COMMENT PAPER

DNV comparative study of concrete and steel substructures for FOWT

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OCERGY
sustainable offshore solutions

Contents

1 Abbreviations

BB	Bottom Beam
CC	Center Column
EAF	Electric Arc Furnace
EPD	Environmental Product Declaration
FEED	Front-End Engineering Design
FOWT	Floating Offshore Wind Turbine
GHG	GreenHouse Gases
GWP	Global Warming Potential
HTV	Heavy Transport Vessel
O&M	Operation and Maintenance
OC	Outside Column
TB	Top Beam
WTG	Wind Turbine Generator
WWJ	WindWorks Jelsa

2 Executive Summary

In 2022, DNV AS Energy Systems issued a comparative study [1] between steel and concrete substructures for a Floating Offshore Wind Farm of 67 units (x 15MW = 1 GW) in Norway (Utsira Nord). This study was commissioned by WindWorks Jelsa AS (WWJ), whose purpose was to establish a large industrial plant to enable efficient large-scale production of concrete substructures for floating offshore wind. Unsurprisingly, the study results indicate that concrete floaters have lower carbon footprint and costs than their steel counterparts.

The purpose of this comment paper is to show that conclusions of the DNV report can be reversed by considering a lighter and modular steel semi-submersible concept such as OCG-Wind™, and by considering today and near-future (by 2030) capacities of low-emission steel heavy plates production.

In this comment paper, we only focus on the carbon footprint. The assessment methodology used by the DNV is not challenged and results for concrete concepts are taken as they are. We only update the following assumptions for steel semi-submersible concept:

- The floater of reference is no longer the UMaine VolturnUS but the OCG-Wind™ semi-submersible. The primary steel mass of the substructure then decreases from 3720 tons to 2800 tons for a 15MW-Wind Turbine Generator (WTG). The production of steel being a key driver of the final carbon footprint of a foundation, the 25% decrease of primary steel mass leads to a saving of approximately 900 tons CO_2-eq/foundation, which represents around 10% of saving over the total carbon footprint of the DNV semi-submersible floater when considering 70% of recycled steel (cf. Table 5).
- The number of floaters per Heavy Transport Vessel (HTV) such as the Blue Marlin HTV from Boskalis is no longer 2 but 6, thanks to the modular philosophy of the OCG-Wind™ semi-submersible. If manufactured in Asia, the transport is also a key driver of the final carbon footprint of a foundation. By multiplying by 3 the number of floaters per voyage, the carbon footprint of the integration phase is then divided by 3, which represents a saving of approximately 2500 tons CO_2-eq/foundation or around 20-30% of saving over the total carbon footprint of the DNV semi-submersible floater.

Considering only these 2 updated assumptions, with manufacturing in China and 70% of recycled steel as in DNV report sensitivities, OCG-Wind™ semi-submersible and the concrete semi-submersible from DNV have similar carbon footprint.

If we update the % of recycled steel to 100%, then OCG-Wind semi-submersible has a carbon footprint approximately **30% lower than concrete semi-submersible and equivalent to concrete spar**. This update is justified by the fact that all steel grades and thicknesses used in the OCG-Wind™ semi-submersible can be produced as recycled steel, without any technical obstacles, based on up-to-date Environmental Product Declarations for Recycled Steel Heavy Plates (such as [3]). Moreover, by 2030, 187 600 tons (67 x 2800 tons) of steel heavy plates will then represent only between 3.8% and 12.5% of the yearly production of low-emission steel heavy plates in Europe. The recycled steel production can thus be considered in Europe instead of in Asia.

The modular philosophy of the OCG-Wind™ semi-submersible allows the manufacturing of sub-assemblies to be shared among several manufacturers, that could each specialize in manufacturing one particular part of the floater. This approach enables us to find European players that can deliver units at the target capacity. **By considering manufacturing in Europe, the OCG-Wind™ carbon footprint can be 60% lower than concrete semi-submersible and 40% lower than concrete spar by using recycled steel carbon intensity considered in DNV study.** In a more conservative scenario with increased carbon intensity for recycled steel plates from a recent Environmental Product Declaration (EPD) by ArcelorMittal, the OCG-Wind™ steel semi-submersible carbon footprint is 30% lower than a concrete semi-submersible, and equivalent to a concrete spar.

It should also be noted that DNV did not include a number of elements such as the mooring system and installation carbon footprint, assuming they are similar for steel and concrete floaters, however these elements will likely have a larger footprint on concrete floaters due to their bigger size. This will further increase the advantage of lighter steel floaters from the GHG standpoint.

