LCA of Three Innovative Offshore Wind Foundations

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Comparative assessment of the environmental impacts of innovative technical solutions intended to optimise the offshore wind farm lifecycle

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Introduction

- Use life cycle analysis (LCA) to examine the environmental impacts of three innovative foundations developed for the LEANWIND project.
- Not strictly a comparative LCA, due to differences in analysis tools and design conditions of foundations.
- Floating jacket foundation (Figure 1) has floater/suction buckets to allow the foundation to be towed to site and then act as anchors to fix the foundation to the sea bed once installed, avoiding the need for piles [1].
  - For the LEANWIND 8 MW turbine, water depths ≤ 60 m.
- Floating foundation (Figure 2) is a 3 column semi-submerged foundation, held in place by a 3-catenary-line mooring system [2].
  - For the NREL 5 MW turbine, mooring lines sized for 100 m water depth.
- Gravity base foundation (GBF, Figure 3) is designed for manufacture in a floating dock, and also floats for towing to site before being ballasted on to a pre-prepared sea bed [1].
  - For the LEANWIND 8 MW turbine, water depth of 40m.

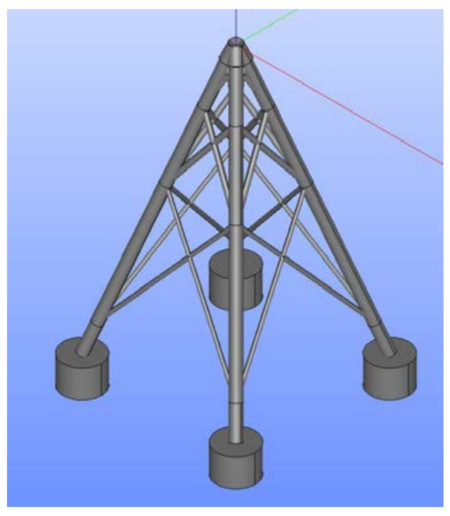

Figure 1 – Floating jacket foundation

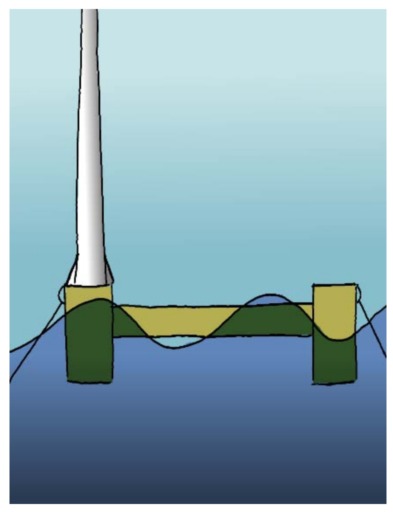

