2. Low carbon

Carbon targets for offshore wind foundations: a proposed SCORS-style rating scheme

Cameron Archer-Jones, **Eduardo Calderon Asensio**, **Romina Shkurtaj** and **Chenyu Zhang**
present a proposed structural carbon rating scheme specific to offshore wind foundations, the major bespoke structures within offshore wind developments.

Introduction

The upfront carbon emissions of renewable infrastructure are often disregarded due to such projects being seen as 'inherently sustainable', since they are commissioned to displace fossil fuels from electricity generation. Global construction activity within the offshore wind industry is rapidly accelerating to support countries' net-zero ambitions, and with this activity there is a significant opportunity to reduce upfront carbon emissions associated with constructing major offshore wind developments. This will become increasingly important as the conventional grid decarbonises, weakening the displacement argument.

Although offshore wind turbine foundations are relatively niche structures, they are the major bespoke elements of an offshore wind development **(Figure 1)** requiring site-specific civil/structural engineering input. Typically, they can represent between 5000 and 15 000tCO_2e per foundation, and up to 50% of the total upfront emissions in an offshore wind development. As a result, they represent one of the greatest opportunities for carbon savings in new developments.

Following on from the original Structural Carbon Rating Scheme (SCORS) for buildings[1], and the proposed rating scheme for bridges[2], this article presents a proposal for a carbon rating scheme for offshore wind turbine foundations. Although the context of offshore wind construction is different from buildings and bridges, this is the first carbon rating scheme that can be used to set realistic baselines and targets– a core component of any carbon management strategy.

FIGURE 1: There is a significant opportunity for carbon reductions in the foundation structures of new offshore wind farms

SCORS for offshore wind foundations

The proposed rating 'sticker' for offshore wind foundations is depicted in **Figure 2**. The rating system adopts the same A++ to G coloured ratings as SCORS for buildings to provide a clear indication of carbon performance, applicable to individual assets, complete developments, or a portfolio of foundations.

The rating is based on the estimated A1–A5 upfront emissions of the wind turbine foundation/substructure, calculated following the philosophy of the *How to calculate embodied carbon* (HTCEC) guide[3] and normalised per PAS 2080 using a functional unit[4]. The asset scope included in the assessment is depicted in **Figure 3** and includes:

- **primary structures**: monopile, transition piece, jacket, piles, gravity base structure
- **secondary structures**: internal and external platforms, boat landing arrangement, internal and external access ladders, railings, J-tubes, corrosion protection, mudmats

→| **ancillaries**: dredging, groundworks, scour protection.

A5 activity-linked emissions (A5.2) represent the greatest uncertainty due to the limited data available on specialist offshore wind construction vessels. A5.2 estimates for this assessment have been derived based on available offshore wind vessel fuel use data resulting from operation, transit and standby.

For power-generating infrastructure, the functional unit for whole-life carbon assessments is typically kWh energy delivered to the grid; however, for an upfront carbon assessment (A1–A5), the power rating (i.e. maximum theoretical power generation) in MW has been used.

Using the power rating removes whole-life influences such as site conditions, specifically exposure to wind, to provide a direct way of comparing design and construction efficiency. It can also be useful to consider the influence of other input parameters, such as water depth or foundation type. This simpler assessment approach can then more directly motivate engineers to reduce the emissions within their scope of influence, particularly once a site has been selected.

A detailed carbon assessment methodology for offshore wind has recently been developed by the authors in partnership with the ORE Catapult (https://ore.catapult.org.uk/), covering whole-life assessments for complete offshore wind developments. This work will contribute to an industry-wide methodology which is planned to be published later in 2024. This methodology has been developed to further assist the industry to understand, quantify and manage carbon emissions associated with offshore wind projects.

Potential further work in the next phase of this project could be to develop a carbon model and database into which a carbon assessment can be uploaded, to help drive progress, much like what has been done for buildings (e.g. Built Environment Carbon Database, LCA Collect and others).

Benchmarking the rating scheme

The proposed carbon rating scheme has been developed using the same methodology as the original SCORS for buildings proposal[1].

The scheme has been benchmarked using over 100 bottom-fixed (i.e. non-floating) offshore wind foundation designs from COWI's project database **(Figure 4)**. Carbon emission factors are typically based on global averages, aligning with the international supply chains used for the major components in offshore wind structures.

