

SUSTAINABILITY JOINT INDUSTRY PROGRAMME

Offshore wind industry product carbon footprinting guidance

Guidance for measuring the life cycle carbon
footprint of offshore wind developments

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For further information about the SUSJIP programme or the development of this industry guidance, please reach out through our website, www.carbontrust.com/contact

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1. Introduction

1.1. Background

The transition to a decarbonised global energy system is essential for meeting the goals of the Paris Agreement and mitigating the most severe effects of climate change. Low carbon electricity generation is central to this transition, with offshore wind expected to play a crucial role in expanding the capacity of global renewable electricity generation. The Sustainability Joint Industry Programme (SUSJIP), operated by the Carbon Trust, is a collaborative initiative among offshore wind developers. This consortium is united by a common goal: to drive decarbonisation and achieve a Net Zero offshore wind industry.

A key measure in this effort is the product carbon footprint (PCF) for an offshore wind (OSW) development. The PCF quantifies the life cycle emissions and removals associated with an OSW development and is referred to as the 'carbon footprint'. To ensure comparability across different projects, the emissions calculated using this guidance refer to the primary output of the OSW development: electricity, which has been measured with a standardised functional unit [see 2.3]. Carbon footprinting for OSW involves a comprehensive assessment of the emissions from various activities throughout the development's life cycle. This includes the extraction and processing of raw materials, the manufacturing of assets and components, construction, operation, and finally, the decommissioning and disposal of infrastructure. By accurately quantifying the carbon footprint, developers can identify emission hotspots, plan interventions to reduce the carbon impact, improve their carbon performance, and effectively communicate their environmental impact to stakeholders.

With this guidance document and the associated calculator tool, the SUSJIP consortium aims to standardise carbon footprint calculations across the offshore wind industry. This standardisation will empower decision-makers to compare the environmental impact of different developments and technologies, ensuring informed actions are taken to decarbonise future developments and strive for a Net Zero offshore wind industry.

Programme operator

The Carbon Trust

Programme partners

1	EnBW	5	ScottishPower Renewables
2	JERA Nex	6	SSE Renewables
3	Ørsted	7	TotalEnergies
4	RWE		

1.2. Aims of the guidance

The primary aim of this document is to produce a standardised set of guidelines for assessing the product-level carbon footprint of an OSW development and harmonise the approach across the industry. To achieve this, we have defined a series of objectives that provide the basis for the content included in this document:

- Provide **sector-specific guidance** on the application of existing standards for PCF. Provide additional context for the application of organisational carbon footprints (OCF) and life cycle assessment (LCA) standards for the OSW industry.
- Provide guidance for **harmonising the calculation approach** within the industry, improving comparability and transparency of PCF for OSW developments and enabling stakeholders to understand the impact of different designs and technologies.
- Provide a **framework for developers to calculate and report different emissions metrics** for their developments, including but not limited to:
 - The GHG emissions and removals of the offshore wind development per functional unit of electricity (gCO₂e/kWh) delivered to the grid at the onshore substation.
 - Absolute GHG emissions and removals of the OSW development broken down by life cycle stage and module (tCO₂e).
 - Absolute GHG emissions and removals of the OSW development broken down by assets and components in the infrastructure (tCO₂e).
- Develop a **framework to improve data quality** and enable standardised data exchange between partners in the OSW supply chain.

1.3. Glossary

Term	Definition
Activity data	A quantitative measure of a level of activity that results in greenhouse gas (GHG) emissions.
Allocation	The process of partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.
Attributable	Related to the product and included in the product system.
Avoided carbon/Avoided emissions	Emissions reductions that occur outside of a product's life cycle or value chain but arise because of the use of that product.
Biogenic carbon	Carbon (including CO ₂ , CH ₄) derived from (non-fossil) biological processes.
Carbon dioxide equivalent (CO₂e)	CO ₂ e is used to express the combined climate change impact of all applicable GHG emissions in the product system relative to that of carbon dioxide. Relevant GHGs are described in 1.4.1.
Carbon footprint of a product (CFP)	The sum of GHG emissions and removals in a product system, expressed as CO ₂ e and based on the life cycle assessment (LCA) method, using the single impact category of climate change (synonymous with PCF, but defined by ISO 14067).
Co-product	Any of two or more products resulting from the same process or product system which cannot be produced without the other being produced, and which have a market value.
Customer	May refer to a consumer or company.
Data quality indicator (DQI)	An assigned indicator rating the quality of each activity datapoint and each emissions factor.
Declared unit	The reference unit for a partial footprinting boundary, as defined by ISO 14067.
Decommissioning stage	Phase covering the end-of-life activities of an offshore wind installation, including full or partial dismantling, offshore operations, transport to

	shore, site restoration where applicable, and treatment of materials and components.
Direct land-use change (dLUC)	Emissions (primarily from carbon stock losses) due to recent (preceding 20 years before occurrence of the relevant activity) land conversion directly on the area of land that a company owns/controls or on specific lands in the company's value chain.
End-of-waste state	The point in the waste management process where a waste stream has been recovered or processed to such an extent that it ceases to be waste and obtains the status of a secondary product, material, or substance.
Error	A mistake such as an incorrect emission factor allocated to represent an activity.
Environmental product declaration (EPD)	A standardised document that describes the environmental impact of a product. Shows the results of an underlying LCA, prepared according to specific EPD programme rules, while protecting sensitive information. The document is typically prepared in compliance with ISO 14025 as a Type III environmental label.
Fossil carbon	Carbon (including CO ₂) which is derived from fossilised material, in particular fossil fuels such as coal, oil, natural gas, and peat (with regards to combustion).
Functional unit	The functional unit for a full footprinting boundary, as defined by ISO 14067. This can include the function or service a product provides and the duration or service life. It is the unit of output or function to which the inventory results are normalised for the product system (e.g., kgCO ₂ e/kg of product).
Global warming potential (GWP)	Factor used to describe the radiative forcing of a GHG relative to that of CO ₂ .
Greenhouse gas statement	Factual and objective declaration that provides the subject matter for the verification or validation.
Greenhouse gases (GHGs)	Gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds.
Input allocation	Allocation of inputs (incl. materials, energy, etc.) to a product.

Mass balance	Conservation of mass in the system, e.g., checking that all the inputs to a process equal all the outputs (main product, co-products, waste).
Mass-balance approach	Chain of custody model (within a supply chain or organisation's internal processes) in which materials or products with a set of specified characteristics are mixed according to defined criteria with materials or products without that set of characteristics.
Materiality	The significance (%) of the contribution of a single flow (material, energy or emissions) to the total flows within the system boundary.
May	Used to indicate an option that is allowable or permissible.
Offshore Wind (OSW)	The generation of electricity from wind resources located in bodies of water (typically seas or oceans).
Omission	An emission source, which is either unintentionally or intentionally not included in the calculated PCF where it is required to either be included or justifiably excluded.
Organisational Carbon Footprint (OCF)	The sum of GHG emissions and removals related to an organisation (defined by the GHG Protocol's <i>'Corporate Accounting and Reporting Standard'</i>).
Output allocation	Allocation of emissions from all life cycle stages up to this point between multiple outputs, such as co-product allocation.
Primary data	Quantified value of a process or an activity obtained from a direct measurement or a calculation based on direct measurements.
Product	Goods or services.
Product carbon footprint (PCF)	The sum of GHG emissions and removals related to a product (defined by the GHG Protocol's <i>'Product Life Cycle Accounting Standard'</i>).
Product category rules (PCRs)	A set of specific rules, requirements and guidelines for developing Type III environmental declarations and footprint communications for defined product categories.
Product emissions report (PER)	A report summarising the results of the PCF. Also referred to as an emissions inventory report (terminology used in the GHG Protocol's <i>'Product Standard'</i>).

Product system	Collection of unit processes with elementary flows and product flows, performing one or more defined functions and which models the life cycle of a product.
Recycling allocation	Allocation of the benefits of recycling between products using recycled materials and products that are recycled to provide those materials.
Reference flow	The inputs to or outputs from processes in a product system, which are required for the product to fulfil its function defined in its functional unit.
Sea-based land-use change (LUC)	The transformation of marine and sea environments for activities such as building infrastructure, which can impact biodiversity and ecosystems.
Secondary data	Data that does not fulfil the requirements for primary data. It is not directly collected from the specific processes within the product's life cycle being assessed. Instead, it is derived from external sources, such as industry averages, published databases, literature, or generic datasets. Secondary data is typically used when primary data is unavailable, difficult to obtain, or when the product's life cycle includes processes that occur outside the control or direct observation of the organisation conducting the footprint analysis.
Shall	Used to indicate what is required for a PCF to conform with this guidance.
Should	Used to indicate a recommendation, but not a requirement, of this guidance.
Statistical land-use change (sLUC)	Emissions (primarily from carbon stock losses) due to recent (preceding 20 years before occurrence of the relevant activity) land conversion within a landscape or jurisdiction. sLUC can serve as a proxy for dLUC where specific sourcing lands are unknown or when there is no information on the previous states of the sourcing land.
Validation	Process for evaluating the reasonableness of the assumptions, limitations and methods that support a statement about the outcome of a design-stage assessment.
Verification	Process for evaluating a statement of historical data and information to and evaluating the reasonableness of the assumptions, limitations and methods that support a statement about the outcome of the assessment of an operational development.

1.4. How the guidance may be used

1.4.1. What is product carbon footprinting?

Product carbon footprinting (PCF) is a collection of methods for the quantification of GHG emissions and removals associated with a product or system. The method is defined in two main standards, 'ISO 14067: Carbon footprint of products. Requirements and guidelines for quantification' [1] and the 'Greenhouse Gas Protocol (GHGP) Product Life Cycle Accounting and Reporting Standard' [2].

Derived from the LCA method, product carbon footprinting focuses on assessing a single impact: the climate change impact of the product or product system. The methods provide a standardised approach for evaluating the total GHG emissions and removals, referred to in this document and across industry as the 'carbon footprint', occurring over the full life cycle of the product or system. This is referred to as the 'climate change' impact category in LCA and aligns with the requirements of ISO 14040 [3] and ISO 14044 [4], but the PCF standards introduce additional specific requirements for assessment.

Box 1.1: What impacts are included in a PCF assessment?

A PCF calculates the total impact of GHG emissions and removals from a product system and is expressed in carbon dioxide equivalents (CO₂e).

The Intergovernmental Panel on Climate Change (IPCC) describes GHGs as 'gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds.'

The impact of the emissions of different GHGs on our climate is described by their GWP, which is a factor that describes the radiative forcing of a GHG (climate change impact) over a specific time frame. This is usually 100 years, relative to that of CO₂, and is expressed in CO₂e. Different GHGs have different GWPs due to their varied molecular structures and atmospheric lifetimes (how long they remain in the atmosphere following emission). GWP allows the total impact of the emissions of different GHGs to be added together based on their impact on the climate relative to that of CO₂.