This study shows that without changing the impact assessment methodology from DNV comparative study (figures are directly taken from [1]) and by adapting some assumptions (primary steel mass, transport strategy, % of recycled steel and manufacturing country), the carbon footprint of the OCG-Wind steel semi-submersible can be significantly lower than that of reinforced-concrete floaters even made under highly optimized manufacturing scenarios.

3 Summary of original DNV LCA analysis

3.1 Presentation and important assumptions

In 2022, DNV AS Energy Systems issued a comparative study [1] between steel and concrete substructures for Floating Offshore Wind Turbine (FOWT) from three different perspectives: 1) carbon footprint, 2) cost, 3) potential for Norwegian local content. In this comment paper, we only focus on the carbon footprint study.
To perform the carbon footprint comparison of FOWT concrete and steel concepts, four base cases were established:

- 1 concrete spar,
- 1 concrete semi-submersible,
- 1 steel spar,
- 1 steel semi-submersible.

Table 1 presents common assumptions for all base cases.

Parameter	Value
WTG capacity	15 MW
Farm capacity	1 GW
Annual capacity of production facility	67 units/annum
Structure design life	25 years
Target deployment site	Utsira Nord

Table 1: Common assumptions for base cases

The comparison is based on a life cycle approach considering GreenHouse Gases (GHG)-emissions for each of the life cycle stages; from raw material extraction to end-of-life. It should be noted that the study focuses on main differences between concrete and steel concepts, and if life cycles stages are assumed to generate similar GHG-emissions for both concrete and steel concepts, these stages are not considered in the comparison.

The following components are assumed to be identical for all base cases: WTG, tower, mooring lines and anchors (this assumption is discussed in §6), and ballast system. It is also assumed that secondary steel for concrete and steel floaters is comparable. These components are therefore not included in the life cycle approach as they are considered equal between all base cases. Therefore, only primary steel is considered in the comparative study.

It should also be noted that some life cycle stages have been assessed to have equal level of GHG emissions and are therefore not included in the comparison:

- Integration of the tower and WTG.
- Installation : Differences in energy consumption are not considered to be significant and thus are excluded from the comparison. This assumption is discussed in §6.

- Operation & Maintenance (O&M) : Given the uncertainties in establishing this portion of the life cycle, O&M aspects are excluded from the comparison.

About the end-of-life phase, in this comment paper, we only focus on the scenario of the foundations being recycled for end-of-life, instead of being deposited at landfill, which is not an option for a sustainable FOWT industry. It should be noted that the subsequent opportunities for use of recycled steel material has been assumed to be 90% of virgin steel, while the subsequent opportunities for use of recycled concrete has been assumed to be 20% of virgin concrete.

In this comment paper, we only focus on updating the assumptions for semi-submersible floaters based on the OCG-Wind™ semi-submersible. In Table 2 we recall the assumptions considered in the DNV comparison for semi-submersible floaters. This table is reused in Table 7 by adding updated assumptions for the OCG-Wind™ scenarios presented in Table 8.

Life cycle phase	DNV steel semi-submersible concept	Comments
Raw material	Structural steel. % of recycled steel: 0% (base case); 35% and 70% (as sensitivity studies). Solid Ballast (concrete considered with raw materials as per concrete concepts). Magnadense.	
Manufacturing	Site: China (or Germany as a sensitivity study).	In DNV comparison study, it is assumed that the only location where availability of raw materials (finished steel products) and large-scale production capacity can meet the target demand is Asia.
Integration	Transport to integration site: Heavy Transport Vessel: Blue Marlin Transport of 2 units/voyage. 11 000 nm x 2 journeys (Asia to Europe and back)	
Parameter	**DNV semi-submersible concept**	**Comments**
Primary steel [tons]	3720 (floater of reference: UMaine VolturnUS)	
Concrete ballast [tons]	2600	
Material	**Carbon footprint [kg CO_2-eq/kg]**	**Comments**
Virgin steel	2.25	Slightly higher than the emission intensity given for the overall iron and steel industry in China. This value is provided in DNV comparison study.
Recycled steel	0.45	cf. Comment 1

Table 2:Important assumptions for steel semi-submersible concept in DNV study. These assumptions will be reused and challenged in §4.2

Comment 1: The carbon intensity value for recycled steel production was not found in DNV comparison study. It is stated that it has been obtained from EcoInvent 3.6 with IPPC 5th Assessment Report, 2014 (GWP 100a) considering recycled steel produced in Europe. It has been estimated in this comment paper based on scenario 2 (cf. second bullet point below Table 6).