The average carbon intensity for new offshore wind foundations from COWI's database is 650tCO_2e/MW (standard deviation ~160tCO_2e/MW), with dependency to water depth (average from database = 46m; min. = 18m and max. = 70m) and structural form **(Figure 5)**. The dependency to water depth is intuitive when the structure is simplified as a base-supported cantilever, although a more detailed statistical assessment with more data is needed to provide further insight into the independent influence of form, ground type, design life, etc.

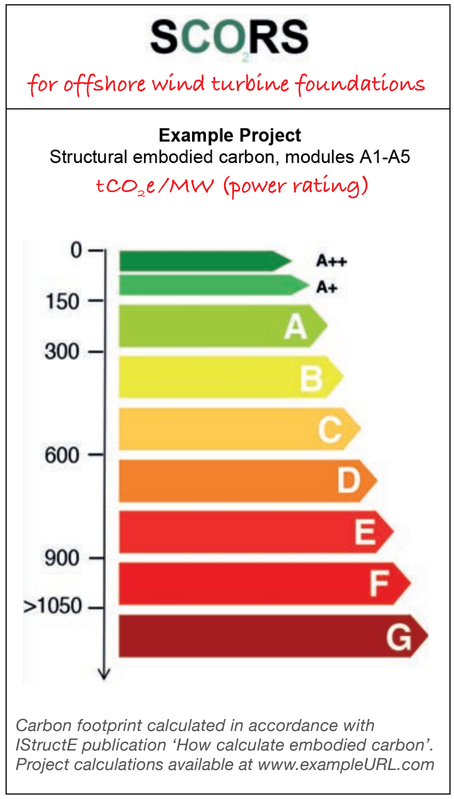


FIGURE 2: Equivalent proposed rating scheme for offshore wind turbine foundations

What about floating foundations?

The proposed rating scheme is based on bottom-fixed offshore wind foundation designs since there are far fewer complete floating offshore wind foundation designs available and, hence, a lack of data. Of the five preliminary floating designs in COWI's database, the average carbon intensity of their substructures is approx. 1350tCO_2e/MW, but these are early conceptual designs used in water depths over 250m. It is envisaged that the rating scheme could either be extended or recalibrated in future to account for floating foundations once sufficient data is available.

What does 'good' look like for offshore wind foundations?

The rating scheme is intended to provide a clear indication of how optimised a structure's equivalent carbon footprint is for the proposed power rating. The scheme is established to align with the first-principles approach for a net-zero trajectory described in detail by Arnold *et al*.[1] and Archer-Jones and Green[2] since there is no definitive decarbonisation