The GHG defines six greenhouse gases, or greenhouse gas families for inclusion within a product carbon footprint, including:

1. CO₂
2. Methane (CH₄)
3. Nitrous Oxide (N₂O)
4. Sulfur Hexafluoride (SF₆)
5. Perfluorochemicals (PFCs)
6. Hydrofluorocarbons (HFCs)

1.4.2. Timing of PCF assessment in OSW development

Depending on its goals and intended use, a PCF assessment may be conducted at various stages in the development life cycle. In this guidance, we define two main categories of PCF assessment which help inform the calculation approach, as well as data quality, uncertainty, and reporting.

Table 1: Types of PCF assessment defined by this guidance

Assessment category	Definition	Description
Operational PCF	PCF of an OSW development that has been fully commissioned and is in regular operation.	An 'operational' PCF assessment may be conducted on any OSW development that is fully constructed and connected to the electrical grid and in regular operation after commercial operation date. It is acknowledged that some of the data included in the 'operational' assessment may still be design-stage or forward-looking, e.g., data related to the lifetime maintenance and repair activities, or decommissioning and end-of-life [life cycle modules C1-C5, see 2.4.2] for the development, which may not have occurred at the time the assessment is undertaken. Operational PCF assessments may be conducted for several reasons, including information gathering and meeting regulatory requirements. Assessments conducted at this stage will not provide the information necessary to decarbonise the upstream supply chain for the studied OSW development [life cycle Modules A1-A3, see 2.4.2], as technology and design choices, including materials used in main assets such as turbines and foundations, have already been selected. However, operational PCF assessments can be fully verified based on the requirements of relevant assurance standards. Practitioners may use this guidance to assess the carbon footprint of an existing, operational OSW development, including: • Carbon intensity of the operational OSW development per unit of electricity delivered to the grid. • Absolute carbon footprint of the OSW development over the full life cycle, sub-categorised life cycle stage, and core assets and components.

Design-stage PCF	PCF assessment of planned or partially built OSW development, which is not yet in regular operation	A ‘design-stage’ PCF assessment is defined in this guidance as a forward-looking assessment of an OSW development that is designed, planned, or under construction, but is not yet in regular operation. It is acknowledged that some of the activities included in the ‘design-stage’ assessment may have occurred, e.g., production of some of the assets for the development if the assessment is undertaken after the technical design phase. Design-stage PCF assessments may be conducted for several reasons, including for design and technology comparison or meeting non-price criteria for auctions. PCF assessments conducted during design phase can provide the information required to make choices related to technologies and materials that can significantly impact the life cycle carbon footprint of the development before design decisions are locked in. Design-stage PCF assessments cannot be fully verified but may be validated based on fulfilling the requirements of relevant assurance standards. Practitioners may use this guidance to assess the carbon footprint of a design-stage OSW development, including: • Carbon intensity of the planned OSW development per unit of electricity delivered to the grid. • Absolute carbon footprint of the planned OSW development over the full life cycle, sub-categorised life cycle stage, and core assets and components. A design-stage PCF is an attributional assessment of the same type as an operational PCF. This type of PCF uses the best available assumptions and proxies based on the available knowledge during design stages about how the OSW farm will be built and operated. It is inherently more uncertain than an operational PCF, as there may not be any primary data available at design stage for the assets and activities which are the most significant contributors to the OSW PCF. This results in an increase in the uncertainty associated with the assessment parameters and the stated results for a design-stage PCF [See 3.8 for further guidance on data quality and uncertainty]. Due to this heterogeneity, a design-stage PCF should not be compared to an operational PCF.
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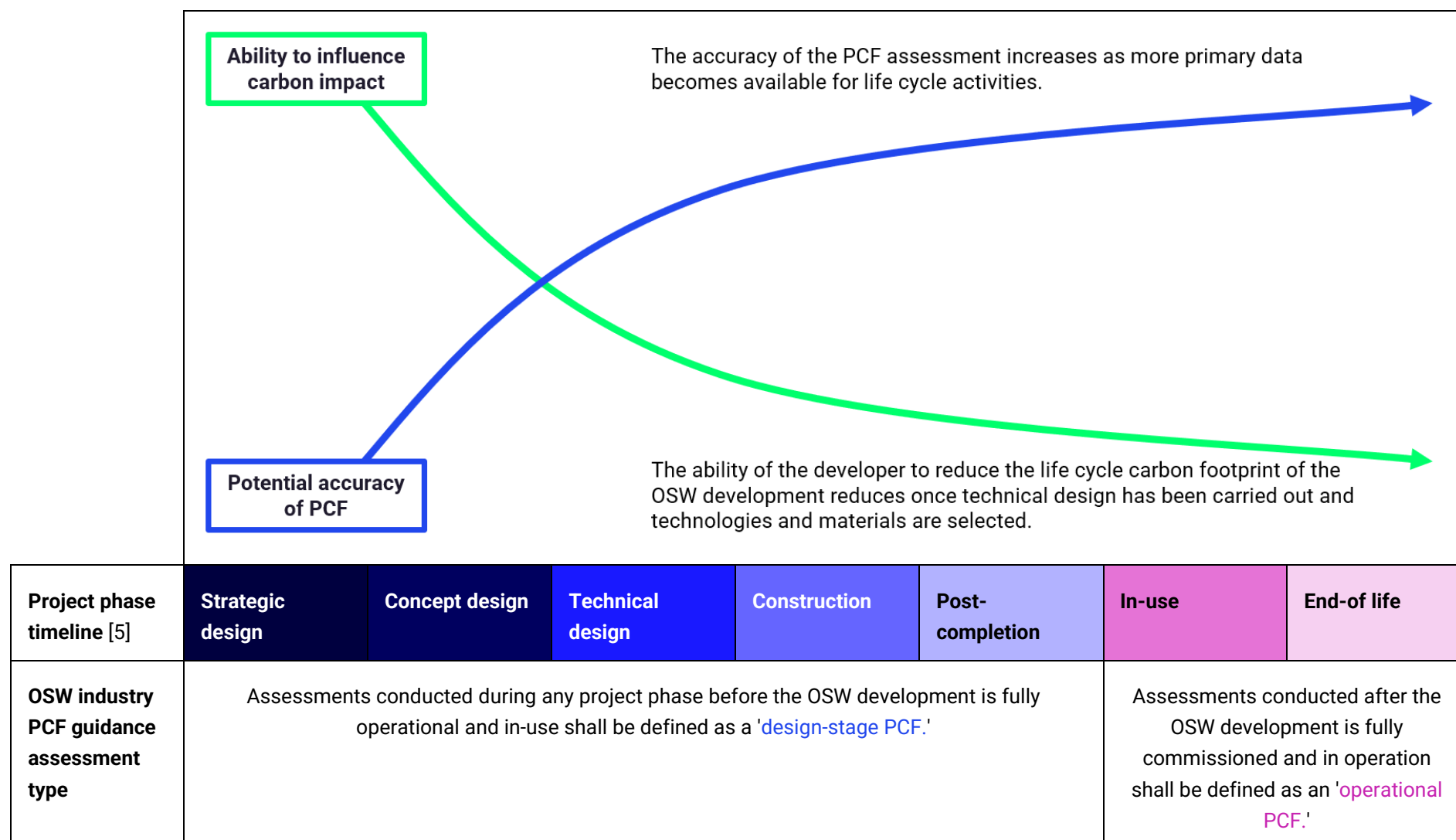


Figure 1: OSW industry PCF guidance assessment types at different stages of development life cycle

1.5. Reporting standards

This document is intended to provide sector-specific guidance for the application of the following core standards for product-level assessment of carbon footprints:

- ISO 14067: Carbon footprint of products. Requirements and guidelines for quantification
- GHGP Product Life Cycle Accounting and Reporting standard
- ISO 14040: Environmental management – Life Cycle assessment – Principles and framework
- ISO 14044: Environmental management – Life Cycle assessment – Requirements and guidelines

It also draws on additional requirements and terminology outlined in the following supplementary standards and guidance documents:

- ISO 21931-2: Sustainability in buildings and civil engineering works – Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment – Part 2: Civil engineering works.
- ISO 21930:2017: Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services.
- EN 15978: Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method.
- EN 15804: Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.
- EN 17472:2022: Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods.
- ISO 14025: Environmental labels and declarations – Type III environmental declarations – Principles and procedures.
- International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment.
- WBCSD PACT Pathfinder Framework v3.
- PAS 2080:2023 Carbon management in buildings and infrastructure.
- RICS: Whole Life Carbon assessment for the built environment.
- The Carbon Trust: Product carbon footprints requirements for assurance – Part 1: Technical, v3.0.
- GHGP Scope 2 guidance: An amendment to the GHGP Protocol Corporate Standard.

1.5.1. Additional context for reporting standards

What are the relevant standards?

A 'standard', as referred to in this guidance, is an agreed set of requirements published by a standards body to define methods for assessing and reporting environmental impacts. There are several types of standards that exist for the assessment of carbon footprints, which are written by independent standards bodies to apply across a variety of sectors and industries. The aims of the guidance were considered first when selecting the appropriate standards and existing standards documents were mapped to identify any potentially relevant standards for the creation of this sector-specific guidance.

Table 2 provides an overview of the international standards for carbon footprinting and the international bodies that publish them, citing the 'PACT Pathfinder Framework V2' [6] Appendix C.

Table 2: Typical international reporting standards for carbon footprinting

Publisher	Geographical focus	Organisational carbon footprint (OCF)	Product carbon footprint (PCF)	Life cycle assessment (LCA)
International Organization for Standardization (ISO)	Global	ISO 14061-1	ISO 14067	ISO 14040 ISO 14044
Greenhouse Gas Protocol (GHGP) - WRI/WBCSD	Global	Corporate, Scope 2 and Scope 3 Standards	Product Life Cycle Standard	None

Within the two primary strands of organisational-level and product-level standards, there are several additional standards and guidance documents built on the generic standards listed in Table 2. They exist to provide further guidance for their application to specific product categories or sectors, and are referred to as:

- Product category rules (PCRs)
- Sector-specific guidance documents (SSGDs)

Due to the significant level of generalisation and ambiguity in the generic standards, specific clauses or requirements can be open to different interpretations. This creates a need for PCRs and SSGDs to enable practitioners to interpret the generic standards and make consistent and comparable assessments for organisations and products within the same industry or category.

How we chose the 'core' compliance standards

Core standards are those upon which the requirements of this guidance have been developed. Its primary aims are:

- To provide guidance for the assessment of a life cycle carbon footprint for an OSW development in terms of its primary output, electricity.
- To produce accurate and comparable assessments that enable stakeholders to make decisions and plan interventions that lead to the decarbonisation of the sector.