By using database EcoInvent 3.6 with impact assessment method: IPPC 2013 (GWP 100a) and by considering only one process: (steel production, electric, low-alloyed | steel, low-alloyed | APOS, U – RER), a consistent carbon footprint of 0.48 kg CO_2-eq/kg steel is found. Note that this carbon footprint does not include the hot rolling to obtain heavy plates. This value is therefore increased in scenario 5b for OCG-Wind™ (cf. Table 8) with a value from a sourced Environmental Product Declaration (EPD) considering both steelmaking of slabs in Electric Arc Furnace (EAF) and hot rolling to obtain heavy plates used in the manufacturing of steel semisubmersible floaters.

3.2 Impact assessment comparisons

Three different scenarios for steel semi-submersible concepts considered in DNV comparative study are presented in Table 3. They are modified in Table 7 by updating one or several assumptions from Table 2. Table 3 also presents the assumptions for concrete concepts that are constant throughout all comparisons with scenarios 1 to 5b for steel semi-submersible concept. It can be noticed that the base case scenario for concrete concepts is already optimized.

Assumptions	Concrete Concepts (spar/semi-submersible)	Scenario 1 for steel semi-submersible DNV = "100% virgin - China"	Scenario 2 for steel semi-submersible DNV = "70 % recycled - China"	Scenario 3 for steel semi-submersible DNV = "100% virgin - Europe"
Virgin or recycled steel as raw material (and % of recycled steel if any)	100% recycled steel as described in EPD[1] for Steel Reinforcement Products for Concrete, by Celsa Steel Service [2]	100% virgin (2.25 kg CO_2-eq/kg)	30% virgin (2.25 kg CO_2-eq/kg) 70% recycled steel	100% virgin (2.25 kg CO_2-eq/kg)
Transport of steel from production site to manufacturing site.	Short transport by vessel from production site in Norway to manufacturing site.	Structural steel is assumed to be produced close to manufacturing facility, i.e. no transport of raw material is considered.		Transport of steel raw material from Shanghai to Hamburg with a > 10 000 dwt general cargo ship
Manufacturing country (city)	Norway (close to integration site)	China (Shanghai)	China (Shanghai)	Germany (Hamburg)
Transport from manufacturing city to integration site (Stavanger)	As the integration of concrete foundations is assumed to take place in the same area as the manufacturing site, no GHG emission is accounted for in relation to transport of foundations to integration site.	By using the Blue Marlin vessel from Shanghai to Stavanger (2 units/voyage)		By using the Blue Marlin vessel from Hamburg to Stavanger (2 units/voyage)
End-of life: recycling or being deposited at landfill?	Recycling (20% for concrete – 90% for steel)	Recycling (90%)	Recycling (90%)	Recycling (90%)

Table 3:Different scenarios of interest presented in DNV comparative study

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[1] In the EPD for Steel Reinforcement [2] used by the DNV, it is stated that the production of low-alloyed steel from scrap and additional alloying metals is done in EAF in Norway. So, steel reinforcement products considered in the DNV study are from recycled steel.

In the DNV comparison study, the impact assessment of the foundation concepts is based on the latest 100-year GWP from IPPC Fifth Assessment Report, 2014. The GHG impact has been documented as ton of CO_2-eq per foundation. This functional unit is also kept in this comment paper.

Results of comparisons of emissions per foundation are presented in Table 4, Table 5 and Table 6, respectively for concrete concepts compared to steel semi-submersible concept in scenarios 1, 2 and 3. Figures have been estimated based on graphics in DNV comparative study.

Phase	**ton CO_2-eq / foundation**		
	Concrete semi	**Concrete spar**	**Steel semi DNV – scenario 1 "100% virgin – China"**
Raw material	3210	1940	8420
Manufacturing	70	150	1080
Integration	0	0	3790
End-of-life	2180	1680	1090
Total	5460	3770	14380
Ratio steel semi/concrete concept	2.6	3.8	

Table 4: Emissions [ton CO_2-eq / foundation] for concrete concepts (semi & spar) and DNV steel semi in scenario 1 "100% virgin – China". Results are estimated based on Figure 4-4 and Figure 4-5 in [1].

Phase	**ton CO_2-eq / foundation**		
	Concrete semi	**Concrete spar**	**Steel semi DNV – scenario 2 "70% recycled – China"**
Raw material	3210	1940	3680
Manufacturing	70	150	1080
Integration	0	0	3790
End-of-life	2180	1680	500
Total	5460	3770	9050
Ratio steel semi/concrete concept	1.7	2.4	

Table 5: Emissions [ton CO_2-eq / foundation] for concrete concepts (semi & spar) and DNV steel semi in scenario 2 "70% recycled – China". Results for steel semi are estimated based on Figure 4-10 in [1].

