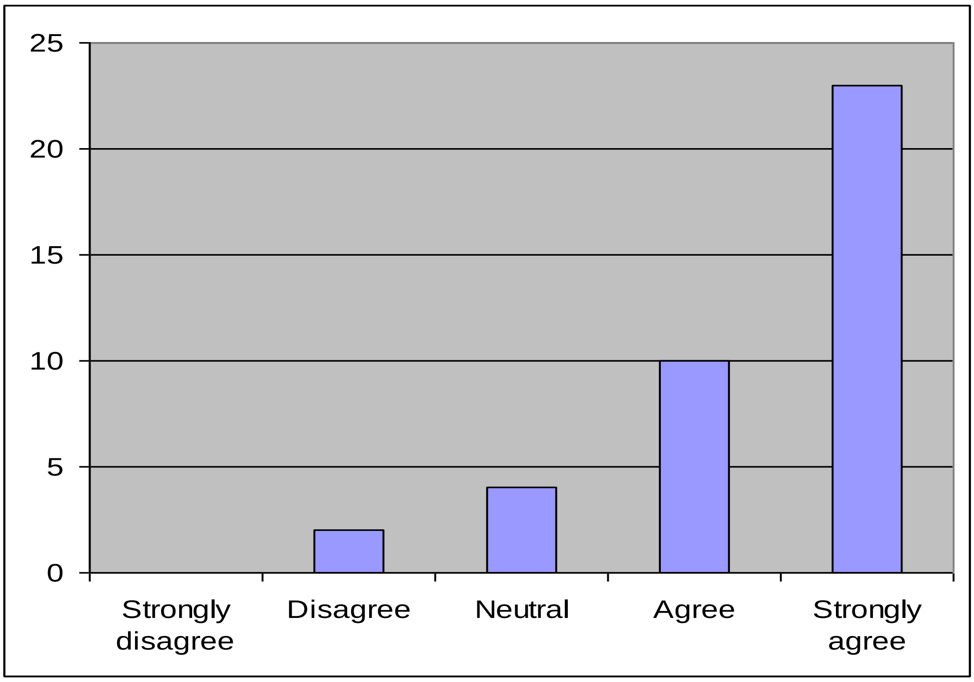
Table 22 Respondents' data from the interviews

label	Respondent no.	Statement 1	Statement 2	Statement 3	Statement 4	Statement 5	Statement 6	Statement 7	Statement 8	Statement 9	Statement 10	Statement 11	Resp. ave.
PA1	1	2	-2			1	0	-2	2		2	-1	0.43
PA2	2	-1	0			2		-2	2	0	0		0.14
PA3	3	1	-1	2		2	-1	-2	2	2	1	-1	0.67
BA1	4	2	-2	2	-2		-2	-2	2	2	-1	-2	-0.11
BA2	5	2	-2		-2	2	-2	-2	2	2	-1	0	-0.11
OD1	6	2	-2	2	0	2	-2	-1	1	2	-1	1	0.30
OD2	7	2	-2	1	-2	2	-2	-1	2	1	0	1	0.10
OD3	8	2		1	-1	2	-1	-2	2	2	-2	0	0.33
OD4	9	2	0	2	-1	1	-1	-2	2	1	-1		0.30
OD5	10	1	-1	1	-1	1	-2	-2	2	2	-1	2	0.00
OD6	11	1	-1	2	1	1	0	-1	1	2	-1	1	0.50
OEM-1	12	2	-2	2	2	2	-2	0	0	2	0	2	0.60
OEM-2	13	2	-1	2	0		-2	-1	2	-1	1	1	0.22
OEM-3	14			2	-2	2	-1	-1	1	2	-1	0	0.25
OEM-4	15	2	1	1	-2	2	-1	-2	1	2	0	-1	0.40
T12-1	16	2	0	2	-2	2	1	-2	2	1	-1	-2	0.50
T12-2	17	2	-2	2	1	1	0	-1	2	0	0	1	0.50
T12-3	18	1	-2		-2	2	-1	1	-1	2	-1	0	-0.11
T12-4	19	0	-1	1	-1	0	-1	0	0	2	-1		-0.10
T3+1	20	0	-2	1	-1	2	-2			2	0	0	0.00
T3+2	21	2	-2	2	1	2	-1	1	0	2	-2	0	0.50
T3+3	22	1	-2	2	1	1	-2	-1	1	1		-1	0.22
T3+4	23	2	-1	1	0		-1	-2	2	1	-1	1	0.11
T3+5	24	1	-1	0	-2			-2	2	1	-1		-0.25
T3+6	25	1		1	-2	2	-1	-2	2	2	0	0	0.33
LO1	26	2	-2	2	-1	0	-1	-2	2	2	-1	1	0.10
LO2	27	2	0	2	-1	2	-2	-2	2	1		-1	0.44
LO3	28	2	-1	2	-1	2	-2	-2	2	1			0.33
LO4	29	2	-2	1	0	2	-2	-1	1	2	-2	0	0.10
LO5	30	0	-2	-1		2	-1	-1	1	0	0	0	-0.22
LO6	31	2	-2	2		2	0	-2	2			-1	0.57
OM1	32	1	-2	2	-1	1	-1			2	-2	-2	0.00
OM2	33	1	-2	2	-2	1	-2	-1	1	2	-2	1	-0.20
OM3	34	2	-2	2	0	2	-2		2	2	-1	0	0.56
OM4	35	2	-1	2	1	2		1	-1	2	0		0.89
OM5	36	2		1	2	1	-1	-2	2	1	-1	0	0.56
OM6	37	2	0	-1	0	-1	-2	-2	1	1	-1	1	-0.30
CS1	38	-1	0	0	0	2	0	-2	2	2	-1	-1	0.20
CS2	39	2	-1	0		2	-1					0	0.40
CS3	40		-1	1		2	-1			2	0	-1	0.50
OTH1	41	2	-2	1	-1	2	-2	-2	2	0	2	0	0.20
OTH2	42	2	-1	1	-1	2	-1	-2	2	-1	2	-1	0.30
	Ave. statement	1.48	-1.29	1.34	-0.63	1.58	-1.23	-1.38	1.45	1.38	-0.51	-0.06	
nonblank		40	38	38	35	38	39	37	38	39	37	36	
Strongly disa	count -2	0	19	0	10	0	16	22	0	0	5	3	
Disagree	count -1	2	12	2	11	1	17	10	2	2	17	9	
Neutral	count 0	3	6	3	7	2	5	2	3	4	10	13	
Agree	count 1	9	1	13	5	9	1	3	9	10	2	9	
Strongly agre	count 2	26	0	20	2	26	0	0	24	23	3	2	
No answer	blank	2	4	4	7	4	3	5	4	3	5	6	