Considering the primary aims of the guidance, it was deemed appropriate to apply product-level carbon accounting standards.

PCF standards

Within the PCF strand, the two most widely applied global standards are *ISO 14067 - Greenhouse Gases – Carbon Footprint of Products – Requirements and Guidelines for Quantification* [1] and the *Greenhouse Gas Protocol (GHGP) – Product Life Cycle Accounting and Reporting Standard* [2]. Both standards follow an LCA approach, derived from LCA standards, but may have more specific requirements for the assessment criteria. For this guidance, we reviewed the requirements of these standards and published detailed research [7]. While the terminology differs in places, an assessment may simultaneously satisfy the requirements of both standards where the stricter requirements and additional criteria from each are met.

This guidance first applies the terms and definitions defined in Section 3 of ISO 14067. Where the GHG protocol product standard terms or definitions diverge from ISO 14067, e.g. in their stated terminology for the functional unit, the GHGP Protocol term is described alongside the ISO term.

LCA standards

The PCF approach is a single impact assessment derived from the LCA approach, with more specific requirements for assessing the carbon footprint. ISO 14040 and ISO 14044 are the international standards that define the LCA approach on which PCF is based; therefore, they are listed as core standards for this guidance and their requirements have been followed through the application of PCF standards.

How we chose the 'supplementary' compliance standards

The supplementary standards are those that provide additional requirements deemed relevant to PCF assessment for OSW developments. Our guidance integrates the requirements of these standards where they do not conflict with those of the core standards.

Product category rules (PCRs)

PCRs are sets of additional rules, written by panel groups (involving industry groups) for assessing the PCF or LCA of specific categories or sectors of products. They are typically developed by standards bodies or environmental product declaration (EPD) programme operators and are designed to standardise methodologies for reporting within specific product categories. This includes the standardisation of assessment criteria such as the system boundary and the functional unit.

Construction products and civil works standards

Several standards have been published to provide guidance and requirements for environmental assessment methods specific to construction products and works. These are typically used in conjunction with life cycle methodologies (PCF and LCA) to provide PCRs for the construction and infrastructure sector, including widely applied requirements for the categorisation of life cycle stages and modules. These standards were deemed relevant for our assessment as the construction of OSW developments falls within the category of infrastructure works, and their requirements have been followed where they do not conflict with those of the core standards.

Additional standards and guidance documents

The *PACT Pathfinder Framework V2* [6] provides guidance for the standardisation of calculation and exchange of PCF data across industries. The framework builds on key PCF standards (ISO 14067, GHGP Product Standard), offering further guidance on creating consistent and comparable PCFs and exchanging the data across the supply chain. Improving inventory data across the supply chain is a key aim of the SUSJIP programme; therefore, we have integrated some of the recommendations and requirements of the Pathfinder Framework into our guidance.

PAS 2080:2023 Carbon Management in Buildings and Infrastructure [8] was developed to standardise the management of carbon emissions across infrastructure projects. Developed to complement the core compliance standards, it offers guidance on good practice and key enablers for decarbonisation across the infrastructure value chain.

The *Carbon Trust: Product Carbon Footprints - Requirements for Assurance* [9] is a publicly available guidance document that defines additional requirements for organisations to verify the carbon footprint of their products, principally for the purposes of external communication. Improving the transparency and comparability of carbon footprint disclosures is another key aim of the SUSJIP programme; therefore, assurance is a relevant topic for our guidance.

RICS Whole Life Carbon Assessment for the Built Environment [5] provides comprehensive methodologies for assessing the carbon impact of buildings and infrastructure over their entire life cycle. It is designed to standardise the approach to carbon measurement and reporting within the construction industry, ensuring all stages of a building's life cycle – from material extraction to demolition – are considered.

Given the relevance of each of these standards and guidance documents, the SUSJIP programme has incorporated additional recommendations and requirements from them where they do not conflict with the requirements of the core standards.

1.5.2. Relationship between PCF and OCF

OCF standards, including the GHG Protocol Corporate Standard and ISO 14064-1, are designed to assess the life cycle carbon footprint associated with a company's operations in a given reporting year.

The GHGP commonly used for corporate reporting, categorises organisational GHG emissions into different sources or 'Scopes', including direct emissions (Scope 1), indirect emissions from energy procurement such as electricity, heating, cooling, and steam (Scope 2), and all other indirect emission sources associated with the company's activities (Scope 3). ISO 14064-1 categorises GHG emissions only as direct or indirect.

The primary difference between OCF and PCF is the boundary for activities that are required to be assessed. Table 3 shows the boundary of each assessment from a physical, temporal, and geographical perspective.

Table 3: Boundary comparison for OCF and PCF

Assessment Boundary	OCF	PCF
Physical boundary	The physical boundary for an OCF encompasses all activities (Scope 1, 2, and 3 emissions, direct and indirect) of an organisational entity for a reporting year. This boundary may vary depending on the chosen control approach (operational, financial, and equity share) and includes emissions, both direct (occurring in assets controlled by the reporting entity) and indirect (occurring in assets not controlled by the reporting entity) resulting from the activities of the reporting entity for the given year.	The physical boundary for a product footprint includes all activities and processes defined as part of a product system boundary, irrespective of ownership and control. This means there may be a standard list of included activities for the product system (e.g., an OSW development) regardless of who owns the different areas of the system.
Temporal boundary	The temporal boundary for an organisational footprint is the chosen reporting year, meaning that the life cycle GHG emissions of activities of the organisational entity occurring in the specified reporting year are assessed. In the context of OSW development, this limits the ability to apply organisational footprinting standards to long, multiyear projects (e.g., the footprint for Year 1 may include wind turbine generators (WTG), Year 2 may include cables, and Year 3 may include substations).	The temporal boundary for a product footprint is defined by the life cycle of the product system (ISO 14067). This means the time boundary for activities may extend beyond a chosen reporting year, and any activities or processes that are inputs or outputs of the product system are included (e.g., including infrastructure purchased, deployed, and operated across a span of years, as in the case of OSW development).

Geographical boundary	The geographical boundary for an organisational footprint is multi-regional, and all activities relevant under the physical and temporal boundary are included regardless of geographical region.	The geographical boundary for a product footprint is multi-regional, and all activities relevant under the physical and temporal boundary are included regardless of geographical region.
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In summary, OCF and PCF are complementary approaches that allow entities to quantify and report their carbon footprint from different perspectives to gain a comprehensive understanding of the impact of their activities. A considerable proportion of the activities included in the boundary of each type of assessment will overlap, and companies can use some of the data and guidance defined in this document for the assessment and reporting of organisational emissions. We have developed additional guidance in Appendix 1, Table 3 to support the mapping of emissions sources between product and organisational boundaries for OSW developers.

Box 1.2: Is there a data overlap between PCF and OCF assessments?

There is a significant overlap between an organisation's carbon footprint and the carbon footprint of specific goods and services that it develops or produces. For instance, activity data and emission factors collected for a PCF assessment for an OSW development – e.g., describing the emissions associated with the manufacturing of a WTG – may also be used within that organisation's Scope 3, Category 1 assessment for the year in which they purchased the WTG, according to the selected control approach.

An accurate PCF can therefore significantly improve the accuracy of a company's organisational footprint and inform reduction planning in line with organisational frameworks, such as the Science Based Targets initiative.

1.5.3. Relationship between PCF, LCA, EPD and PCF

The LCA method has been developed and defined in the standards documents ISO 14040 and ISO 14044 to assess a wide range of environmental impacts associated with a product, service, or system over the course of its entire life cycle.

The LCA approach considers a broad range of environmental impacts, including but not limited to the 'climate change' impact of a product, service, or system. LCA may also include assessments of other impacts, such as a system's impact on biodiversity, human toxicity, or resource use. The 'climate change' impact category is a specific LCA impact category that assesses the potential climate impact of GHGs emitted during the life cycle of a product. This impact category is also referred to across industry and academia as the 'carbon footprint,' 'GHG footprint,' 'whole-life carbon footprint,' and similar terms.

PCF is a specific application of the LCA method that relies on the same assessment principles but focuses on only one impact category, 'climate change,' or, in simple terms, the carbon footprint of the product, service, or system over its life cycle. The approach has been derived directly from LCA and developed and defined in standards documents such as ISO 14067 and the GHGP Product Standard, providing more detailed guidance.

In the context of OSW development, a full LCA may be undertaken where the practitioner wants to understand the development's impact on other environmental processes, such as marine or terrestrial ecosystems. Impact categories are targeted based on the goal and scope of the LCA assessment. However, this may provide a less specific and comparable assessment of the carbon footprint than a PCF assessment, due to the broader scope and varying assessment criteria. The PCF standards introduce more stringent assessment requirements than LCA standards, designed to improve accuracy and increase comparability. This aligns with the primary goal of this guidance, which is to assess and compare developments on a like-for-like basis to enable the decarbonisation of OSW developments, and specifically, the decarbonisation of the supply chain.

An EPD is a Type III environmental declaration, compliant with the requirements of ISO 14025. It consists of an underlying verified LCA report that may not be made publicly available but is conducted in accordance with a verified EPD programme. A public EPD document is made available detailing the LCA results, assumptions, and additional context to provide information about the LCA of a product or system without compromising the underlying intellectual property.

Box 1.3: Why do we have PCF standards?

Specificity: PCF standards are designed to measure only the climate change impact category (carbon footprint). If the primary goal of an assessment is understanding and reducing the carbon footprint, using these standards may result in a more consistent approach. PCF standards provide specific guidance, e.g., on impact methodologies, requiring that footprints are calculated using the IPCC characterisation factors for GHGs. Specificity on such criteria increases the comparability of PCF assessments.

Resource intensity: PCF standards provide more detailed guidance for calculating GHG emissions and removals as a single criterion. Guidance in ISO 14040/ISO 14044 recommends the assessment and disclosure of multiple impact categories.

Comparability: By providing a more detailed methodology and specific assessment criteria focusing solely on carbon footprinting, PCF standards may improve the comparability of carbon footprint results compared to assessments made using ISO 14040/ISO 14044. This is important for benchmarking purposes or for communicating results to customers and stakeholders.

1.6. Reporting principles

Both the ISO and the GHG Protocol define a set of reporting principles that underpin their standards. These are interpreted for the purposes of this guidance.

1. **Relevance** – The footprint measurement and associated reporting must be useful in decision-making for the intended audience.
2. **Completeness** – All relevant emission sources for the OSW development are accounted for in the footprint and are aligned to the specified boundaries for the assessment defined by the guidance.
3. **Consistency** – Provide guidance that enables practitioners to choose methodologies and data in a consistent manner to enable fair comparison between developments and technologies.
4. **Transparency** – Clearly describe the sources of footprint data and state any assumptions, estimates, or proxies used in the assessment. Methodological and data weaknesses affecting the results of the assessment should be reflected in the data quality and uncertainty assessment.
5. **Accuracy** – Ensure that emissions are neither overestimated nor underestimated, aiming for the most accurate results possible.