Figure 2 – Floating foundation

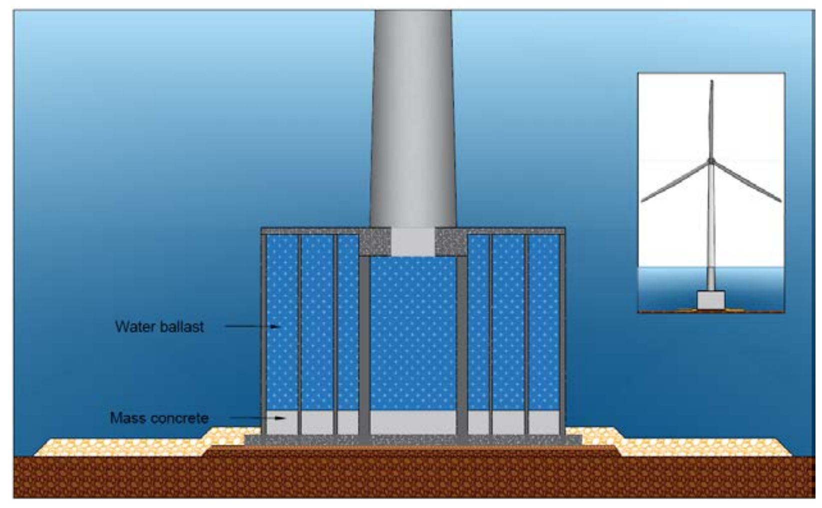

Figure 3 – Gravity base foundation

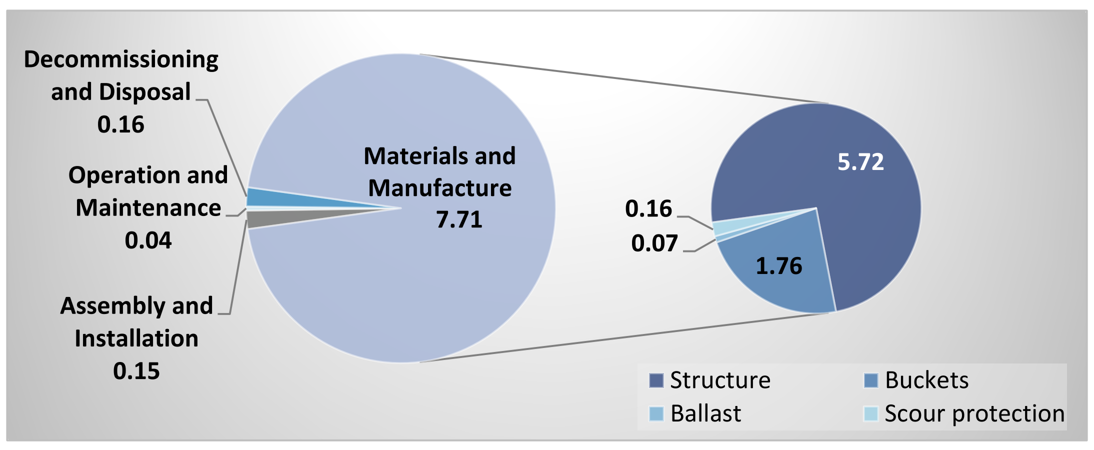

Figure 4 – Global warming potential of jacket foundation by life cycle stage (g CO_2eq/kWh)

Analysis Method

- Focuses solely on the foundations, and therefore excludes the turbine, transition piece, cables, etc.
- Results normalised per unit of energy output of the associated turbine, based on a conservative capacity factor of 40%.
- Hypothetical case-study location 30 km from shore and 100 km from port.
- Design life of the foundations expected to be 20 years.
- As the analysis was carried out by teams at both the University of Edinburgh and ACCIONA Construcción, two different sets of software, databases and impact assessment methods were used:
  - SimaPro v8.3 PhD with Ecoinvent 3 database, CML-IA baseline 2013 and the cumulative energy demand methods for jacket and floating foundations
  - GaBi 6 software with Ecoinvent, ELCD and GaBi databases, CML 2001 and the primary energy demand methods for the GBF.
- Jacket and floating foundation: materials, manufacture, assembly, installation, maintenance, decommissioning and disposal stages.
- GBF: materials, manufacture, assembly and installation stages only. Manufacture and assembly information more comprehensive than for other foundations.