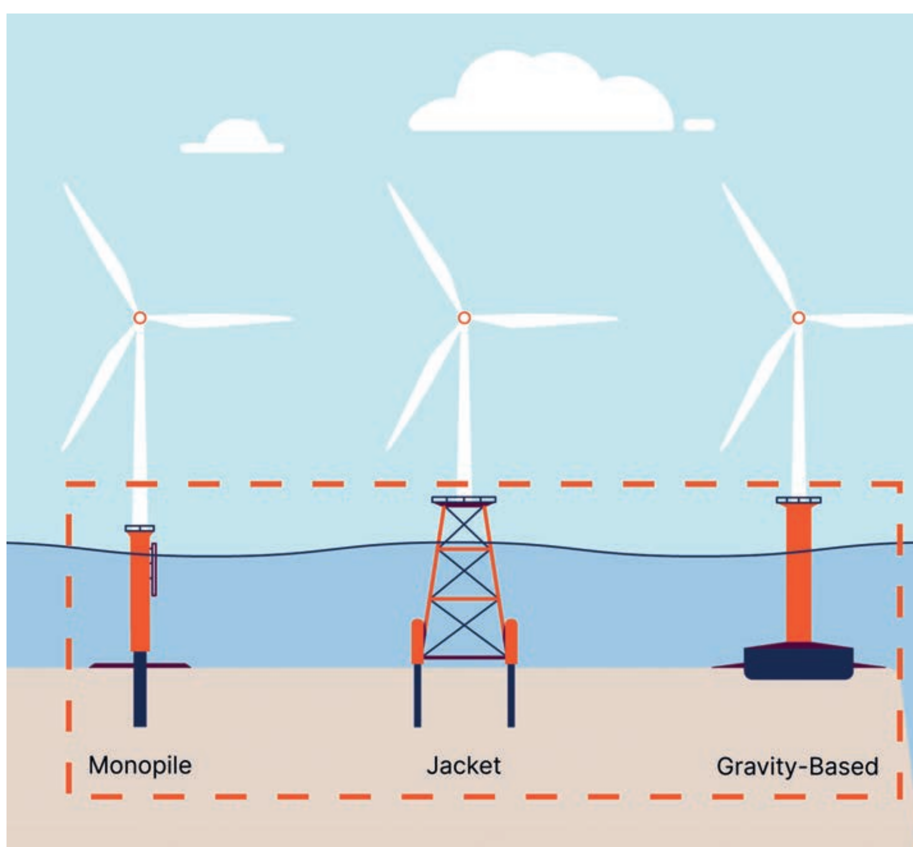


FIGURE 3: Foundation asset scope of SCORS for offshore wind

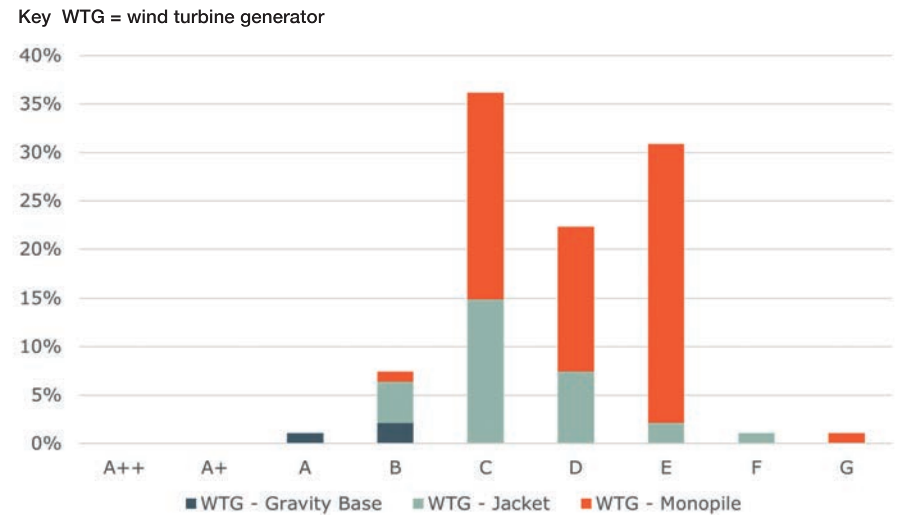


FIGURE 4: Histogram of proposed rating scheme for offshore wind foundations in COWI's dataset

roadmap. It is calibrated such that:

- average current practice results in a D, leaving some differentiation beneath the average but with clear encouragement to improve
- by 2030 the average rating should reach a B, with the industry constantly aiming for further improvement, as newer offshore wind turbines are installed in deeper water depths
- by 2050 the average must reach A++ and as near as possible to zero to provide residual emissions that may feasibly be offset.

It should be noted that, unlike the embodied carbon reduction hierarchy commonly applied to buildings and bridges projects[5], building nothing or building less is not a viable option for renewable energy-generating infrastructure. Building less would lead to greater national carbon emissions compared with maintaining current fossil fuel energy infrastructure.

For deployment of renewable energy-generating infrastructure, it is widely accepted that we need to be building much faster[6], so perhaps the question we should be asking ourselves is: what does 'good' look like and how does it change with time?

What does 'good' look like and how does it change with time?

Short-term view

Simplifying the problem by ignoring other sources of renewable energy and taking the UK government's documented offshore wind development target of 50GW by 2030 (incl. 5GW floating[7]), we can estimate the influence of offshore wind foundations compared with other mega-projects, as well as carbon budgets. Adopting the average 650tCO_2e/MW for the foundations, and simplistically subtracting the approx. 14GW of offshore wind infrastructure already deployed, this would equate to approx. 23.4M tCO_2e of upfront carbon emitted to install the foundations alone.

This is equivalent to more than double the upfront emissions for Phase 1 of the High Speed 2 rail in the UK[8]; or more than five times the upfront carbon that would be required to rebuild all the office space in the City of London (assuming 0.75tCO_2e/m^2).

Averaging this over the six years from 2024 to 2030 gives 3.9M tCO_2e/year. This would account for just under 1% of the UK's total annual carbon budget between 2028 and 2030 (budget period 5)[9].

Looking at the positive impact of deploying this level of offshore wind power by simplistically considering the displaced carbon if assuming the power generated from 36GW of offshore wind (operating at ~40% efficiency/capacity[10]) is used in place of natural gas, the annual benefit is almost an order of magnitude greater (approx. 25M tCO_2e/year based on 0.20tCO_2e/MWh[10]). This figure leaves plenty of room for the other assets that make up a functional offshore wind farm.