6.3.4 Results of opinion statements

Opinion Statement 1 "The Ostend offshore wind industry makes positive contributions to the local economy and community"

Opinion Statement 2 "The Ostend offshore wind industry is a source of problems to the local community"



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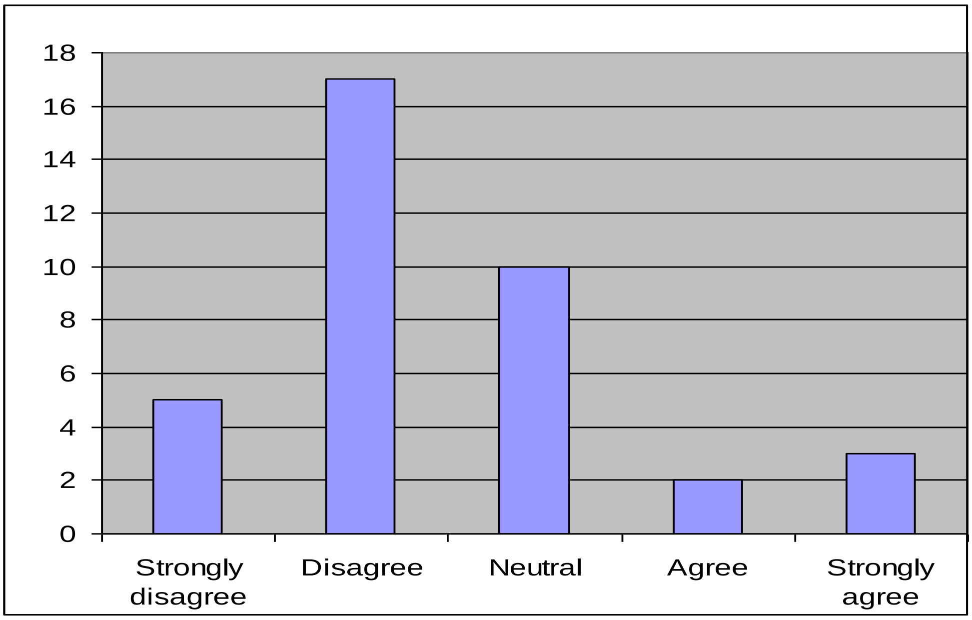
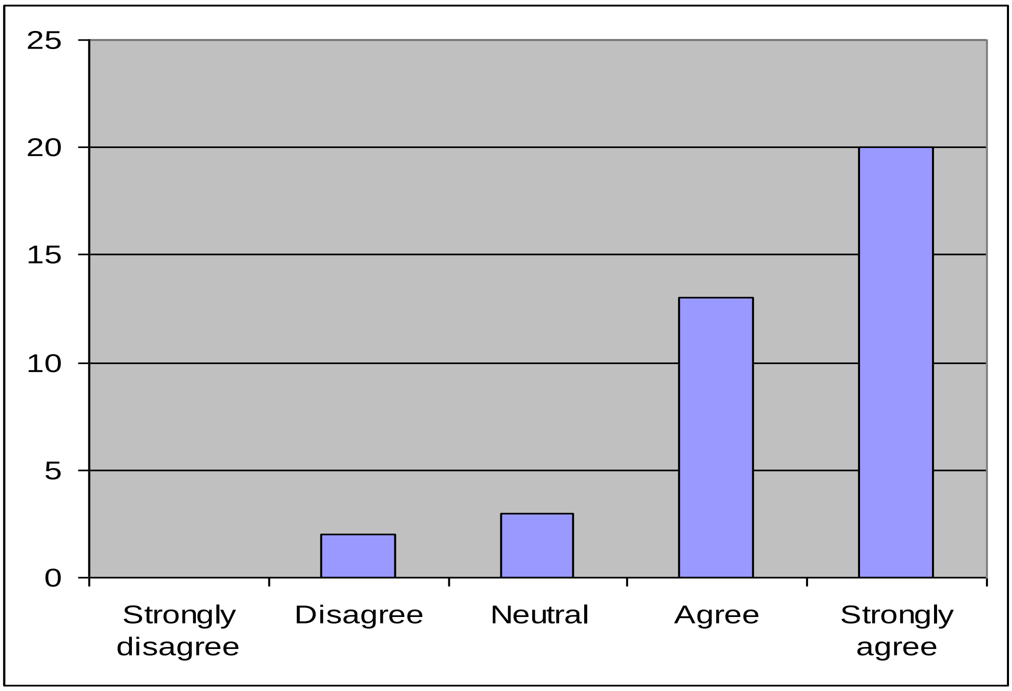


No

Opinion Statement 3
"Being located in the terminal and/or port area is beneficial to our business/activity."

Opinion Statement 4
"Being located in the terminal and/or port area can be risky for our business/activity because of its physical closeness to competitors."



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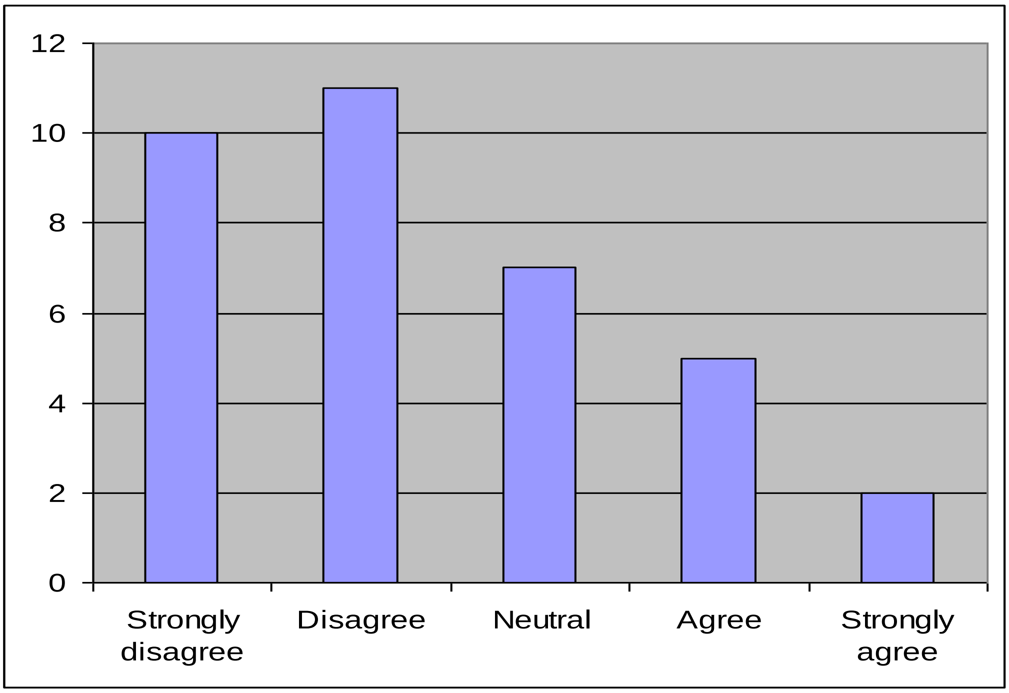