Phase	ton CO_2-eq / foundation		
	Concrete semi	Concrete spar	Steel semi DNV – scenario 3 "100% virgin – Europe"
Raw material	3210	1940	8420
Manufacturing	70	150	1920 [2]
Integration	0	0	160 [3]
End-of-life	2180	1680	500
Total	5460	3770	11000
Ratio steel semi/concrete concept	2.0	2.9	

Table 6: Emissions [ton CO_2-eq / foundation] for concrete concepts (semi & spar) and DNV steel semi in scenario 3 "100% virgin – Europe". Results for steel semi are estimated based on Figure 4-12 in [1].

Some checks have been done to strengthen the graphical estimations presented in above tables.

- According to Figure 4-7 in [1], for the steel semi-submersible concept, the carbon intensity of structural steel accounts for 99% of the total carbon footprint of the raw materials. It seems thus that concrete- and bulk ballasts do not contribute at all to the raw material emissions. Therefore, by dividing the raw material emission of steel semi in scenario 1 by the primary steel mass (cf. Table 2), we should obtain the carbon footprint of virgin steel mentioned in Table 2:

$$\frac{8420\ tons\ CO_2/foundation}{3720\ tons\ of\ virgin\ steel/foundation} = 2.26\ kg\ CO_2eq/kg$$

  Therefore, the graphical estimation of 8420 tons CO_2/foundation for the raw material in Figure 4-5 in [1] is consistent with the 2.25 kg CO_2-eq/kg virgin steel mentioned in Table 2.
- The carbon intensity of recycled steel considered in [1] can be estimated based on the raw material emission of steel semi in scenario 2:

$$70\%\ \times Carbon\ intensity\ of\ recycled\ steel\ \times 3720\ tons/foundation + 30\%\ \times 2.25\ \times 3720 = 3680\ tons\ CO_2/foundation$$

$$\Leftrightarrow Carbon\ intensity\ of\ recycled\ steel = \frac{3680 - 0.3 \times 2.25 \times 3720}{0.7 \times 3720} = 0.45\ kg\ CO_2eq/kg$$

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[2] The increase in manufacturing emissions compared to scenarios 1 and 2 is due to the fact that emissions related to the transport of raw materials are assigned to the manufacturing stage. However, moving manufacturing to Germany represents an emission reduction of about 21% for steel semi-submersible concept compared to manufacturing in China.

[3] On the other hand, the emissions related to the transport to the integration site reduce to 4% of the base case emissions because the distance between Hamburg and Stavanger is 4% of the distance between Shanghai and Stavanger.

4 Description of updates with OCG-Wind™ concept

4.1 Presentation of OCG-Wind™ semi-submersible

The OCG-Wind™ developed by OCERGY is a 4 columns **steel semi-submersible** floating platform for large wind turbines as shown in Figure 1. Three outside columns (OC) are on the vertices of an equilateral triangle, with one column in the center of the triangle which carries the tower and WTG.

The loads are transferred between columns through a tubular frame, consisting of a top beam (TB), a bottom beam (BB), and V-braces in between the top and bottom beams. Steel tendons between outside columns provide additional stiffness to the structure.
The center column (CC) has a diameter identical to the base of the WTG tower. The tower is connected to the center column with a bolted connection.
The platform is designed for 25 years of operation at the site and one additional year for installation/commissioning, with applicable safety factors on fatigue life.

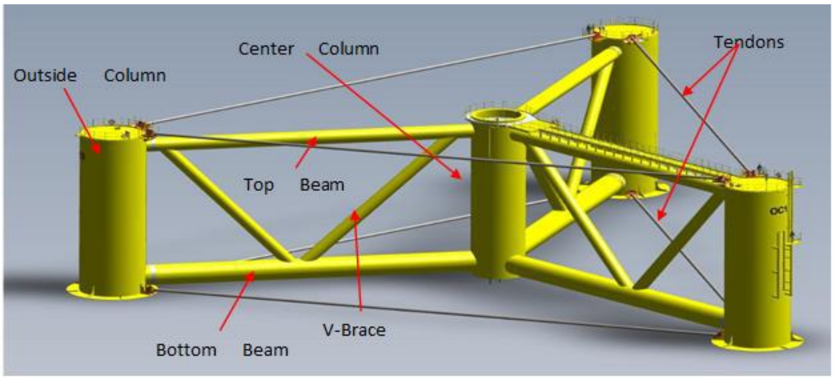

Figure 1:Perspective view of an OCG-Wind™ Floater

The floating structure is built in subassemblies, which are brought to the final assembly site with all equipment installed and pre-commissioned. The main subassemblies are frames, OC, CC and tendons.

Final assembly does not require welding or painting. Mechanical connections only are needed to connect subassemblies together, similarly to WTG components:

- The columns are bolted to the frame TB and BB on either side of the frame.
- The tendons are placed in receptacles, tensioned and secured.

With the WTG and tower fully installed, the FOWT draft is 10.0m or less.