1.7. Guidance terminology

The following terminology has been adopted throughout this guidance document. These terms will differentiate between a requirement that is mandatory and a permissible or allowable option:

- The term 'shall' is used to indicate what is obligatory.
- The term 'should' is used to indicate a recommendation, rather than a requirement.
- The term 'may' or 'can' is used to indicate an option that is permissible or allowable.

A full glossary of terms and definitions used in this guidance is provided in 1.3.

2. Assessment criteria: Product carbon footprints

2.1. Goal and scope

The goal and scope of the PCF assessment shall be defined by the practitioner in accordance with the requirements of ISO 14067 and the GHGP Product Standard. There are several reasons why a developer, individual practitioner, or stakeholder may seek to use this guidance to assess the PCF of an OSW development, some of which are as follows:

- A developer or stakeholder may wish to accurately identify carbon emissions hotspots and use this information to plan interventions to reduce the intensity of different areas of a development.
- A developer or stakeholder may be subject to regulatory requirements for the disclosure of sustainability metrics related to developments or products.
- A developer or stakeholder may wish to compare the life cycle carbon intensity of different developments within their portfolio to gain insight into best practice.
- A developer or stakeholder may wish to compare the life cycle carbon footprint associated with different design options for the same development to minimise the carbon intensity of an OSW development during the design phase.
- A developer or stakeholder may wish to benchmark a development against peers or the industry average to assess the adequacy of a design.
- A developer or stakeholder may wish to use the inventory to inform their organisational carbon footprint.
- An individual practitioner may wish to complete an assessment to support academic research, governmental research or otherwise.

This guidance document states the standard definition for the scope of the assessment in Table 4.

Table 4: Scope of the OSW PCF assessment

Definition scope of PCF assessment
A PCF assessment of OSW development, [DEVELOPMENT NAME], built for renewable electricity generation, covering the full life cycle of the infrastructure development.

2.2. System under study and its functions

Having stated the goal and scope of the assessment, the practitioner must next define the product system under study and its function(s) in accordance with the requirements of ISO 14067. The GHGP Product Standard refers to this process as 'defining the studied product'. Table 5 provides a standard definition for the system under study and the system function for an OSW development, which shall be used in the PCF assessment.

Table 5: Defining the product system and system function

Definitions for product system and system function	
Product system	The product system under study is one OSW development, also referred to as an OSW 'farm' or 'electrical generation plant'. The product system covers the whole OSW farm life cycle, from pre-construction to decommissioning.
System function	The function of the OSW development is the generation of electrical energy (electricity) and delivery at the point of interconnection (PoI ¹) with the grid at the onshore substation ² , whereafter it is transmitted and distributed to the end consumer.

¹ The Point of Interconnection (PoI) is the physical interface where the development's electrical system connects to the external onshore transmission or distribution network at the outgoing terminals of the export switchgear in the onshore substation.

For the *OSW industry PCF guidance*, the system boundary extends to include the onshore substation. This ensures that all infrastructure required to transform and deliver electricity from the development to the national grid, including the offshore export cables, onshore export cables, and the onshore substation equipment (transformers, switchgear, and associated civil works), is fully captured within the assessment.

This approach defines the boundary based on the physical system required to generate and export power from the OSW development, regardless of varying regulatory arrangements (e.g., Offshore Transmission Owner or Transmission System Operator models) that might assign financial responsibility for or ownership of the onshore substation to different parties in different markets.

Note: Onshore battery energy storage systems (BESS) remain excluded from the system boundary as they represent a distinct, non-standard asset class; however, this may be reviewed in future updates of this guidance

Box 2.1: Alternate product system and functions?

It is anticipated that the OSW developments of the future may fulfil alternative functions or multiple functions. For example, a developer may build an OSW development that delivers energy directly to an onsite electrolyser to produce green hydrogen. In this example, the OSW development may be said to be fulfilling an alternative function to that set out by this guidance.

Given that electricity production is currently the dominant commercial function for OSW developments, this guidance only provides methods for assessing the PCF of an OSW development based on the stated function of producing electricity and delivering it to the grid and does not provide detailed guidance on PCF assessment for OSW developments fulfilling alternative system functions.

It is noted that as the global energy transition accelerates, it is likely that alternative commercial functions will emerge for OSW developments, which will require additional information to be considered when defining the PCF assessment criteria. Alternative system functions will be considered in future updates to this guidance.

2.3. Functional unit

The functional unit, also defined as the 'unit of analysis' (*GHGP Product Standard*), is a foundational principle of PCF and LCA. The purpose of the functional unit is to ensure that PCF results are meaningful and comparable. The selection of a suitable functional unit is a critical step in any PCF assessment and influences how the footprint is disclosed and interpreted by stakeholders.

In the context of an OSW development, a suitable functional unit allows us to compare the impact of two developments under a common unit, even if they have different designs, efficiencies, sizes, or technologies. It also enables the results to be aggregated or disaggregated as needed, providing flexibility in how the results of a PCF assessment can be used and interpreted to inform improvements in OSW development. When using the OSW PCF guidance, the practitioner shall define the functional unit as stated in Table 6.

Table 6: Defining the functional unit for the assessment

Definition for the functional unit
The functional unit of the assessment shall be 1 kWh of electricity, net³, generated at [OSW DEVELOPMENT NAME] and delivered at the PoI with the grid at the onshore substation, with [PRACTITIONER DEFINED] MW installed capacity, [PRACTITIONER DEFINED] % capacity factor, [PRACTITIONER DEFINED] years of expected service life.

2.3.1. Additional intensity metrics

To ensure consistency of assessments, one mandatory functional unit is defined for the assessment in Table 6. However, other intensity metrics can be assessed and reported alongside the functional unit to allow for different comparisons and to meet alternative reporting requirements. These additional intensity metrics can provide valuable insights into specific aspects of an OSW development and can be tailored to address stakeholder needs or regulatory demands. For example, while the primary functional unit might focus on the carbon footprint per kilowatt-hour (kWh) of electricity delivered to the grid, other intensity metrics could include:

- **Carbon intensity per megawatt installed (gCO₂e/MW):** This metric could be useful for understanding the carbon footprint associated with the installed capacity of the OSW development, providing a comparison across different projects based on their size and scale.
- **Carbon intensity per unit of investment (£, \$, € /gCO₂e):** This metric could be useful for financial stakeholders who are interested in assessing the carbon efficiency of their investment, allowing them to compare different developments based on the financial cost relative to their carbon footprint.

³ Net of all internal electrical losses. 1 net kWh delivered, includes all internal electrical losses in the system boundary including (but not limited to): array cable losses, export cable losses and transformation losses (offshore) which are considered in the net capacity factor parameter.

- **Carbon intensity per operating year (gCO₂e/year):** This metric could be useful for understanding the annual carbon footprint of the OSW development, providing a time-based comparison that might be useful for long-term operational planning.

2.4. System boundaries

The system boundary should include all attributable life cycle activities associated with the studied OSW development. In addition to the physical boundary of attributable activities, during the data collection stage, the practitioner shall state the geographical and temporal boundaries of the system.

2.4.1. Defining the system boundary

When calculating a PCF, the practitioner shall clearly state the boundary of the assessment, in accordance with the requirements of ISO 14067 and the GHGP Product Standard. This guidance provides a standard definition for the system boundary in Table 7. The system boundary shall include the full set of life cycle activities associated with the infrastructure project. Figure 2 shows a visual representation of the system boundary for an OSW development as defined by this guidance.

Table 7: Defining the system boundary

<i>OSW Industry PCF Guidance definition for the system boundary</i>
The system boundary shall include all life cycle activities associated with the infrastructure development, including preconstruction, extraction of materials, manufacture of assets and components, construction and installation, operation, decommissioning, and end-of-life. The boundary includes all the infrastructure assets and development activities described in Appendix 1. The system boundary ends at the point at which electricity is delivered at the PoI with the grid at the onshore substation.

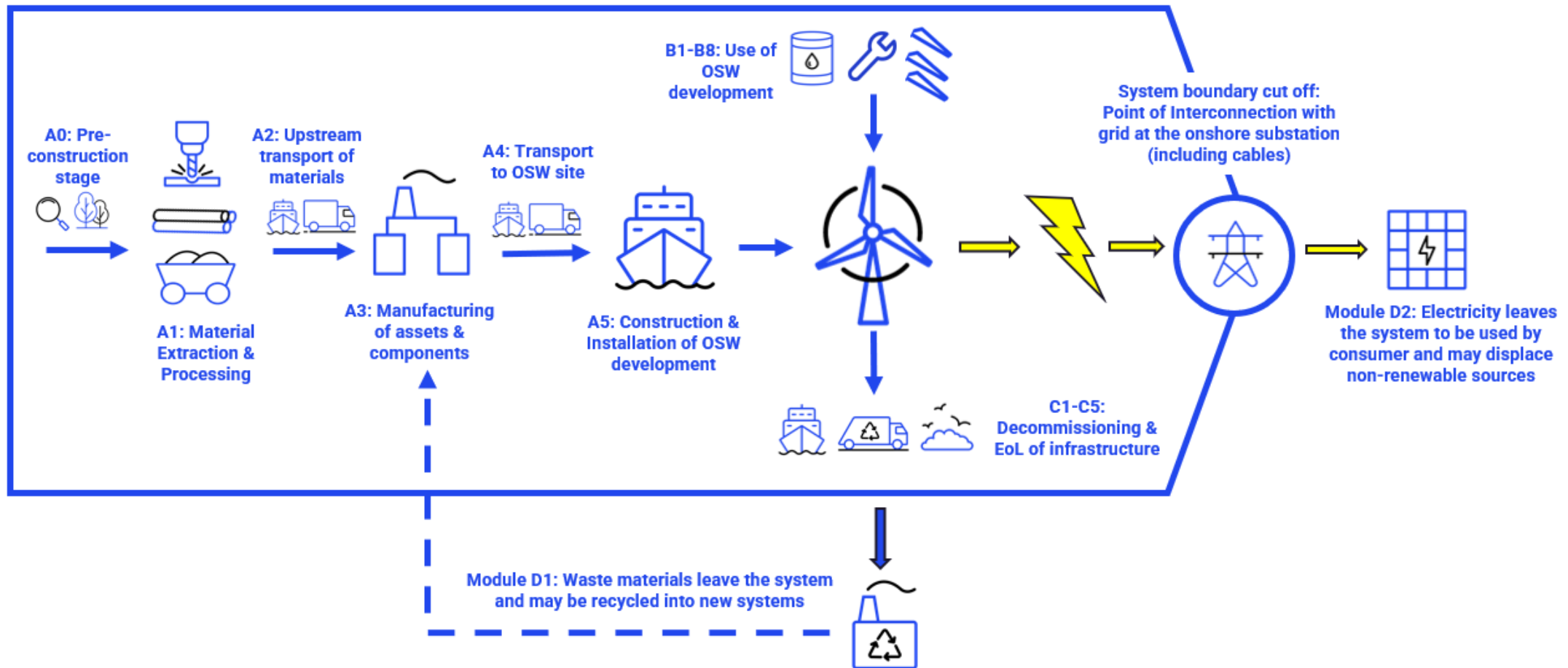
Box 2.2: Infrastructure assessment or energy assessment?