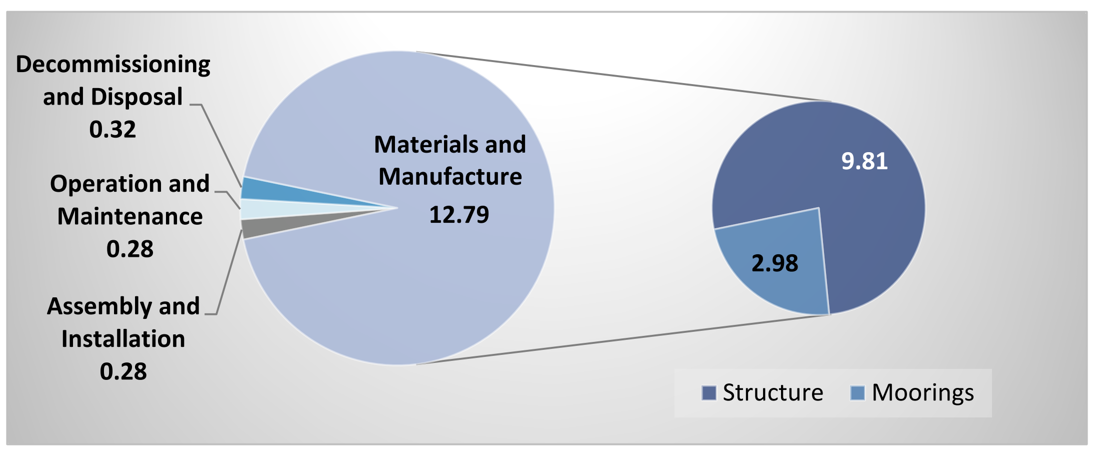

Figure 5 – Global warming potential of floating foundation by life cycle stage (g CO_2eq/kWh)

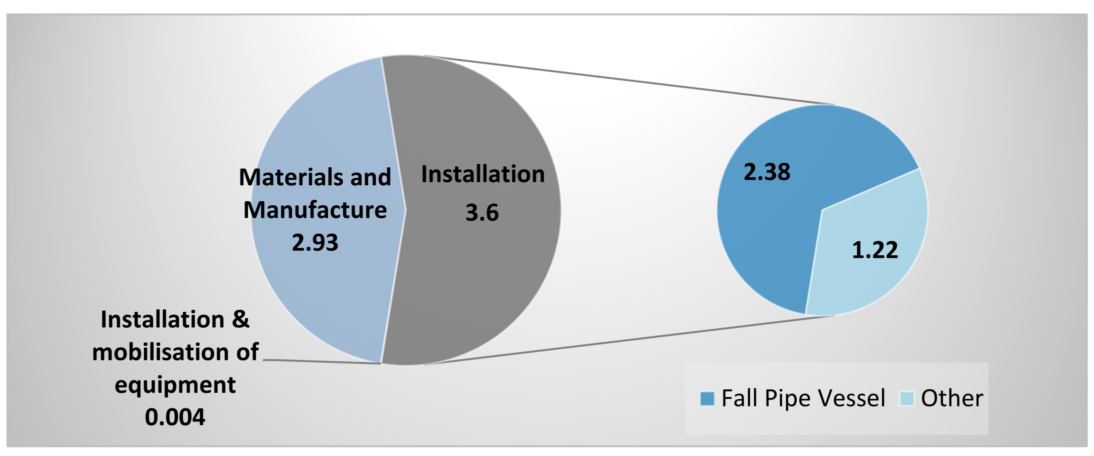

Figure 6 – Global warming potential of GBF by life cycle stage (g CO_2eq/kWh)

Results and Discussion

- Materials & manufacturing stage contributed the highest impacts to the jacket and floating foundations (Figures 4 and 5).
- Installation contributed the highest impacts for the GBF in all categories except ozone depletion potential and depletion of abiotic resources (elements) (Figure 6).
- High impacts of floating foundations due to having the most steel per kWh, particularly the marine-grade mooring lines (Table 1), but these are sized for a 100m water depth.
- GBF showed lower impacts all categories due to significantly lower impacts from materials (Table 1).
  - This analysis, however, does not include all life cycle stages, and the design is for the shallowest water depth (40m).
- Jacket foundation showed highest impacts in categories most sensitive to steel and aluminium production (Table 1).
- Results compared well with those from other published studies (harmonised for the same capacity factor and design life) [3-7] (Figure 7). (Note: only one other study was found for a GBF.)