4.2 Updates of steel semi-submersible concept assumptions based on OCG-Wind™ technology

In Table 7, assumptions about steel semi-submersible concept are updated based on OCG-Wind™ structure.

Life cycle phase	DNV steel semi-submersible concept	OCG-Wind concept	Comments
Raw material	Structural steel. % of recycled steel: 0% (base case); 35% and 70% as sensitivity studies). Solid Ballast (concrete considered with raw materials as per concrete concepts). Magnadense.	Structural steel. % of recycled steel: 70% or 100%. Neither solid ballast nor Magnadense.	See comment 1 below.
Manufacturing	Site: China (or Germany as a sensitivity study).	Site: China or Spain.	See comment 2 below.
Integration	Transport to integration site: Vessel: Blue Marlin Transport of 2 units/voyage. 11 000 nm x 2 journeys (Asia to Europe and back)	Transport to integration site: Vessel: Blue Marlin Transport of 6 units/voyage. If manufactured in China: 11 000 nm x 2 journeys. If manufactured in Spain: 1 120 nm[4] x 2 journeys.	See comment 3 below.
Parameter	**DNV steel semi-submersible concept**	**OCG-Wind concept**	**Comments**
Primary steel [tons]	3720	2800	See comment 4 below.
Concrete ballast [tons]	2600	0	
Material	**Carbon footprint [kg CO_2-eq/kg]**		**Comments**
Virgin steel	2.25		This value is conservatively reused for OCG-Wind concept in scenario "70% recycled – China" (cf. Table 8).
Recycled steel	0.45 (original value used by DNV) or 0.91 (based on more realistic EPD).		The 0.91 kg CO_2-eq/kg is based on EPD from Arcelor Mittal [3]. See comment 5 below.

Table 7: Updates of assumptions for steel semi-submersible concept in DNV study with OCG-Wind™ concept.

Comment 1: The 67 OCG-Wind™ units of 15MW required to obtain a nominal capacity of 1GW represent 67 x 2800 = 187 600 tons of primary steel. Specifically for steel plates, it is

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[4] Estimation of route distance from Gijon to Stavanger (cf. sea-distances.org)

estimated that EU producers will already be able to supply between 1.5 and 5 million tons of low-emission plates per year by 2030. 187 600 tons of steel heavy plates will then represent only between 3.8% and 12.5% of the yearly production of low-emission steel heavy plates. As such, this volume could be sourced in Europe without creating any imbalance in the market. Moreover, a stable and predictable demand for low-emission steel plates from the FOWT segment would positively support European steel producers' investment efforts in low-emission production, by providing greater certainty and visibility regarding future market needs.

Moreover, in EPD from steel producers such as [3], recycled steel plates mean thickness value is 20mm, but the declaration covers the whole range from 5mm up to 120mm. It covers all required thicknesses in OCG-Wind™ concept for a 15MW, and all required grades can be technically produced in low-emission steel. Finally, it means that 100% of the OCG-Wind™ primary steel can be procured with recycled steel plates.

Comment 2: The modular philosophy of the OCG concept makes it possible to split the manufacturing between several companies/facilities that can fabricate one sub-assembly (CC, OC, frames). This approach enables full production of the floaters in Europe. Just as an example, Lykomitros Steel S.A in Greece already has a production capacity of 120 000 tons per year for pile foundations and XXL monopiles.

Comment 3: It was estimated that 6 OCG-Wind™ floaters can be loaded onto the Blue Marlin vessel; see Figure 2 which shows the footprint of CCs, OCs and frames on the Blue Marlin top deck level from [4].