The system boundary can sometimes be framed in different ways for similar assessments, depending on the nature of the system under study. For example, in LCA, there are parallel standards and guidance related to the assessment of infrastructure and the assessment of energy, including several dedicated standards (see section 1.5 for further information about infrastructure standards).

The development of energy infrastructure presents complications in framing the system boundary, which may affect how results are interpreted. The reason for this is that energy (in this case, electricity) is a physical product that requires transmission and distribution downstream of the core infrastructure, leading to emissions-generating activities (operation and maintenance of equipment) as well as additional electrical losses.

To satisfy the aims of this guidance — enabling the decarbonisation of OSW development infrastructure and ensuring fair comparison between infrastructure projects —practitioners using this guidance shall frame all assessment criteria, including the system boundary, in terms of the infrastructure project rather than the electricity produced by the development.

Figure 2: Standard system boundary defined in the *OSW industry PCF guidance*



2.4.2. Life cycle stages and information modules in the system boundary

To fully understand all the relevant emissions sources within the system boundary for an OSW development, the practitioner shall categorise each attributable life cycle activity according to the relevant stages and information modules described in this guidance, providing a clear and interpretable set of results. Describing the system in terms of life cycle stages is a requirement of both ISO 14067 (clause 6.3.4) and the GHGP Product Standard (Chapter 7); however, neither standard defines mandatory terminology for the description of these stages. The standards allow the practitioner to classify the stages flexibly to better reflect the life cycle of a specific product or system.

Information modules in construction products and infrastructure assessment

Life cycle information modules have emerged in several parallel International Organization for Standardization (ISO) and European Committee for Standardisation (CEN) product category rules that specifically focus on assessing construction products and infrastructure works [see 1.5].

Life cycle information modules, presented using alphanumeric codes, are subcategories that further describe the broader stages that typify PCF and LCA and have become commonplace in construction and infrastructure LCA. For example, the 'production' or 'manufacturing' stage, which broadly represents the upstream (cradle-to-gate) emissions associated with products and goods purchased for use in the system, is subcategorised into three separate information modules:

- **A1:** Extraction and processing of raw materials
- **A2:** Transport of materials to manufacturer site
- **A3:** Manufacturing of the product

The introduction of information modules allows for a more granular assessment, which is particularly valuable in the construction sector for identifying hotspots and planning reduction interventions. However, the relevant standards describe the life cycle modules slightly differently, which presents a problem with consistency. The key inconsistencies identified in the information modules as described by the relevant standards are shown in Table 8, and may be summarised as follows:

- **A0:** Several construction works standards define a Module A0, which includes preconstruction activities related to the works (i.e. land advice, surveys, etc.).
- **B8:** Several construction works standards define a Module B8, but the boundary of the module differs. EN 17472 refers to B8 as impacts associated with 'user's utilisation' of the asset. ISO 21931-1 refers to B8 as impacts associated with 'users' activities'. ISO 21931-2 does not provide specific guidance on what should be included in B8, instead referring to B6-B8 as including the use of energy, material, and water from operation of the infrastructure.
- **C5:** ISO21931-2 also defines a Module C5, which includes relandscaping activities following decommissioning of the infrastructure. This is not included in the other construction works standards.
- **D1 and D2:** Several construction works standards subcategorise Module D into two information modules, D1 and D2. EN 17472 and ISO 21931-1 refer to D1 as benefits and loads beyond the system boundary associated with 'reuse, recycling, and energy recovery' of materials leaving the system. They both refer to D2 as benefits and loads beyond the system boundary associated with 'exported energy and other utilities', which is relevant to OSW developments.

Table 8: Information modules in infrastructure standards

Standards category	Standard	Information modules included
Infrastructure standards focusing on the assessment of construction products (e.g. concrete, structural steel and other materials that may be used in an OSW development)	EN 15804, construction products	A1-A5, B1-B7, C1-C4, D
	ISO 21930, construction products	A1-A5, B1-B7, C1-C4, D
Infrastructure standards focusing on the assessment of construction works (e.g. buildings, civil infrastructure works)	EN 15978, buildings	A1-A5, B1-B7, C1-C4, D
	EN 17472, civil works	A0-A5, B1-B8, C1-C4, D1-D2
	ISO21931-1, buildings	A0-A5, B1-B8, C1-C4, D1-D2
	ISO21931-2, civil works	A0-A5, B1-B8, C1-C5, D

This guidance aims to provide guidance for the carbon footprint assessment of full OSW development infrastructure projects, rather than solely of constituent construction products. To achieve this, the guidance primarily adapts the requirements of both *EN 17472 - Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods* [10] and *ISO 21931-2 - Sustainability in buildings and civil engineering works* [11] to define the life cycle stages and information modules (sub-stages).

Practitioners applying this guidance shall assess the carbon footprint according to the information modules (A-D), defined in more detail in Table 9, to produce a clear and interpretable set of results for the carbon footprint of the studied OSW development.

Table 9: Life cycle stages and information modules

Life cycle stages and information modules for this guidance																																										
Information module descriptions the in the system boundary for an offshore wind Development	Stage name	Pre-construction stage		Production stage		Construction stage		Use of OSW development stage						End of life of OSW development stage			Benefits and loads beyond the system boundary																									
	Stage code	A0		A1-A3		A4-A5		B1-B8						C1-C5			D1-D2																									
Information module descriptions the in the system boundary for an offshore wind Development	A0: Land and associated fees/advice		A1: Raw materials		A2: Transport to manufacturing site		A3: Manufacturing of products		A4: Transportation to the development site		A5: Construction of the OSW development		B1: Use of the OSW development		B2: Maintenance		B3: Repair		B4: Replacement		B5: Refurbishment		B6: Operational energy use		B7: Operational water use		B8: User activities not covered in B1-B7		C1: Deconstruction and demolition		C2: Transport to waste processing or disposal		C3: Waste processing		C4: Disposal of waste		C5: Relandscaping		D1: Reuse, recycling, and energy recovery of materials leaving the OSW development system		D2: Impacts of exported electricity beyond the system boundary.	

— Mandatory
 Optional

2.4.3. Modules A-C: Summary of activities in mandatory life cycle stages and information modules for the OSW Industry PCF Guidance

Table 10 provides a summary of the activities that shall be included in the system boundary for an assessment of an OSW development as defined by this guidance. A full, detailed summary of the activities, including specific assets, components, and materials to be included, is provided in Appendix 1.

Table 10: Summary of mandatory emissions and removals sources to be included in the assessment

Life cycle stage	Relevant emissions and removals sources
Preconstruction stage (A0)	The practitioner shall include emissions from preconstruction activities such as surveys on land and at sea for the OSW development site, and site preparation activities not otherwise included in other information modules, including: • Emissions arising from fuel and energy use in vehicles and vessels conducting surveys of the site. • Upstream emissions arising from material usage in site specific preconstruction equipment (e.g. lidar, met mast build for OSW development).
Production stage (A1-A3)	The practitioner shall include upstream emissions and removals from material extraction and processing, material transport and manufacturing activities for assets, components and materials used in the development of the infrastructure: • Upstream emissions arising from production of infrastructure assets, components and materials [see 2.9.1 and Appendix 1, for further detail], including: ○ Extraction and processing of raw materials used as inputs for assets, components. ○ Transport of materials to upstream manufacturing site (supplier site). ○ Energy used in the manufacturing of assets and components. ○ Waste associated with manufacturing of core infrastructure assets and components. • Upstream emissions arising from production of ancillary materials used in the OSW development (e.g. coatings, oils, lubricants). • Upstream removals arising from the use of biogenic construction materials in the infrastructure development (e.g. balsa wood used in turbine blades).

Construction and installation stage (A4-A5)	The practitioner shall include emissions from construction and installation activities at the construction port and offshore site, including: • Emissions arising from transportation of assets, components, and materials to site, including any air, road, and sea freight. Transportation typically includes transport from supplier or manufacturing site to the construction port but may include transportation directly to offshore site. • Emissions arising from the development of any temporary works at the construction port or offshore site to support site activities or asset assembly at construction port and offshore site. • Emissions arising from fuel and energy usage in vehicles and vessels used in construction and installation at the offshore site. • Emissions arising from land-use change related to site preparations, e.g., onshore or offshore clearances required for construction and installation of infrastructure assets. • Downstream emissions arising from treatment of waste from construction activities, including waste materials and temporary works.
Use of infrastructure stage (B1-B8)	The practitioner shall include emissions from standard activities associated with the operation of the infrastructure during its operational lifetime. • Direct emissions arising from use of the infrastructure (e.g. fugitive emissions such as leakage of insulating gasses from substation equipment). • Upstream emissions arising from the production of assets, components and ancillary materials used in the ongoing maintenance, repair, and replacement of OSW development infrastructure. • Emissions arising from the transportation of assets, components and materials used in the ongoing maintenance, repair, and replacement of OSW development infrastructure, including any air, road, and sea freight. Typically focusing on transport from supplier or manufacturing site to the construction port but may include transport direct to offshore site. • Emissions arising from the use of sea vessels and vehicles used in the transportation of maintenance personnel, equipment, and components to the offshore site to conduct maintenance, repair, and replacement activities.