This type of carbon payback consideration is not new, but in the context of defining what good looks like for upfront carbon in offshore wind foundations, it does highlight that, in the short term, we need to focus on maximising the speed of deployment while also minimising upfront emissions as much as possible (which will also typically reduce upfront cost[4]).

Longer-term view (beyond 2030)

The positive benefit of displaced carbon decreases with increased renewable power-generating capacity. The UK government has planned for up to a total of 125GW of offshore wind power-generating capacity to be installed by 2050. Looking at this simplistically again, if the displaced carbon from energy generation approaches zero, then the approach of maintaining existing infrastructure and building as little new infrastructure as possible becomes more appropriate. For offshore wind foundations, this is expected to result in extensive investigations into life extension with restricted replacement of components of elements that have expired.

An industry effort

Given the proposed scale of construction for offshore wind developments, this industry, like all areas of construction, needs to include carbon assessments within projects now, to be able to inform decisions linked with managing carbon. Having a consistent approach to assessing carbon is important but, drawing on the ethos of the IStructE's HTCEC guide[3], we shouldn't be put off by uncertainties in calculating carbon as early as possible on a project. The call to action is therefore threefold:

1) Engineers familiar with carbon assessments for construction of new buildings, bridges, etc. should assist their energy department colleagues in calculating and managing embodied carbon to ensure that carbon emissions are always included as an evaluation parameter when recommending a design option.
2) Any civil/structural engineer should participate in exploring and proposing efficiencies that can reduce material use and construction effort to reduce the upfront carbon in these structures.
3) All engineers should share data and best practice.

Conclusion

Although the pace of deployment is more critical in the short term, the upfront carbon associated with the forecast offshore wind infrastructure presents a massive opportunity for carbon savings over the next five to 10 years. The proposed rating scheme can be applied on projects, or within organisations, to establish benchmarks and set carbon reduction targets for offshore wind foundations.

The structural engineering community can play a key role in helping improve the carbon performance of these major assets, sharing lessons learned from the more mature processes in place for buildings and transport infrastructure. Where significant carbon savings are achieved relative to the status quo, these also need to be shared to allow the entire industry to learn and improve.

Any readers interested in collaborating with an offshore wind-specific focus should contact the authors or IStructE (climateemergency@istructe.org). Similar studies are being undertaken for tunnels and telecommunication masts and towers. If readers are interested in collaborating in relation to these other asset types, they are also encouraged to reach out to COWI or the IStructE.

Cameron Archer-Jones
BEng, MSc, DIC, MIStructE, CEng, MIEAust, CPEng

Cameron is an Associate for COWI operating both as the company's Carbon Management Lead in the UK and also a member of its internationally renowned bridge team. He has 11 years' experience with an increasingly broad portfolio of work.

Eduardo Calderon Asensio
BEng, MSc

Eduardo is a technical specialist within offshore wind foundation design and construction for COWI based in Copenhagen. He has been practising for over seven years in the UK and Denmark.

Romina Shkurtaj
MSc

Romina is a Project Manager and sustainability specialist in COWI's renewable energy unit based in Copenhagen. With more than six years' experience, she has worked in the architectural, engineering and construction industries with a focus on lifecycle analysis.

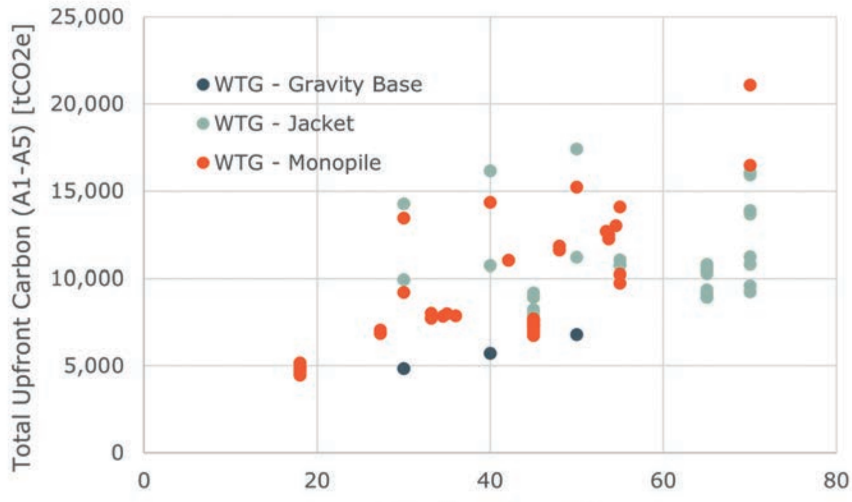
Chenyu Zhang
BEng, MSc, DIC, GMICE

Chenyu is an Assistant Engineer with COWI's offshore wind team in London, with two years' experience in the design of global offshore wind structures and soil seismic analysis.