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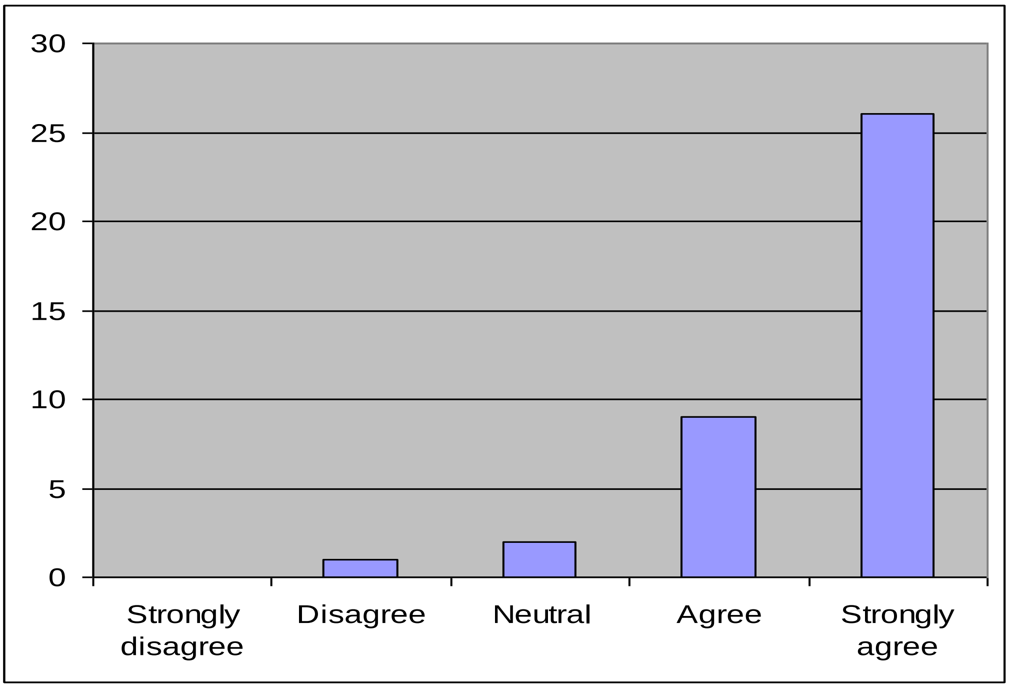
Opinion Statement 5 "REBO/the Port/the Authorities have done a good job facilitating our operations here."

Opinion Statement 6 "Other ports and other companies/organisations with previous experience inother kinds of offshore energy (oil & gas) are better prepared for being successful in offshore wind."



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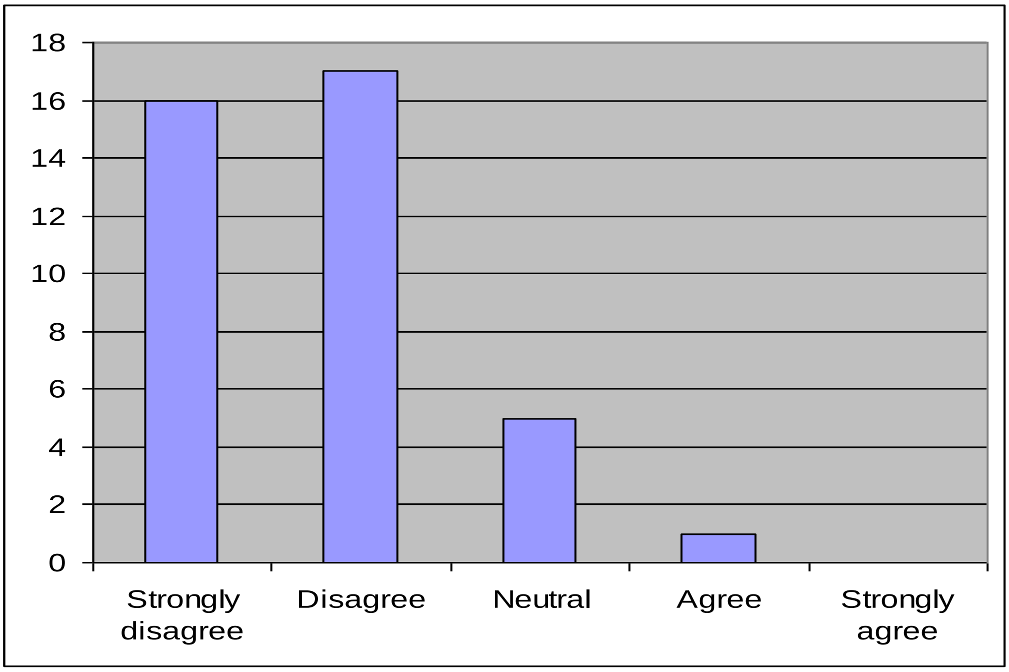
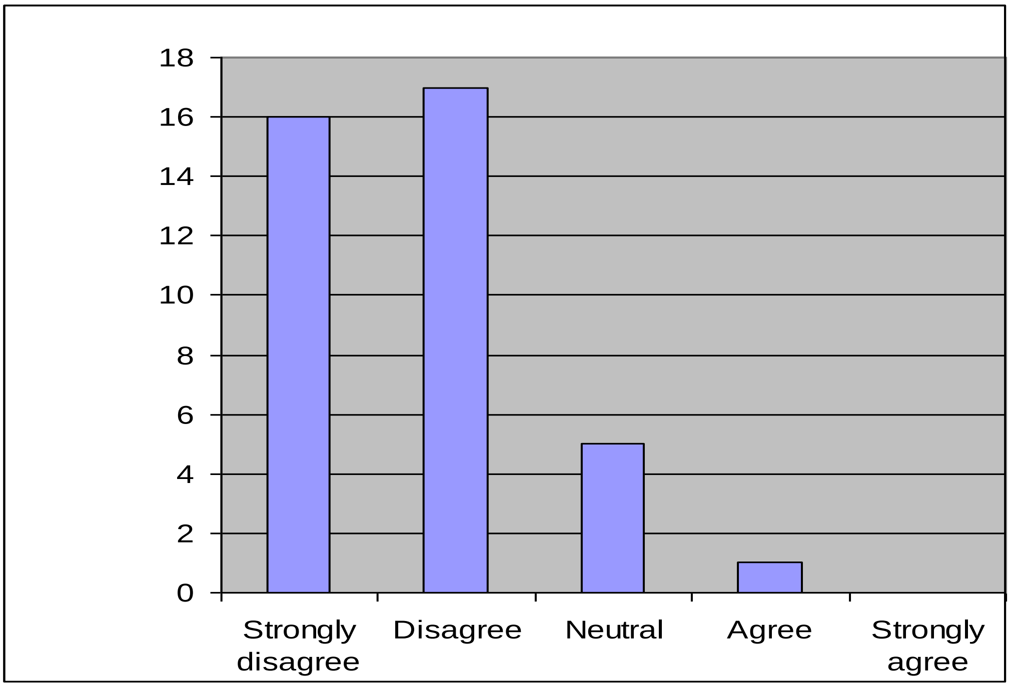