	- Emissions arising from the operational consumption of fuels, electricity, and water during regular operation of the infrastructure, including: - Electricity consumed by OSW development infrastructure from grid during startup or otherwise. - Fuel used in operation of static assets (e.g. backup generators used in substation equipment). - Operational water consumption on site.
End-of-life of infrastructure stage (C1-C5)	The practitioner shall include emissions arising from decommissioning and end-of-life activities associated with the OSW development infrastructure. - Emissions arising from fuel and energy usage in vehicles and vessels used in decommissioning and demolition of the core infrastructure at the offshore site, including transportation to the decommissioning port. - Emissions arising from transportation, including any air, road, or sea transportation of waste materials from decommissioning port to the waste processing or disposal facility. - Emissions arising from waste processing, treatment and sorting required before the material reaches end-of-waste state, where the material is deemed ready for disposal or recovery (reuse, recycling, and energy recovery). - Waste materials sent for reuse, recycling, and recovery reach 'end-of-waste state' following processing and sorting. After processing, these materials are put into a subsequent system which may be a new OSW development. Emissions associated with downstream processes, including energy recovery, which use the recovered materials to make new products are beyond the system boundary defined in this guidance. The impact of recovered materials leaving the system may be assessed in Module D1 (see 2.4.4). - Emissions arising from final disposal of waste materials which are not sent for reuse, recycling, or recovery. This includes emissions associated with disposal at landfill, or emissions associated with incineration (without energy recovery). - Decommissioning of offshore wind farms may be partial or incomplete – there are few OSW farms that have reached the state of decommissioning and there is uncertainty whether infrastructure such as foundations or buried cables will be removed or left in place. Therefore, practitioners should assume full removal of OSW infrastructure, unless alternative plans are in place. Where alternative plans are in place, this should be stated within methodology and data to support this assumption should be in place. - If, at decommissioning, components such as foundations or cables are left in the sea, the practitioner shall assess the long-term impacts of the residual infrastructure left in place - quantitatively where possible, or qualitatively if data is not sufficient. - Emissions arising from equipment, vehicles and vessels used for any relandscaping activities required at onshore or offshore site.

2.4.4. Module D

Module D described as 'benefits and loads beyond the system boundary' is a concept widely used in buildings and infrastructure LCA and described in the relevant infrastructure standards [see 1.5]. However, it is not currently included in the core standards from PCF, outside of general requirements for estimating avoided emissions. This life cycle information module is optional and involves the supplementary quantification of emissions impacts, including benefits (avoided emissions), or loads (emissions) occurring beyond the system boundary because of activities or occurring within the product system boundary [see Box 2.4 for additional context].

The practitioner may optionally calculate Module D, and it shall be reported separately from the results for mandatory life cycle stages A-C and not used to produce a net result between A-C and Module D. Furthermore, the practitioner shall not relate Module D to the functional unit for the assessment. Assessment of Module D is based on assumptions about the impact of the OSW development on other systems which may take place in the future; therefore, there is a significant amount of uncertainty associated with the measurement. Practitioners shall clearly state and justify any assumptions made during the estimation of Module D.

Table 11: Summary of mandatory sources of emissions and removals to be included in the assessment

Life cycle stage	Relevant emissions and removals sources
Benefits and loads beyond the system boundary (D)	The practitioner may optionally include an assessment of Module D, which includes emissions avoided or produced due to the impact of materials or energy leaving the OSW development product system. - Emissions arising or avoided from waste materials: When waste materials from the OSW infrastructure reach end-of-waste state and become inputs into new systems, associated emissions or avoidances may be assessed. Material flows in Module D shall align to assessed material flows in Modules C3 and C4. - Emissions arising or avoided from the export of electricity from the OSW development to the grid: When electricity is exported from the OSW development it may displace other sources of electricity resulting in emissions or avoidances. Electricity flows shall align to the annualised reference flow [see 2.5]. Assessment should be based on a marginal displacement calculation that considers how much of the exported electricity displaces other sources of generation or simply adds to grid capacity.

Box 2.3: Module D in OSW development

The primary use of Module D is to provide insight into other potential impacts of the system beyond the activities that make up the bulk of the study. The results of Module D assessments may be useful in informing sustainable construction practices such as material circularity or determining the marginal carbon savings associated with adding renewable generation capacity to the grid.

Waste materials (D1) example: Sorted scrap steel from the turbine towers, aligned with material flows in Module C3, leaves the product system and becomes an input into a steel manufacturing process, resulting in new structural steel. Recycling scrap steel from the OSW development reduces the need for producing 'virgin steel', which typically involves refining 'pig iron' using an energy-intensive conventional blast furnace. This recycling process produces a steel product with a lower carbon intensity compared to conventional steel production. When this new steel product is utilised by subsequent systems, it results in emission avoidance, roughly corresponding to the difference in carbon intensity between virgin steel and recycled steel, beyond the OSW development's system boundary.

Exported electricity (D2) example: Electricity from the OSW development is exported to the national grid, potentially displacing electricity produced by a combined cycle gas turbine (CCGT) power plant connected to the same grid. The CCGT may now be ramped down or shut off during periods of additional wind capacity on the grid. Therefore, the OSW development contributes to emission avoidance beyond the system boundary. It is crucial that any assessment of exported electricity be based on marginal displacement, meaning the practitioner must consider the extent to which the exported electricity displaces other forms of electricity or simply adds to the grid's capacity to meet rising consumer demand.

2.4.5. Geographical boundary

The geographical boundary refers to the locations where the activities that make up the product system occur. Understanding and labelling the geographical boundary of activities is important for several reasons, including but not limited to:

- Regional differences in technologies
- Regional differences in environmental regulations and fuel standards
- Regional differences in energy sources

These regional differences may change the type or quantity of activities included in the system boundary. Regional differences may also change the emissions intensity of certain activities, such as electricity generation in different countries.

While several life cycle stages (A4-A5, B1-B8) will be made up of activities that take place in the country or region where the asset is being developed, it is important to note that the geographical region of the study may extend further, particularly for upstream activities (A1-A3) such as the procurement of raw materials and components. Clearly identifying and defining the geographical boundary increases the accuracy and interpretability of the assessment.

2.4.6. Temporal boundary

The temporal boundary refers to the period during which the activities that make up the product system occurs. The temporal boundary of the assessment therefore spans the full time for which activities are taking place. In the case of an OSW development, the temporal boundary will be large, covering the period from the extraction and processing of raw materials (i.e. the iron ore that is used to manufacture the steel used in WTGs) until decommissioning of the asset at the end of its expected productive lifetime [see 2.5].

Clearly identifying and defining the temporal boundary will help the practitioner to consider scenarios for activities that may change over time in terms of quantity, or carbon intensity in a way that may affect the result of the assessment, such as:

- Changes in the carbon intensity of maintenance activities due to forecasted use of low carbon fuels or electrification of service vehicles.
- Changes in the carbon intensity of electricity consumed on site over the life cycle of the development.
- Technological improvements in the decommissioning and recycling of components.

It is important to be conservative when considering the different scenarios for temporal changes in carbon intensity that may affect the OSW PCF.

2.4.7. Cut-off criteria (exclusions)

When applying the requirements of this guidance, all attributable processes and activities as defined in Table 10 and Appendix 1 should be included. Where data availability is poor, it is preferable to include activities using assumptions or extrapolations rather than completely exclude activities from the assessment.

It is acknowledged that in some instances, data collection for specific activities is impracticable based on the materiality of the activity (overall contribution of the activity to full energy, material, or emissions flows in the system boundary) and/or data availability. In this instance, it may be acceptable to exclude these activities in line with the cut-off criteria [see Table 12] where those activities are deemed to be immaterial, and the level of effort or resource required to collect data outweighs its importance based on contribution to total GHG emissions.

This guidance defines separate exclusion criteria for operational PCF and design-stage PCF [see 1.4.2], acknowledging the varying levels of data availability depending on the assessment type. The additional potential for exclusion of emissions in design-stage assessment shall be reflected in the uncertainty assessment. Please note the cut-off criteria thresholds are based on a selected number of existing industry OSW LCAs.

Table 12: Cut-off criteria for the assessment types

Assessment type	Cut-off criteria
Operational PCF	- Non-material contributors may be excluded for practical reasons (data availability, data quality, or other stated justification) if the highest reasonable estimate for that source of emissions does not exceed 0.2% of the total footprint. Aggregate exclusions should not exceed 2% of estimated the total footprint. - See Appendix 1 for a list of activities for mandatory inclusion for an assessment of an OSW development. - Exclusions shall be stated clearly in the assumptions along with their GHG emissions estimates. The above thresholds shall be met, and the organisation shall document a simple justification for these exclusions. If exclusions exceed the thresholds listed above due to practical limitations, the practitioner shall clearly describe the exclusions and justify the approach. The results shall not be disclosed or used in comparison studies. - See Example 2.1 for using an estimation approach for including sources of emissions within the system boundary.
Design-stage PCF	- Non-material contributors may be excluded for practical reasons (data availability, data quality, or other stated justification) if the highest reasonable estimate does not exceed 1% of the total footprint. Aggregate exclusions should not exceed 5% of the total footprint. - See Appendix 1 for a list of activities for mandatory inclusion for an assessment of an OSW development. - Exclusions shall be stated clearly in the assumptions and listed the product emissions report, along with their GHG emissions estimates. The organisation shall document a simple justification for these exclusions. If exclusions exceed the thresholds listed above, this shall be clearly documented and disclosed.

Exclusions should be assessed against the cut-off criteria stated in Table 12 based on expected emissions materiality of the activity, rather than materiality based on total mass or energy flows for the system, which may not fully capture the emissions intensity of the activity under study [see Example 2.1]. Practitioners shall therefore make an estimation of emissions based on data available and use this estimate as a basis for an exclusion; however, it is preferable to include all attributable activities, even in instances of poor data quality.

Example 2.1: Exclusions made on expected emissions materiality instead of mass or energy flows

A non-expert practitioner is conducting a PCF of their OSW development and is struggling to collect data related to the charge and leakage of sulphur hexafluoride (SF₆), which is used as an insulating gas in OSW infrastructure. The gas is used in the operation of the electrical switchgear, which is contained in the WTGs and in the substations, both offshore and onshore. During regular operation, switchgear equipment may only leak up to 0.1% w/w of its SF₆ charge per year, which is a very small amount. However, on rare occasions, the equipment will malfunction, known as a 'blowout', and all the SF₆ contained in the switchgear may be leaked to the atmosphere. (Vestas [2] have stated that one in 2,000 pieces of switchgear equipment will experience a blowout over a 20-year life cycle.)

The practitioner can show that the quantity of SF₆ in kg charged to the switchgear in the turbines is approximately 50 kg per turbine, and the quantity leaked is negligible compared to the mass flows of other materials used in the development. Therefore, on a mass flow basis, the practitioner deems that SF₆ is a reasonable exclusion from the system boundary.

The practitioner is unaware that SF₆ is an extremely potent GHG, with a GWP100 of 25,200 as characterised by the IPCC in AR6. This means that every kg of SF₆ leaked to atmosphere has the equivalent effect on global warming as the emission of 25.2 tonnes of CO₂ (tCO₂e). Although unlikely, if the switchgear in a single turbine experiences a blowout over the course of the lifetime of the wind farm, it may result in GHG emissions of 1,260 tCO₂e (50x 25.2), which may constitute a significant source of emissions (>0.2% of total emissions for OSW development) depending on the characteristics of the OSW development under study.

By making a materiality assessment of the expected emissions of the activity, rather than excluding it based on the mass of materials in the system, the practitioner can ensure that all relevant activities are included.