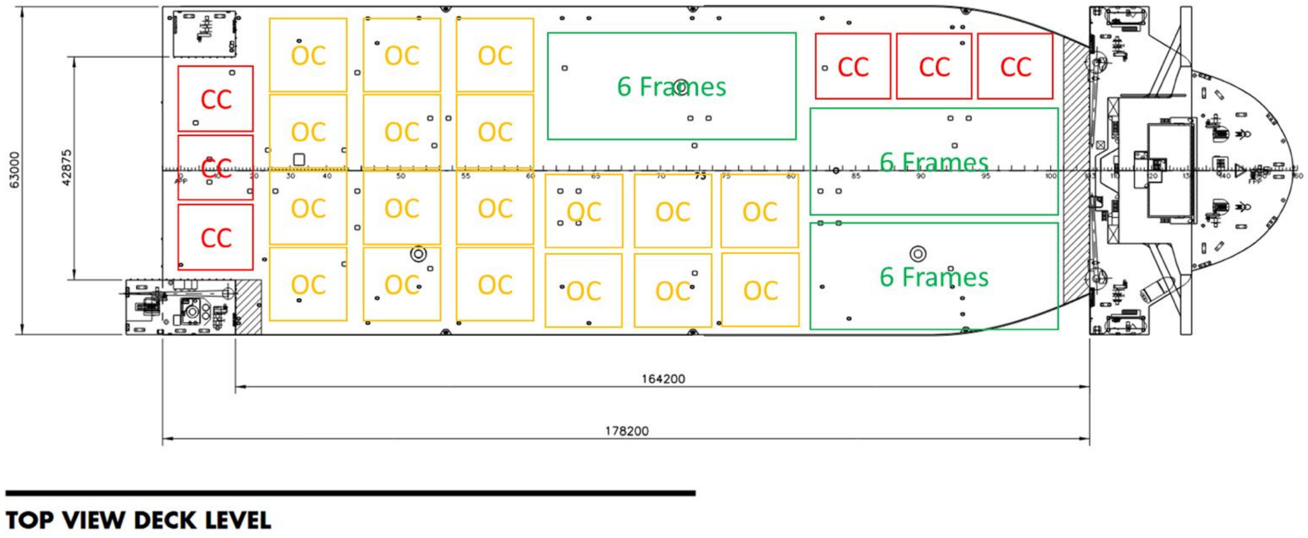

Figure 2: Footprint of 6 OCG-Wind subassemblies on top deck of the Blue Marlin vessel (top view, cf.[4])

Comment 4: The mass of primary steel used for the OCG-Wind™ 15MW in this report is the result of a Front-End Engineering Design (FEED) for a site with environmental conditions similar to the ones in Utsira Nord (cf. Table 1).

Comment 5: The carbon footprint value of recycled steel used by DNV is less conservative than actual EPD of steel producers such as [3]. As a sensitivity, the carbon footprint (including steps A1 to A3) from the EPD is used in scenario 5b (cf. Table 8). It includes both steelmaking of slabs in Electric Arc Furnace (EAF) and hot rolling to obtain heavy plates

The above assumptions are used in the various scenarios presented in Table 8.

Assumptions	Concrete Concepts (spar/semi-submersible)	Scenario 2 for OCG-Wind = "70% recycled - China"	Scenario 4 for OCG-Wind = "100% recycled - China"	Scenario 5/5b for OCG-Wind = "100% recycled - Europe"
Virgin or recycled steel as raw material (and % of recycled steel if any)	100% recycled steel as described in EPD for Steel Reinforcement Products for Concrete, by Celsa Steel Service [2]	30% virgin (2.25 kg CO_2-eq/kg) 70% recycled steel (0.45 kg CO_2-eq/kg)	100% recycled steel (0.45 kg CO_2-eq/kg)	100% recycled steel (0.45 kg CO_2-eq/kg for scenario 5 or 0.91 kg CO_2-eq/kg for scenario 5b)
Transport of steel from production site to manufacturing site.	Short transport by vessel from production site in Norway to manufacturing site.	Structural steel is assumed to be produced close to manufacturing facility, i.e. no transport of raw material is considered.		NB: For scenario 5, it is assumed that structural steel is produced close to manufacturing facility as for scenarios 2 and 4. For scenario 5b, it is already accounted for in carbon footprint of raw material. It considers the production of slabs at ArcelorMittal Industeel Charleroi, in Belgium and the transport to ArcelorMittal Gijon in Spain for hot rolling (cf. [3]).
Manufacturing country (city)	Norway (close to integration site)	China (Shanghai)	China (Shanghai)	Spain (Gijon)
Transport from manufacturing city to integration site (Stavanger)	As the integration of concrete foundations is assumed to take place in the same area as the manufacturing site, no GHG emission is accounted for in relation to transport of foundations to integration site.	By using the Blue Marlin vessel from Shanghai to Stavanger (6 units/voyage)		By using the Blue Marlin vessel from Gijon to Stavanger (6 units/voyage)
End-of-life: recycling or being deposited at landfill?	Recycling (20% for concrete – 90% for steel)	Recycling (90%)	Recycling (90%)	Recycling (90%)

Table 8: Scenarios of interest studied for OCG-Wind concept

5 Results of studied scenarios with OCG-Wind™ concept

Results of emissions per foundation are presented in Table 9, Table 10, Table 11 and Table 12 respectively for concrete concepts compared to OCG-Wind™ steel semi-submersible concept in scenarios 2, 4, 5 and 5b. Figures for concrete concept are the same as in §3.2. Otherwise stated, figures for OCG-Wind™ are direct linear interpolation (based on mass) of carbon footprint of the semi-submersible concept in the DNV comparative study.