No

Opinion Statement 7 "Our business/activity here is short-term in nature; our plan horizon is 2 years or less."

Opinion Statement 8 "Our business here is part of a longer term strategy; we intend to stay 3 years or more."



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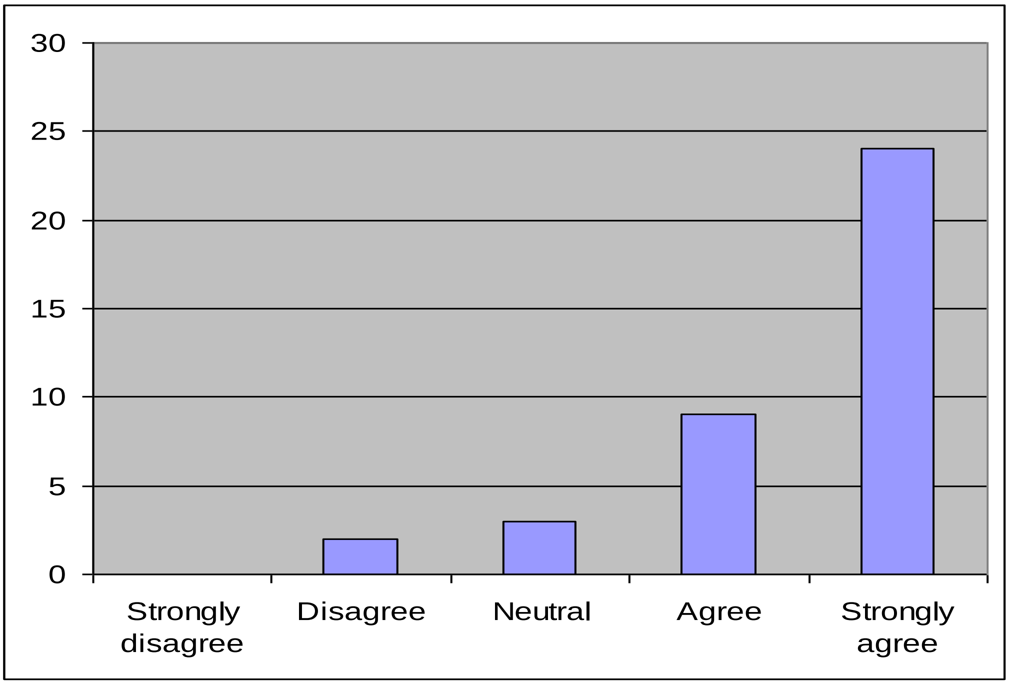
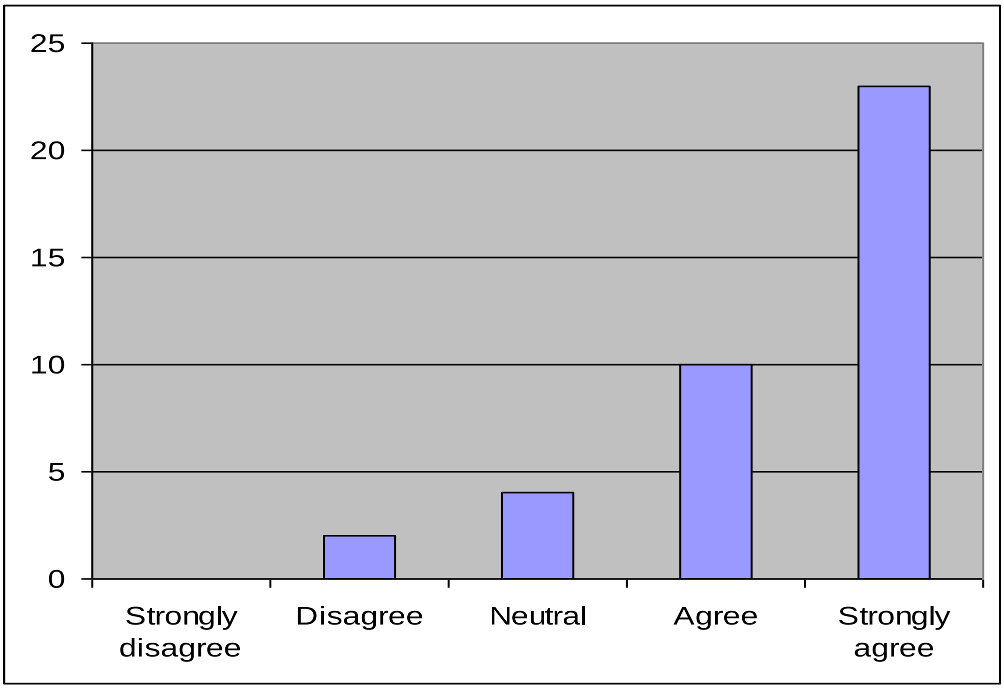


No

Opinion Statement 9
"The most important keys to success in offshore wind is to use only reliable, well-proven technologies that guarantee developments to be completed on time and within budget".