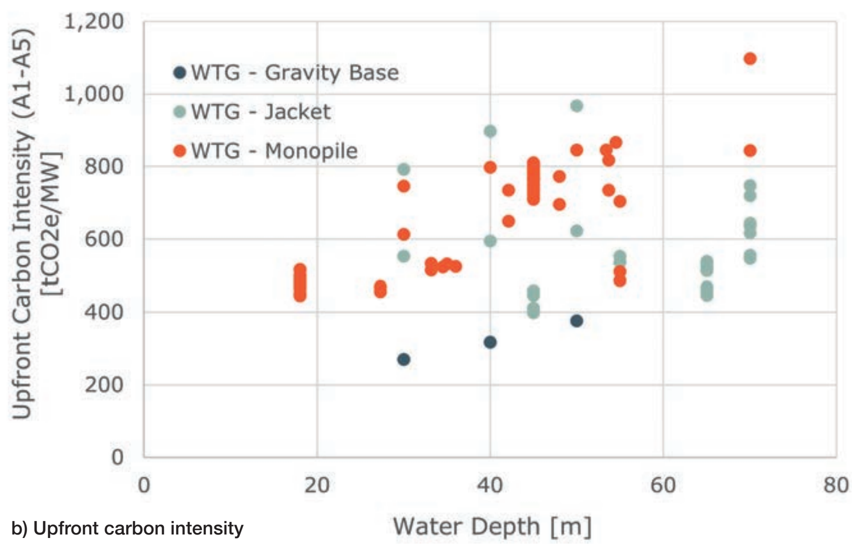
Acknowledgements

The authors would like to give special thanks to COWI's offshore wind design teams for supporting the efforts to gather project carbon data.

Key WTG = wind turbine generator



a) Total upfront carbon



b) Upfront carbon intensity

↗FIGURE 5: Upfront carbon in bottom-fixed offshore wind foundations in COWI's database

REFERENCES

1) Arnold W., Cook M., Cox D., Gibbons O. and Orr J. (2020) 'Setting carbon targets: an introduction to the proposed SCORS rating scheme,' *The Structural Engineer*, 98 (10), pp. 8–12; https://doi.org/10.56330/SQDI8782

2) Archer-Jones C. and Green D. (2021) 'Carbon targets for bridges: a proposed SCORS-style rating scheme', *The Structural Engineer*, 99 (10), pp. 14–18; https://doi.org/10.56330/PAPI6611

3) Gibbons O.P., Orr J.J., Arnold W., Archer-Jones C. and Green D. (2022) *How to calculate embodied carbon* (2nd edn.), London: IStructE Ltd

4) British Standards Institution (2023) PAS 2080:2023 *Carbon management in buildings and infrastructure*, London: BSI

5) Orr J.J., Cooke M., Ibell T.J., Smith C. and Watson N. (2021) *Design for zero*, London: IStructE Ltd

6) Sharpe S. (2023) *Five times faster: rethinking the science, economics, and diplomacy of climate change*, Cambridge: Cambridge University Press

7) Department for Energy Security and Net Zero & Department for Business and Trade (2023) *Offshore Wind Net Zero Investment Roadmap* [Online] Available at: Offshore Wind Net Zero Investment Roadmap (publishing.service.gov.uk) (Accessed: January 2024)

8) HS2 (2022) *Net Zero Carbon Plan: A cleaner, greener future* [Online] Available at: 25357_HS2_NetZeroCarbonPlan_CS1656_Final_InteractiveWeb.pdf (Accessed: January 2024)

9) Department for Energy Security and Net Zero & Department for Business, Energy & Industrial Strategy (2021) *Carbon Budgets* [Online] Available at: www.gov.uk/guidance/carbon-budgets#setting-of-the-fifth-carbon-budget-2028-2032 (Accessed: January 2024).

10) RenewableUK (2023) *Wind Energy Statistics Explained* [Online] Available at: www.renewableuk.com/page/UKWEDExplained/Statistics-Explained.htm#:~:text=onshore%20wind%3A%20 26.34%25,offshore%20 wind%3A%2040.58%25 (Accessed: January 2024)

11) HM Government (2023) *Greenhouse gas reporting: conversion factors 2023 – full set (for advanced users)* [Online] Available at: www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023 (Accessed: January 2024)