Phase	**ton CO_2-eq / foundation**		
	Concrete semi	**Concrete spar**	**OCG-Wind™ – scenario 2 "70% recycled – China"**
Raw material	3210	1940	2800*(0.3*2.25+0.7*0.45) = 2772
Manufacturing	70	150	1080*2800/3720 = 813
Integration	0	0	3790*2/6 = 1263
End-of-life	2180	1680	500*2800/3720 = 376
Total	5460	3770	5225
Ratio steel semi/concrete concept	1.0	1.4	

Table 9: Emissions [ton CO_2-eq / foundation] for concrete concepts (semi & spar) and OCG-Wind™ in scenario 2 "70% recycled – China".

Phase	**ton CO_2-eq / foundation**		
	Concrete semi	**Concrete spar**	**OCG-Wind™ – scenario 4 "100 recycled – China"**
Raw material	3210	1940	2800*0.45 = 1260
Manufacturing	70	150	813
Integration	0	0	1263
End-of-life	2180	1680	376
Total	5460	3770	3713
Ratio steel semi/concrete concept	0.7	1.0	

Table 10: Emissions [ton CO_2-eq / foundation] for concrete concepts (semi & spar) and OCG-Wind™ in scenario 4 "100% recycled – China".

Phase	ton CO_2-eq / foundation		
	Concrete semi	Concrete spar	OCG-Wind™ – scenario 5 "100% recycled – Europe"
Raw material	3210	1940	2800*0.45 = 1260
Manufacturing	70	150	813*0.79 = 642 [5]
Integration	0	0	3790*1120/11000*2/6 = 129
End-of-life	2180	1680	376
Total	5460	3770	2407
Ratio steel semi/concrete concept	0.4	0.6	

Table 11: Emissions [ton CO_2-eq / foundation] for concrete concepts (semi & spar) and OCG-Wind™ in scenario 5 "100% recycled – Europe".

Phase	ton CO_2-eq / foundation		
	Concrete semi	Concrete spar	OCG-Wind™ – scenario 5b "100% recycled – Europe"
Raw material	3210	1940	2800*0.91 = 2548
Manufacturing	70	150	813*0.79 = 642
Integration	0	0	3790*1120/11000*2/6 = 129
End-of-life	2180	1680	376
Total	5460	3770	3695
Ratio steel semi/concrete concept	0.7	1.0	

Table 12: Emissions [ton CO_2-eq / foundation] for concrete concepts (semi & spar) and OCG-Wind™ in scenario 5b "100% recycled – Europe".

Figure 3 summarizes all results presented in this paper. All presented steel semi-submersible scenarios (DNV and OCG ones) are compared with the concrete concepts.

Some observations:

- In all considered scenarios, the carbon footprint of OCG-Wind™ is lower or equal to the one of concrete semi concept.
- In all considered scenarios, except scenario 2, the carbon footprint of OCG-Wind™ is lower or equal to the one of concrete spar concept.
- Without changing the impact assessment methodology from DNV comparative study (figures are taken from [1]) and by adapting some assumptions (primary steel mass, transport strategy, % of recycled steel and manufacturing country), it

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[5] It is considered that moving manufacturing to Spain represents the same emission reduction as in Germany of about 21% for steel semi-submersible concept compared to manufacturing in China.

is shown that the carbon footprint of OCG-Wind™ steel semi-submersible is lower than highly optimized manufacturing scenarios of concrete concepts.

In the next section, some assumptions about concrete concepts are further discussed.