Opinion Statement 10
"Using the most advanced new technologies and applying the latest innovations from R&D and by the offshore wind supply sector are the most important keys to success."



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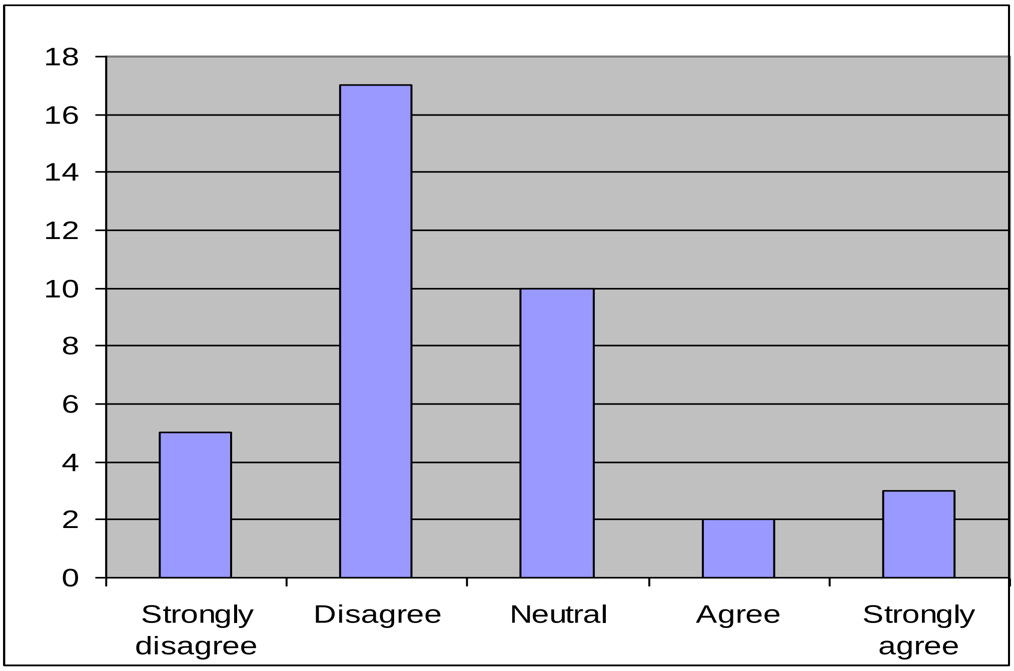
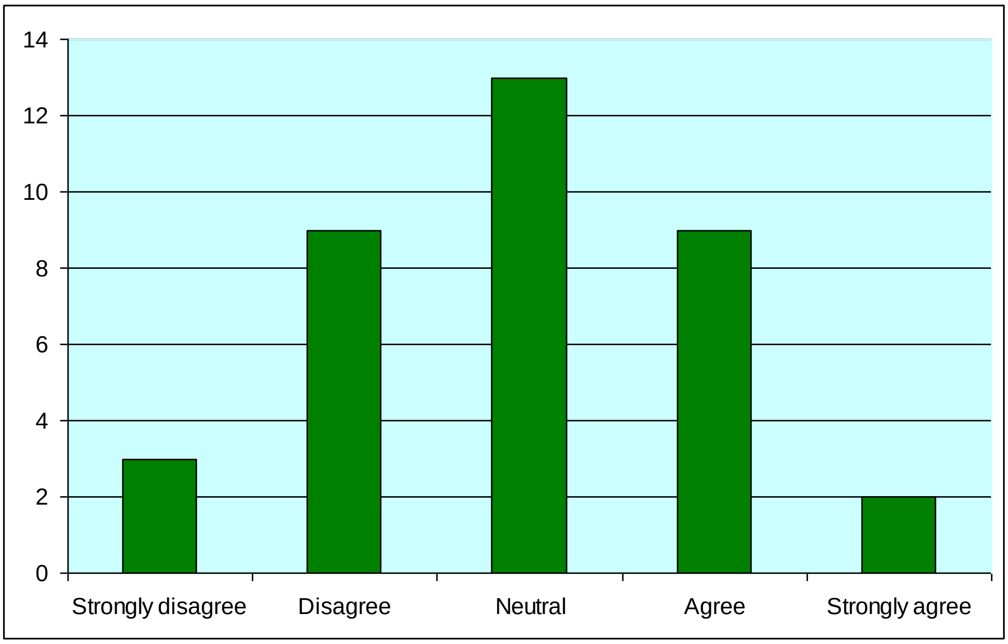


No

Opinion Statement 11
"It may be negative for our business here if the prices for offshore wind in Belgium fall to the much lower levels indicated by recent auctions and tenders elsewhere."



No

Comments to Statement 11

This statement was added during the study, motivated by mounting debate after the low tender/auction prices for offshore wind projects in Netherlands, Denmark and Germany. The location of the Dutch Borssele concession areas/planned developments, all directly adjoining the Belgian ones, make the situation acute. Clearly, attitudes are uncertain. It was mentioned that at least the earlier tenders were post-2025. Some errors may result as the formulation of the question was not at the beginning 100% consistent.

This statement was formulated with the earliest interviews in the Spring of 2016, just as the first successful low-cost bids started to appear and respondents spontaneously went on to comment. Even though the formulation was not always as consistent as for the ten "paired" questions, in order to maintain consistency of analysis, it has been attempted to analyse the responses in the same way. Several respondents commented that in light of recent auction results in Netherlands, Germany and Denmark, they expect also costs in Belgium to fall, and continue falling. Another comment came to the effect that falling costs was a business opportunity for the company concerned – and for Ostend, if it was able to secure export business for other countries, especially the neighbouring Borssele area in Dutch waters. One respondent pointed out lower cost (in Ostend) compared to setting up business elsewhere.

This is a special situation as Belgium has less sea area available for offshore wind than most other EU countries, once the awarded concessions have been built and so will be more sensitive to winning exports than any other economies, including the Netherlands.

Comments to each of the paired statements 1 to 10.