Impact category	Unit	Gravity base foundation	Jacket foundation	Floating foundation
Global warming (GWP100a)	**g CO_2 eq/kWh**	**6.53 (-19%)**	**8.06**	**13.7 (+70%)**
Ozone layer depletion (ODP)	$x10^{-9}$ g CFC-11 eq/kWh	34.1 (-94%)	610	906 (+49%)
Acidification	$x10^{-3}$ g SO_2 eq/kWh	26.5 (-41%)	45.0	86.1 (+91%)
Eutrophication	$x10^{-3}$ g PO4--- eq/kWh	5.84 (-74%)	22.2	37.3 (+68%)
Photochemical oxidation	$x10^{-3}$ g C_2H_4 eq/kWh	2.55 (-34%)	3.88	6.55 (+69%)
Abiotic depletion	$x10^{-6}$ g Sb eq/kWh	3.88 (-96%)	105	189 (+80%)
Abiotic depletion (fossil fuels)	kJ/kWh	74.6 (-15%)	87.51	147 (+68%)
Cumulative Energy Demand/ Primary Energy Demand	**kJ/kWh**	**85.7 (-18%)**	**104**	**176 (+69%)**

Table 1 – LCA results, with difference relative to jacket foundation in brackets

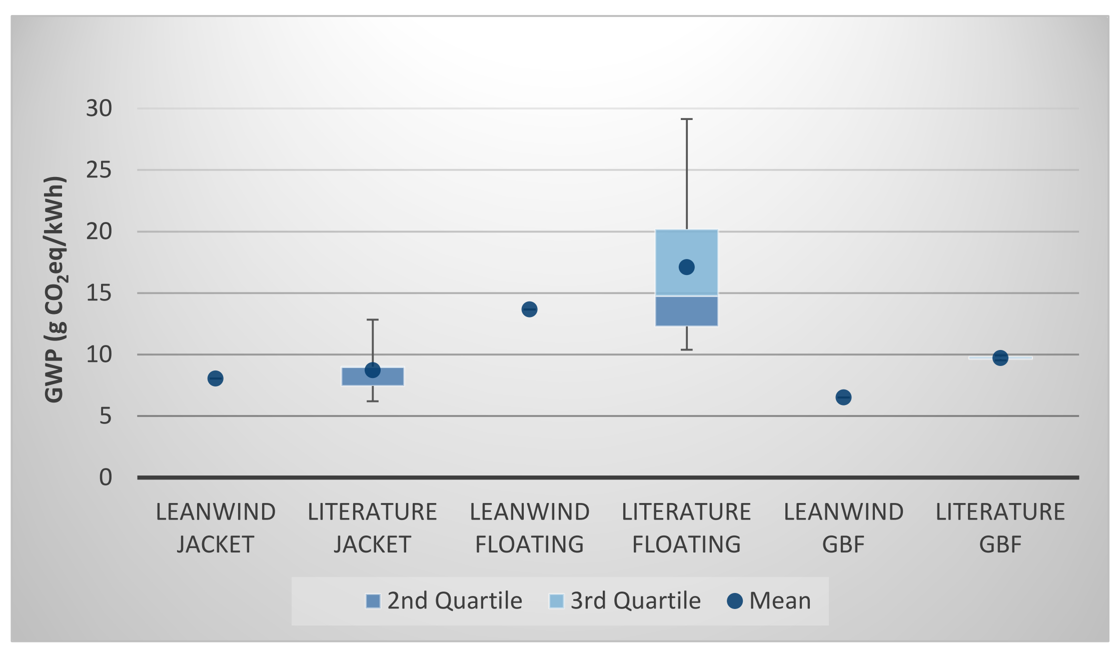

Figure 7 – Comparison of global warming potential of LEANWIND foundations with literature [3-7]

Conclusions

- Floating foundation has the worst environmental impacts, but the greatest flexibility over installation location.
- The GBF has the lowest impacts in all categories.
- The greatest potential reduction in impacts could be achieved by:
  - Reducing the length of the mooring lines for the floating foundation;
  - Encouraging installation vessel innovations to achieve a better performance;
  - Optimising the design of the jacket foundation for minimum steel and aluminium consumption.
- Differences in LCA tools, methodology and design conditions of foundations mean that this is not strictly a comparative LCA, so it's difficult to draw a definitive conclusion on the relative environmental performance of the foundations, particularly the jacket and GBF.

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