2.4.8. Specific sources of GHG emissions and removals included in the boundary

There are various relevant sources of GHG emissions and removals that should be assessed separately when applying the requirements of this guidance. The PCF standards, ISO 14067 and GHGP Product Standard, define these emissions sources as fossil, biogenic, and land-use change. The practitioner shall include and should separately report GHG emissions and removals from the various sources in their product emissions report [see 4.2].

Separate reporting may not always be possible depending on data availability e.g. where an practitioner integrates an EPD from a supplier into their assessment [see 3.3.3] that reports the net impact of all sources as one result (GWP100). Where the practitioner cannot separately report the source of GHG emissions and removals associated with specific activities, they shall clearly document and justify this alongside their assessment.

2.4.8.1. Fossil sources

Fossil GHG emissions and removals shall be included in the PCF assessment and should be expressed separately where possible. Fossil carbon emissions include emissions from the combustion of fossil fuels as an energy source for attributable activities in the product system.

Fossil removals may include any capture of CO₂ through non-biological technologies. Examples may include removal methods such geological sequestration occurring within the system boundary, or carbonation of concrete materials (occurring in Module B1), which involves the absorption and permanent sequestration of atmospheric CO₂ in concrete construction materials over the lifetime of the infrastructure project.

2.4.8.2. Biogenic sources

Biogenic GHG emissions and removals shall be included in the PCF assessment and should be expressed separately where possible. Biogenic emissions may include emissions related to the use of biofuels as an energy source for attributable activities in the product system (A1-C5), or from the disposal of biogenic materials at end of life (C4).

Biogenic removals include any sequestration of CO₂ in organic materials during growth. Removals may occur upstream of the OSW development (Modules A1-A3), e.g. CO₂ stored and sequestered in timber which is used as construction material input into the OSW development. Key sources of biogenic removals within the system boundary for an OSW development may include balsa wood used in blade construction, which is an organic material that has sequestered carbon during growth.

Biogenic emissions may be calculated through use of an appropriate emission factor or calculated separately through use of information on the carbon content of the biogenic material. Where secondary emission factors are being used, the methodology should be sense checked to ensure the relevant biogenic emissions are being captured.

The biogenic emissions calculation or emission factor will depend on the end-of-life destination of the product containing biomass. Where the EoL destination is reuse, incineration or recycling, an equal and equivalent biogenic CO₂ emission (to the biogenic CO₂ removal) shall be included. Where the EoL destination is landfill, a net increase in emissions shall be accounted for due to CO₂ being converted into CH₄ in anaerobic conditions. This method ensures that biogenic emissions and removals are

calculated and reported, yet no credit is taken for the biogenic removal as there will be an equivalent biogenic emission within a 100-year timeframe.

Biogenic removals may also occur during regular operation of the OSW development due to site management practices, e.g. due to cultivation or growth of biogenic matter on OSW development structures at sea. The net effect of OSW developments on sea-based biogenic material growth is not currently well understood. Initial studies [12] have indicated OSW developments may result in net biogenic removals over the course of their lifetime due to epifaunal colonisation due to new habitat creation at the turbine foundation. When using this guidance, the practitioner may qualitatively describe any sea-based biogenic removals arising from the development in their product emissions report but will not be required to quantify this as the IPCC does not yet provide the required data to accurately quantify sea-based biogenic removals.

2.4.8.3. Direct land-use change (dLUC) sources

dLUC emissions and removals shall be included in the PCF assessment. dLUC refers to human induced alterations to land use and land cover. In the context of OSW development, this typically includes any construction activities that result in changes to carbon stocks on land, to soil or above ground biomass, or at sea, to marine ecosystems. dLUC impacts include the following sources of emissions and removals:

- Biogenic CO₂ emissions due to the change in carbon stock resulting from the conversion of land resulting from the construction and operation of the OSW development, e.g. biomass burning or limiting, land clearances, marine ecosystem clearance, soil, and seabed disturbance.
- Biogenic CO₂ removals due to purposeful measures such as afforestation and reforestation within the system boundary, or restoration of wetland areas.

The practitioner shall calculate and report at minimum emissions and removals from land based dLUC that has occurred within the system boundary due to OSW development activities. The temporal boundary for dLUC emissions and removals is 20 years, meaning that dLUC emissions that occurred due to activities in the system boundary during the preceding 20 years prior to the start of infrastructure development activities, shall be assessed in accordance with the IPCC guidelines for national GHG inventories. Any purchased material that has associated LUC, for example clearing of forest for balsa wood, shall include LUC emissions within the emission factor of the purchased material.

Land-based dLUC in OSW development

Land-based direct land use change refers to any change in carbon stocks in the land due to construction activities for the OSW development. There may be several types of carbon stocks on land (forest or woodland, soil, etc) that are cleared or disturbed for the construction of the OSW development. For OSW development, this may be particularly relevant for on-land activities such as the construction of an onshore substation, and any related land clearances required to enable this. This shall be included and reported within A4-A5.

Sea-based dLUC in OSW development

Sea-based land use change refers to any change in carbon stocks at sea or in marine ecosystems due to construction activities for the OSW development. There may be several types of carbon stocks in the

sea (mangrove forests, seagrass meadows, tidal marshes, etc) that are cleared or altered during the construction or operation of an OSW development.

When using this guidance, the practitioner should qualitatively describe any sea-based dLUC emissions and removals arising from the development in their product emissions report but will not be required to quantify this as the IPCC does not yet provide the required data to accurately quantify sea-based dLUC.

2.5. Reference flow

The reference flow is a measure of the total inputs or outputs of the product system that is used to relate the total GHG emissions and removals of the system to its stated function. It is defined by ISO 14067 (clause 3.1.3.9) as 'the measure of the inputs to or outputs from processes in a given product system required to fulfil the function expressed by the functional unit'.

The reference flow may be defined in terms of total inputs, e.g., total material flow in tonnes or energy flow in MJ required to deliver the stated functional unit, 1 kWh electricity, net, delivered at the grid [see 2.3.1] according to specific parameters. It may also be the total output of the product system, which, in the case of an OSW development, may be the total quantity of electricity delivered at grid, which can be used to quantify the results per functional unit.

When using the OSW PCF guidance, the practitioner shall, at minimum, calculate the reference flow of system outputs as stated in Table 13. The practitioner may calculate reference flows associated with inputs where necessary to provide further insight into material or energy use within the system boundary.

Table 13: Defining the reference flow for a PCF of an OSW development

This guidance's definition for the reference flow
The reference flow (outputs) shall be defined as the total quantity of electricity (kWh) generated by the OSW development and delivered at the PoI with the grid at the onshore substation over its full-service life based on the capacity and performance conditions.

Example 2.2: Using the reference flow (outputs) in OSW PCF to relate emissions to the functional unit for the assessment

For a developer making an assessment using this guidance, the functional unit is stated as ‘1 kWh of electricity, net, generated at [OSW DEVELOPMENT NAME] and delivered at the Pol with the grid at the onshore substation, with a 500 MW installed capacity, 45 % capacity factor, and 25-year service life.’

The total calculated impact of the OSW development (cradle-to-gate) is 821,400 tCO₂e, and the reference flow (total electricity, net, delivered to the grid) is calculated to be 4.93×10¹⁰ kWh.

When estimating the impact of the development per functional unit, the reference flow becomes the denominator of the equation, and the resulting calculation allows different developments or technologies to be compared on their relative carbon intensity:

$$\frac{GHG \text{ emissions } (gCO_2e)}{\text{Reference flow } (kWh)} = \text{Emissions per functional unit}$$

For this example, the calculation is as follows:

$$\frac{821,400 \times 10^6 (gCO_2e)}{4.93 \times 10^{10} (kWh)} = 16.67 gCO_2e \text{ per } 1 \text{ kWh, net delivered to the grid}$$

2.5.1. Estimating the reference flow for outputs (life cycle electricity delivery)

The following parameters shall be clearly stated by the practitioner and used in the reference flow calculation:

1. Installed capacity of the OSW development (MW)
2. Capacity factor (%)
3. Service life (years)

The practitioner shall state the values for the parameters that have been used to calculate the reference flow in their Product Emissions Report. The reference flow shall be calculated by the practitioner using the formula provided in Table 14.

Table 14: Reference flow formula

Formula for calculating the total quantity of electricity, net, generated by the OSW development over its life cycle and delivered to the grid at the onshore substation

$$\begin{aligned} \text{Reference flow (outputs), total kWh of electricity, net, generated and delivered to the grid (kWh)} = \\ (\text{Installed capacity (MW)} \times 1000 \text{ (kW per MW)}) \times (\text{capacity factor } (\%)) \\ \times (\text{service life (years)} \times 8760 \text{ (hours per year)}) \end{aligned}$$

Reference flow parameters: Installed capacity of OSW development:

Capacity per turbine (MW) × no. of WTG installed

The capacity refers to the rated power of the WTG in MW, determined by the manufacturer, and shall be defined by manufacturer specifications. The manufacturer and model number shall be specified in the offshore wind product emissions report (OSW PER) [see 4]. A reference to the model specification document should be provided in the assumptions for the assessment.

Reference flow parameter: Capacity factor

The capacity factor refers to the measure of how effectively the OSW development converts available wind energy into electricity. It is defined as the ratio of the actual energy produced over a specific period relative to the theoretical maximum energy that could have been produced if the wind farm operated at its full rated capacity continuously during that same period. It can be measured as gross (potential energy generation based on wind resource) or net (actual energy delivered after internal losses). The net capacity factor over the operational lifetime of the OSW development may vary depending on site characteristics and depends on parameters such as:

- Wind resource: Average wind speed and consistency at hub height.
- Operational efficiency: Downtime for scheduled and unscheduled maintenance (availability).
- Development efficiency: Internal and external wake effects, and performance degradation over the project lifetime.
- Electrical losses: Dissipation within the system boundary, including inter-array cables, electrical equipment, and export cables.

The capacity factor for the OSW development under study shall be calculated on a net basis. The practitioner shall clearly disclose the methodology for calculating the capacity factor in the assumptions for the assessment, including additional comment on the key performance characteristics such as expected wind resource, development efficiency and electrical losses.

Where primary data for the capacity factor is unavailable, the default capacity factor for an OSW development shall be 42% (based on WindEurope capacity factors for modern developments, which they estimate to range between 42% and 55%). This value shall also be used for the sensitivity analysis [see section 3.8.3].

Reference flow parameters: Service life

The service life is defined as the total productive lifespan of the OSW development, from the point at which the OSW development becomes fully operational to the point at which it is permanently powered down and enters the end-of-life stage.

The default service life for an OSW development shall be 25 years. The service life is based on a survey of SUSJIP partners and industry reporting [13]. It is expected that as the OSW industry matures, more data will become available on service life, and this will be considered in any revision to this guidance.

Alternative service life lengths may be considered. The practitioner should state the year planned for OSW farm decommissioning, at this point, the calculations may be revisited if the OSW farm is still in operation. The method for lifetime extension or repowering and appropriate supporting documentation shall be disclosed to justify deviation from the default service life.