Comments to 1 and 2*(whether offshore wind is a “solution” or “problem”)*

No attempt was made to systematically chart *how or in* what way positive contributions, respectively problems, were perceived buy the interviewees. The nature of the positive contribution was however sometimes spontaneously described as (no particular order):

- Providing jobs
- Attracting talent/new business
- “Placing the city on the map”

As for problems, the few who partly agreed with Statement 2 mentioned:

- Offshore wind subsidies add to the tax burden of (local) citizens
- Energy is seen as a domain of corporations, “not for the common man”

The overwhelming positive attitude could be linked to the 75% dominance of industry in the sample. Nevertheless, non-industry responders were also positive. Issues that some studies have addressed, such as noise and local pollution/waste, were not mentioned.

Comment to 3 and 4*(“benefits versus risks of being located in a cluster” issues)*

All respondents were familiar with cluster terminology and considered it to describe well the Ostend “wind industry village”. These responses massively confirm that “cluster benefits” are perceived as greater than fears of commercial risk versus competitors. This might be different in another context, e.g. if there is a larger number of operators in the same segment. (The small size of the Ostend cluster probably still limits this from being seen as a problem). The slightly higher rate of “no answer” chosen by respondents could indicate a slight trend in this direction, however.

Comment to 5 and 6*(“location satisfaction” issues)*

With initial respondents, the explicit reference to oil & gas oriented ports was not made, but given if asked. Later, the explicit clarification was inserted in subsequent interviews.

The competitive situation of Ostend and Zeebrugge is one clear example. The responses show clearly and across the board that respondents (who, it must be said, are in Ostend) do not believe that having oil & gas experience necessarily is positive for a port entering offshore wind. A few textual comments noted indicated it could be negative, specifically because of the higher costs and operational margins in that industry (hydrocarbons).

Comments to 7 and 8

The long term nature of most companies’ involvement is evident. Several respondents mentioned the fact that the Port and REBO established and made the infrastructure related investments nearly a decade ago, and that their own business success also will need commitment.

Comments to 9 and 10

This pair of statements was formulated with a view to elucidating attitudes to the effect of what could be termed “technological conservatism” vs. “appetite for innovation risk”, with reference mostly to companies engaged in the two most recent Belgian offshore developments, Nobelwind (Bligh Bank 2) and Rentel. These differ in many aspects, such as the choice of turbines (Vestas 3.2 MW vs. the SWT 7.0-154 as well as in foundations and installation procedures. The hypothesis that led to formulation of these statements was that Nobelwind/BB2 would be seen as "more conservative", whereas Rentel might be perceived as "more adventurous". However, the main finding to draw is that industry vastly prefers "reliable and well-proven" technologies. From a few comments made, one could infer a certain challenge to research projects such as LEANWIND in promoting new innovations that not all come from "deep inside industry".

There was indeed a slight trend that respondents who said they were most involved in the recently completed Nobelwind development (Bligh Bank 2) were a bit more in line with Statement 9, and even more in disagreement with 1 than those who engaged more with the ongoing development supported from Ostend, Rentel. However, differences are small and trends may not be statistically significant – also, many respondents said they were active or intended to be active in both developments.

Thus, these opinions/differences should not be over-interpreted: The Rentel project only entered its operational phase in April 2017, installing its first 7.35 MW SWT in April just the day the last of 50 V112-3.3 machines had completed installation at Nobelwind, one month before schedule.

Some respondents making additional comments highlighted securing a highest possible capacity factor as a reason for preferring a "conservative" approach. For Nobelwind, the anticipated annual production is 679 GWh, which would corresponding to a respectable capacity factor [93] of 41.1%. (the average for all planned Belgian developments until 2020 works out at 37.1%, according to data from Elia).[94]

Data available[95]for developments in other countries are in good agreement with these expectations: Danish offshore wind farmHorns Rev achieved 42.0% over 14 years, with its extension Horns Rev II 48.0% over more than seven years.

Similarly, in the UK, Sheringham Shoal, stands at 40.7% over 3 years whereas the much larger London Array is listed with 42.0%

This observation shows that the challenge to "new technologies and latest innovations", whether from the supply sector or from R&D – is relevant for LEANWIND. It is essential to ensure that innovations from collaborative projects are seen as reliable and well-proven. The conundrum of how to achieve such proof remains.

[93] The capacity factor for a power plant is the annual number of full load hours (producing at rated power output) divided by the numer of hours in the year.
[94] Website www.elia.be
[95] Website energynumbers.info

Some general comments of respondents

This section highlights a few comments of a more general nature made by interviewees. Most were spontaneous, resulting from the open and conversational nature of the study.

They have been selected because they relate not perhaps directly to the questions

In contrast to the other comments, which like the data are completely anonymised, here the affiliation of the originator of the comment has been included. In each case this was done after securing explicit permission of the person being interviewed. (None refused.)

"Efficiency of port operations is the paramount issue"

Said by a vessel operator employee, this serves to remind that offshore wind, while a new activity for a port or base, remains essentially Port business.

"Assembly operations need more than space, local logistics providers a big advantage"

Coming from a second-tier supplier executive, this highlights that advantages of being well established in the local environment are crucial. It is here perhaps noteworthy that, even if prodded, respondents were not at all sympathetic to mandated "local content" rules or practices. The issue covered by the comment relates to competitiveness, and cannot easily be justified by mandatory practice.

"Diversification of skill sets available is key to long term business"

Expressed by an O&M service provider with experience from many countries / locations, this comment is highly relevant for the provision and continues improvement of staff and skills available to the industry. The comment came up in the context of discussing what the region / Ostend city should do on the educational side, to better train available staff, however it also relates to the pair of Statements 7 and 8 on the long- vs. short-term-ness of the companies themselves.

"With big non-recourse project finance, you <u>must be</u> secure against repeating mistakes"

Said by a project developer representative, this soundbite encapsulates the nature of the hypothesized choice between proven and "latest advance" in technology choices.

6.4 Conclusions and Outlook

This study reflects, unequivocally in the clear response of the interviewees, the story of how Ostend port, in a period of a mere decade, has become the established basis and centre of the Belgian offshore wind industry. It represents a clear case of the "Rise and Fall of Ports" as recognised by Charlier.[96] Some specific conclusions are:

- Starting from virtually nothing, Ostend has become a thriving offshore port and base for the growing Belgian offshore wind industry;
- Most offshore wind key industries and other actors are established;
- Strong clustering effects are evident across the offshore wind value chain and are felt by participants as far outweighing potential competitiveness risks;
- The success is due to sustained long term commitment by the public and private sectors working together, inside the Port "REBO" and otherwise;
- Experience transfer to other ports should be productive if the competitive situation of each player is taken carefully into account.