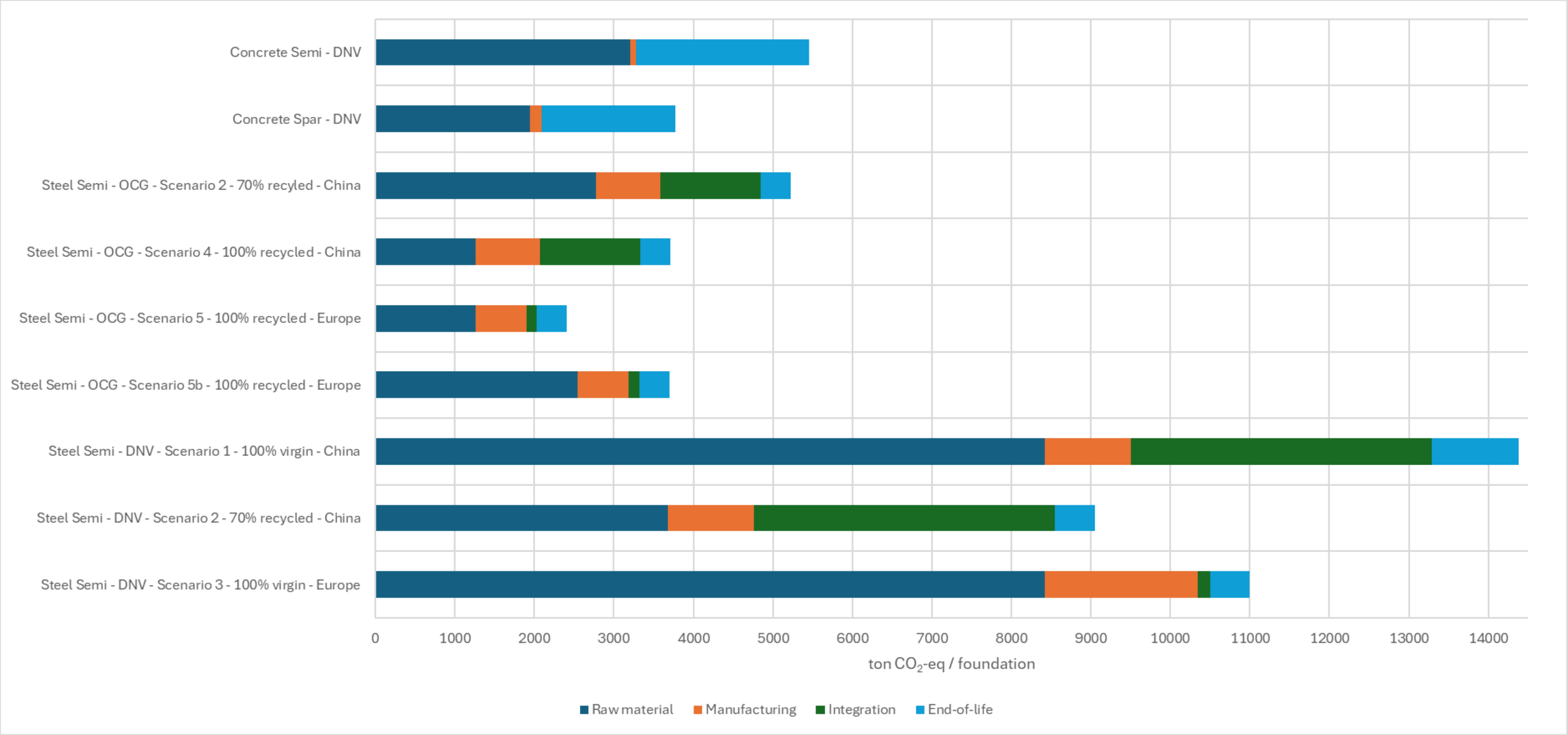

Figure 3: CO_2 emissions (ton CO_2-eq / foundation) for concrete concepts from DNV report [1], OCG steel semi-submersible scenarios and DNV steel semi-submersible scenarios.

6 Discussion about concrete concepts assumptions

As reminded in §3.1, it has been considered in DNV report [1] that mooring lines and anchors are identical for each floater type. However, concrete concepts have significantly larger displacements than steel concepts, leading to higher hydrodynamic loads on the hull and higher tension in mooring lines and anchors, which should consequently be bigger or more numerous than in equivalent steel concepts.

It has also been considered in DNV report that energy consumption during wet tow to installation site are identical for each floater type. However, drag loads on hull during towing will be higher for concrete concepts due to higher drag areas compared to analogous steel concepts.

The load-out is not mentioned in DNV report, but for example the load-out of concrete semi-submersible built at quayside requires the use of a submersible barge due to the high weight of the foundation that cannot be handled by an onshore crane. On the other hand, the load-out of a 15MW OCG Wind semi-submersible can be performed with a ring crane, which is obviously less carbon intensive than mobilizing a submersible barge.

In DNV report, it is stated that the annual capacity for concrete concepts is defined based on the expected capacity of WWJ by 2030 to produce concrete floaters in Norway. DNV also mentioned that the "equivalent" assembly line for steel concepts should be established based on today's installed/available capacity. However, new capacities to produce steel floaters are also expected in Europe [5]. Moreover, the combined capacities of several shipyards have not been considered for steel floaters in DNV's approach, while it is clearly a path to produce modular steel floaters in Europe at the targeted rate.

7 Conclusion

This comment paper shows that the conclusions of the DNV comparative study [1] about carbon footprint can be reversed by considering a lighter and modular steel semi-submersible concept such as OCG-Wind™ semi-submersible, and by considering todays and near-future (by 2030) capacities of low-emission steel heavy plates production.

Indeed, without changing the impact assessment methodology from DNV comparative study (figures are directly taken from [1]) and by adapting some assumptions (primary steel mass, transport strategy, % of recycled steel and manufacturing country), it is shown that the carbon footprint of OCG-Wind™ steel semi-submersible is up to 60% lower than highly optimized manufacturing scenarios of concrete concepts.

8 References

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