As of May 2017, there are 45 companies located in the "offshore village" inside the Port and REBO base, more than 370 permanent jobs at high levels of professional standards. These are permanent jobs, additional construction jobs fluctuate with industry activity – numbers of 15.000 or more are mentioned.[97]

The Ostend business cluster (which could be precisely but pedantically termed a "sub-cluster" of the maritime cluster in the sense of Belgian official statistics) comprises c.30 international companies and 15 "local" companies, current trends showing more growth in the latter. The supply chain is well represented although some parts of it have one or two companies present whereas several more are active in the business as a whole.

Strengthening is on-going, but there are prospects for continued growth are uncertain as the effect of recent very dramatic cost reductions for future offshore wind sinks in.

Ostend is well placed for an export scenario. As described by Stubbe,[98]the growth of the cluster has demonstrated that each project is different with its own challenges. The evolution of the quality and design of offshore components within the past decade has been enormous. Experience teaches that "every sea has its characteristics: what counts for the Belgian waters, does not work in Danish waters."

[96]Charlier 2005, PIANC Seminar on life cycle approach in port infrastructure, reducing financial risks and achieving cost savings", Brussels Belgium February 2, 2005; Charlier 2013, "Life cycle of Ports", Int. J. of Env. Studies Vol. 70 , Issue 4, pp. 594-602.

[97] Timmermans 2017, "The ideal terminal for offshore wind activities", presentation of 31.01.2017 downloaded from REBO website, latest known update 06.07.2017. Downloadable together with other background material on ostend port from: https://www.reboostende.be/downloads andBreyer et al. 2017: "The socio-economic impact of the Belgian offshore wind industry, Report by CLIMACT commissioned by the Belgian offshore Platform, March 2017.

[98] Stubbe 2016, The port of Oostende - Home for the Blue Growth cluster in the Southern North Sea, European Energy Innovation, Winter 2016 issue, published by http://www.europeanenergyinnovation.eu/Latest-Research/Winter-2016/

In the management of the offshore wind parks, electricity production at sea needs to be monitored in function of the supply to the grid for efficient price-setting, influencing the profitability of the investments. This means that wind park managers must have a daily interaction with the different subcontractors, service providers and equipment suppliers.

Stubbe remarks that wind park-owners and developers who have chosen to establish their headquarters in Ostend, have done this to achieve permanent monitoring of their parks at sea. State-of-art operations & maintenance of the wind parks are necessary to keep turbines operating with optimal efficiency. Consequently, service companies have installed their offices at the port of Ostend in order to secure the maintenance and more companies have asked to open a representation in the Oostende offshore village.Whereas the construction phase has been in the focus of other developments,*i.e.* the functions of "staging ports", in Ostend operations & maintenance aspects are prominent and are sources of permanent and sustained business. In the Ostend "offshore village", three international turbine manufacturers (OEM's) have installed offices, warehouses and workshops in order to be able to intervene in case of emergency maintenance. In order to facilitate their establishment, the port refurbished several buildings next to the REBO terminal and also built new premises. Sustained investment over several years also has led to flourishing of the rest of the offshore wind supply chain as reflected also by the good representation in the interviewees of the present study.

In terms of second- and lower-tier subcontractors, a range of services have found their way to Ostend, from IT support companies, via specialised environmental services, to logistics enterprises serving the need of the offshore wind developments. Crew transfer vessels in 2015 registered more than 3500 calls per year by the "Ensor" system. These vesselsare active sailing between the Belgian wind parks and the port of Ostend, with most of the shipping companies headquartered in the UK, Denmark or Norway, but there are also Belgian operators. Highly specialised marine services, such as underwater cable surveys, are also present. One operator based their entire fleet of 17 ships at the port to secure maintenance and fleet management also for other areas than the Belgian wind offshore. Next to these, safety and security specialists have established themselves in order to secure the safety and security on board of the vessels.

Thus the clustering effects, previously studied by many authors for ports and a range of more established port-related businesses, are very real in the case of offshore wind and the Port of Ostend. One excellent such study to which this case can be related has been published by de Langen and Haezendonck [2012].[99]

Challenges

However, the limited extent of the Belgian offshore jurisdiction and its unusually tightly competing uses of the sea in a small area makes Ostend face many future uncertainties and challenges. Unlike larger ports such as Esbjerg, Bremerhaven, soon also Le Havre and/or La Rochelle, and the highly competitive UK ports, Ostend has a rather limited "home market" and a limited time window for securing its growth into the next decade.

[99] De Langen and Hazendonck 2012, "Ports as clusters of economic activity", Chapter 31 in The Blackwell Companion to Maritime Economics, 1st Ed., Blackwell Publishing Ltd.

Positioning the Ostend cluster for increased export of services is therefore essential, both to other EU countries and worldwide, as has been identified by the Belgian Offshore Platform as a priority. In the March 2017 update of its report on the socio-economic impact of the Belgian offshore wind industry,[100] BOP is estimating that offshore wind in Belgium supports about 15.000 jobs (incl. construction) and in a 2030 perspective about two thirds of these will depend on export. This number of jobs is 30% of the entire energy sector jobs, estimated at 50.000. Net added value of offshore wind is given as about €13 billion cumulated over 2010 to 2030, or (in 2030) about €1 bn per year. The contributions included are avoided electricity imports, job creation and less unemployment costs, income taxes and public sector spending at more than €1bn per year. Notably in the BOP's analysis, more of these positive impacts are expected by export than from Belgian developments.

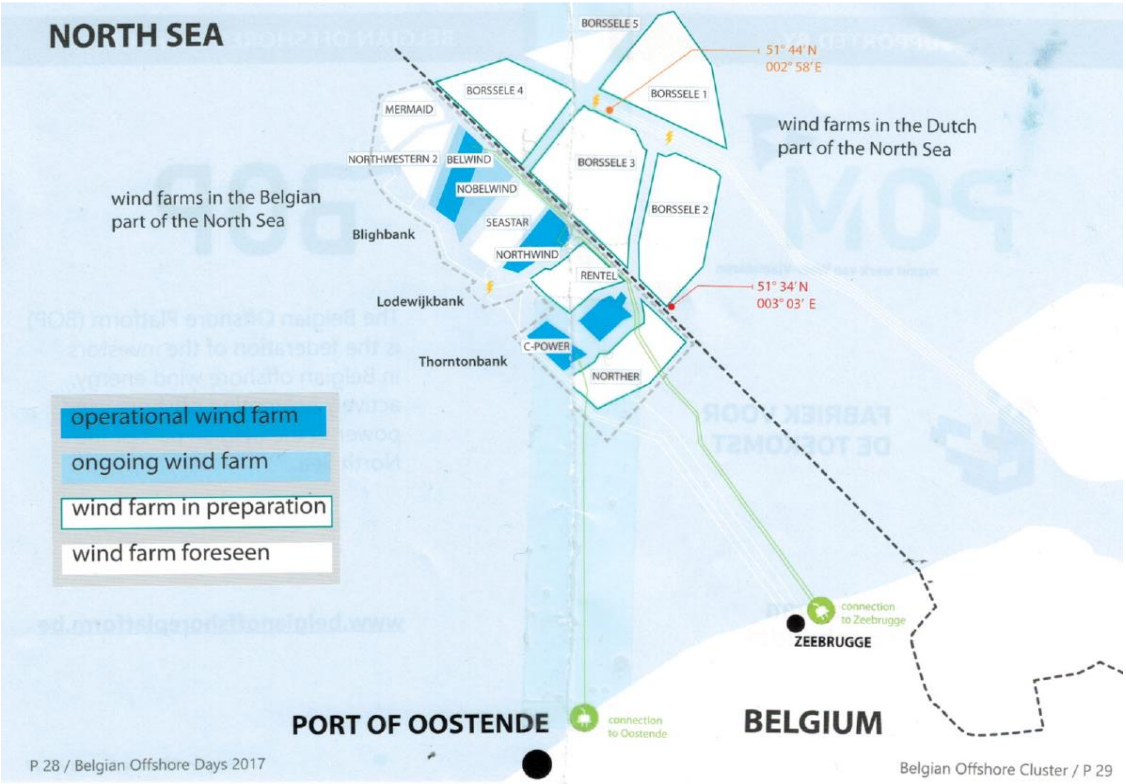


Figure 45Location and development status of Belgian and southern Dutch offshore wind parks. Among already permitted wind parks are Norther, Northwester 2 and Mermaid. Updated as of 31 March 2017 (Belgian Offshore Cluster)

Further outlook: Towards multiple use?

Although perhaps beyond the original scope of the study, the emerging subject of multi-use of the sea space could offer additional opportunities, and merit a few comments, as awareness of the subject is quite widespread in Belgium – at least superficially – and it came up in several of the interviews as part of the conversational discussion.

At the end of 2016, European cumulative offshore wind installed capacity had reached 12,631 MW from 3,589 grid-connected wind turbines in 10 countries. In 2016 itself, a

[100]Breyer et al. 2017: "The socio-economic impact of the Belgian offshore wind industry, Report by CLIMACT commissioned by the Belgian offshore Platform, March 2017.

relatively quiet year on the Belgian EEZ, 11 projects – worth €18.2billion – reached their Final Investment Decision (FID), a 39% increase over 2015 and representing 4,948 MW of new capacity.[101] It is estimated that offshore wind could be 15% of all the energy consumed in Europe by 2050.[102]

When looking at the already strained congestion of development areas, the Belgian EEZ being perhaps the most extreme case, such growth probably cannot be achieved unless multiple uses of the marine space are made possible. Multi-use, either from the start or as a conversion/extension of wind power, could extend the uses of offshore wind farms, provide food security and new jobs, while also contributing to targets for the reduction of greenhouse gases emissions and decarbonisation objectives.[103]

No comprehensive study has been performed of specific opportunities and advantages that Ostend port might offer to Belgian as well as adjoining (mainly Dutch) jurisdictions in the context of multiple use.

However, general trends of the interview data and remarks collected from interviewees point towards multi-use as one possible way for Ostend to continued growth. The well-structured application of Maritime Spatial Planning (MSP) for the Belgian EEZ shows a way forward to an extended implementation of multi-use. Industrial and environmental actors and governance arrangements are not usually aligned, so policies for multi-use are generally not coherent. Policies or MSP activities also are not normally going beyond national borders as would be required in the context of Belgian, Dutch and possibly the British North Sea. One of the few cross-border cases that have been studied from the point of view of MSP concerns the Thornton Bank.[104]

Stimulating the development of multi-use will require a coherent policy framework that secures sustainable use of the marine resources. As the future pathway for developing multi-use is uncertain, this framework should be adaptive, i.e. able to take up changes. The small size of the Belgian sector and the well-developed business infrastructure in Ostend could be used to drive such change.

The 2017 Horizon 2020 call for multi-use projects in the EU *Blue Growth* action provides further argument for this point: This call attracted unusually many high quality proposals, many of which are industry-led. The winning proposal, expected to be announced in late 2017, and most of the runners-up, start from the fact that the vast majority of offshore turbines have been built in the southern North Sea, one of the most congested parts of the world's oceans. Intensive and expanding use of the North Sea creates considerable pressure. Offshore wind is of particular importance, being both the "newest arrival" as a contender for sea space, and the fastest- growing business.

[101] EWEA 2016, European Offshore Wind Statistics for 2015, European Wind Energy Association (now Wind Europe), Brussels 2016.
[102] ECF 2010: ECF European Climate Foundation. Roadmap 2050: a practical guide to a prosperous, low-carbon Europe; 2010.
[103] Ziegler et al. 2013: The Carbon Footprint of Norwegian Seafood Products on the Global Seafood Market. Journal of Industrial Ecology, 17(1), pp. 103-116.
[104] Hommes et al. 2012: The role of knowledge and research in two case studies on cross-border Maritime Spatial Planning in the southern North Sea, ICES CM 2012 / I: Joint ICES PICES session in the use (and misuse) of science and scientific advice in Marine Spatial Planning.

As the development of offshore wind farms inherently requires limits to other activities that can be co-located, marine aquaculture is highlighted as commercial activities that can, in principle, take place both within and between offshore wind concessions. Marine aquaculture (finfish and shellfish) delivers food for society, while advances in molecular biology allow using marine aquaculture products (such as seaweed) to deliver products with pharmacological, nutraceutical and "cosmeceutical" applications.

Converting existing installations to multi-use could also extend the life of the offshore wind parks themselves, opening prospects for re-powering as future generations of more powerful turbines enter the market. It has been estimated that an extension of only 10% in the lifetime of an offshore wind park could create an added value of billions of Euro.[105]

[105]Myhr et al. 2014: Levelised cost of energy for offshore floating wind turbines in a life cycle perspective. Renewable Energy, 66, 714-728.

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