2.5.2. Sensitivity analysis for the reference flow

The reference flow calculation made by the practitioner does not affect the total emissions measurement (tCO₂e) for the OSW development, but it may have a significant impact on the carbon intensity reported per functional unit (kgCO₂e/kWh). The reference flow calculation, therefore, is a significant determinant of the comparability of assessments of OSW developments of varying size, technologies, or other physical characteristics. To ensure that assessments made using this guidance are comparable, the practitioner shall conduct a sensitivity analysis using the default values described in 2.5.1 for the reference flow parameters. The results of the sensitivity analysis shall be reported by the practitioner in the OSW PER alongside the results produced using practitioner values for the reference flow parameters [see Appendix A Table 2].

2.6. Allocation methods

2.6.1. Allocation to products and outputs

In some product systems there is more than one product or output being studied, usually referred to as co-products. Therefore, emissions and removals from activities or processes within the system boundary must be allocated to the co-products that the system produces.

The product system defined by this guidance produces only one output, electricity [Table 5]. Therefore, all emissions and removals from the product system are allocated to the electricity delivered to the grid [see Section 2.3 for guidance on the functional unit]. This document does not provide guidance on allocation for potential co-product systems, such as a multifunctional OSW development that generates electricity and hydrogen simultaneously, but this may be reviewed in future updates when alternative system functions emerge in the industry.

2.6.2. Allocation for shared activities within the system boundary

Although the product system defined in this guidance produces only one output [Table 5], several of the products and materials procured for use in the OSW development [Modules A1-A3, see 2.4.3] may be a co-product of shared manufacturing processes at multifunctional factories or production sites. An example could be where a cable manufacturer uses electricity to operate machinery and equipment that manufactures a variety of cables, including offshore transmission cables and terrestrial cables. Where the data for the co-products cannot be disaggregated, the emissions from the cable manufacturing processes must be allocated fairly to the resultant co-products. This may also be relevant to shared operations and maintenance activities [Modules B1-B8, see 2.4.3], e.g., where operations vessels are shared by multiple OSW developments, and the emissions arising from fuel use in the vessels must be allocated fairly to the OSW developments being serviced.

For activities where allocation is required, physical allocation criteria should be used, which means allocating the emissions from a shared activity to the outputs based on a stated physical relationship. In the example of the cable manufacturer, this would mean allocating emissions from the manufacturing site to the different co-products based on a physical relationship, e.g., the quantity of each type of cable produced, or the size (diameter, mass, length, etc.) of the different types of cables co-produced by the process. In the example of shared operations and maintenance activities, this would mean allocating emissions from operations vessels to the different OSW developments serviced based on a physical relationship such as the capacity of the OSW developments (MW), or their distance from shore (km). In some cases, where the physical relationship between emissions and production cannot be established or does not accurately describe the relationship, other allocation methods may be used in accordance with the requirements of ISO 14067 and the GHGP Product Standard, e.g., economic allocation, which relates the emissions of a multifunctional manufacturing process to its products based on the economic value of the products.

Any allocation methods applied for shared activities within the system boundary shall be clearly stated by the practitioner in the OSW PER.

2.6.3. Allocation due to reuse and recycling activities

Reuse and recycling allocation methods refer to the methods used by the practitioner to allocate the impacts of recycled materials used in the production stage [Modules A1-A3, see 2.4.3], and the impact of materials from the product system that are recycled or recovered at the end-of-life stage [Modules C1-C5, see 2.4.3].

Emissions from recycling processes, because they involve the reclamation of previously used materials, are relevant to two or more product systems. For example, emissions from the processes by which steel from the WTG towers is recycled at end-of-life are relevant for OSW development [Modules C1-C5, see 2.4.3], but also for the subsequent product system that will utilise the recycled steel as an input material [Modules A1-A3, see 2.4.3].

This is true whether the recycled material is used for a similar purpose (e.g. the recycled steel is used in new WTG towers in a new OSW development (closed-loop)), or different purposes (e.g. the recycled steel is processed into an input into other structures (open-loop)). This creates a need for clear allocation of the emissions from reuse and recycling activities to the OSW development under study.

ISO 14067 defines two potential allocation methods in Appendix D which practitioners may apply but does not mandate the use of either and states that other allocation methods may be suitable but must be clearly stated by the practitioner:

- Closed-loop allocation procedure
- Open-loop allocation procedure

The GHGP Product Standard describes two allocation methods (chapter 9) and mandates that the practitioner shall apply one:

- Closed-loop approximation method (0/100)
- Recycled content method (100/0, cut-off)

For assessments made using the *OSW Industry PCF guidance*, the recycled content method shall be applied for reuse and recycling allocation associated with input materials and end-of-life processes included in the system boundary. This aligns with the principles of EN 15804, which uses a recycled content method where the system boundary cut-off is drawn at the “end-of-waste state”. based on the nature of an OSW development system. This approach is mandated based on the nature of an OSW development system and the criteria defined in the GHGP Product Standard:

1. **Procurement influence:** Recycled content method is suitable where the content of recycled materials in the production stage is directly affected by company procurement activities. In the case of OSW development, this is relevant as developers can influence the content of recycled materials where they decide to pay a premium for increasing the recycled content of materials in the core infrastructure (steel in WTGs, copper, aluminium in cables etc).
2. **Uncertainty about End-of-Life:** The system has a long-life cycle and there is significant uncertainty in determining what the end-of-life processes will be and how much material will be recycled. In the case of OSW this is particularly relevant due to the long expected operational lifetime of over 25 years, where the future global conditions of the materials supply chain and recycling systems are highly uncertain.

All recycling allocation methods are inherently imperfect approximations, as they attempt to divide the complex, interconnected environmental burdens of shared material life cycles across distinct product systems, therefore transparency in allocation and reporting is crucial. Applying the recycled content method means that for:

- **Production Stage (A1-A3):** Emissions associated with recycled input materials include only the emissions from the recycling processes (e.g., sorting, re-melting) required to recover them. The original waste material enters the system burden-free (beyond end-of-waste state).
- **End-of-Life Stage (C1-C5):** The system boundary includes impacts up to the point where the material reaches the end-of-waste state. Emissions from subsequent recycling processes (beyond the end-of-waste state) are excluded from the OSW development system boundary and are allocated to the subsequent system.

Module D is a separate, optional, consequential analysis that tries quantifies the net benefits and loads beyond the system boundary (e.g., avoided emissions from displacing virgin material). While the recycled content method defines the boundary (the cut-off) for the main inventory, Module D allows for a separate analysis that can help understand the potential benefits of recovering as much material as possible from the OSW development at end-of-life.

Recycling allocation and Module D

The selection of the recycled content (cut-off) allocation method defines the boundary between the product system and the optional Module D. Under the recycled content (cut-off) method, the system boundary ends when materials reach the 'end-of-waste' state (e.g., sorted scrap steel). Consequently, emissions from subsequent recycling processes (remelting the scrap steel, to produce recycled steel sheets) are allocated to the system that uses the recycled material.

Module D1 (see 2.4.4) is an optional life cycle module, reported separately to the mandatory life cycle Modules A1-C5, which accounts for the net benefits or loads beyond the system boundary associated with the displacement of virgin materials by recycled secondary material or energy flows that originated in the OSW development. For example, steel from the WTGs is recycled at the end-of-life, and the recycled steel becomes available to a subsequent system as an input material, potentially displacing the production of virgin material.

Module D1 may be calculated and reported outside of the system boundary as it represents an uncertain net emissions differential which is credited to the system and is reported alongside the results. Typically, Module D1 calculations will result in a negative emissions value (which may be referred to in other assessments both in PCF and LCA as 'avoided emissions'), as recycled materials typically have a lower emissions intensity than the virgin materials they displace, although this is not always the case.

To accurately quantify this benefit under the cut-off method, the Module D1 calculation must reflect the net impact. This means the practitioner must calculate the avoided emissions from displacing virgin material and subtract the emissions generated by the recycling processes (e.g., re-melting scrap) required to produce the secondary material, as these processing burdens lie beyond the end-of-waste boundary.

Example 2.6: Calculating the impact of steel recycling in an OSW PCF assessment

A developer procures 1 tonne of structural steel with 80% recycled content for a turbine foundation. The steel contains 80% recycled content. At the end of the project's life (25+ years later), 90% of the steel is recovered for recycling, while 10% is sent to landfill.

The developer needs to calculate the mandatory production stage emissions (A1-A3), the mandatory end-of-life emissions associated with the foundation materials (C3-C4) and may also calculate the optional benefit beyond the system boundary (Module D) for separate reporting.

Data sources:

- Virgin steel production (E_{virgin}): 2.5 tCO₂e/tonne (blast furnace route).
- Recycling process ($E_{\text{recycling}}$): 0.5 tCO₂e/tonne (Electric Arc Furnace route - applied to incoming recycled content in A1 and outgoing scrap in Module D).
- Waste processing (E_{sorting}): 0.05 tCO₂e/tonne (collection and sorting up to end-of-waste state).
- Disposal (E_{landfill}): 0.01 tCO₂e/tonne.

Production stage (A1-A3)

Using the recycled content (cut-off) method, the developer allocates emissions based on the specific input materials. The virgin portion carries the full burden of primary production, while the recycled portion carries only the burden of the recycling process (re-melting).

- Virgin portion (20%): 0.2 tonnes x 2.5 tCO₂e/t = 0.50 tCO₂e
- Recycled portion (80%): 0.8 tonnes x 0.5 tCO₂e/t = 0.40 tCO₂e
- Total A1-A3 Emissions: 0.50 + 0.40 = 0.90 tCO₂e

End-of-life stage (C3-C4)

Developer B calculates the impacts of processing the waste material up to the system boundary (the end-of-waste state).

- Module C3 (Processing for recycling): 0.9 tonnes x 0.05 tCO₂e/t = 0.045 tCO₂e (Note: This covers transportation, sorting, shredding up to the point the steel becomes a viable input into the $E_{\text{recycling}}$ process. The actual re-melting is therefore allocated to the next life cycle under the cut-off method.)
- Module C4 (Disposal): 0.1 tonnes x 0.01 tCO₂e/t = 0.001 tCO₂e
- Total C3-C4 Emissions: 0.045 + 0.001 = 0.046 tCO₂e

Module D (beyond system boundary)

The developer wants to separately estimate the net benefit for the 0.9 tonnes of steel that have successfully left the system boundary to become a new resource. This calculation credits the avoided production of virgin steel but debits the emissions required to turn the scrap back into usable steel (the re-melting process excluded from C3).

- Benefit (avoided virgin production): 0.9 tonnes x 2.5 tCO₂e/t = -2.25 tCO₂e
- Burden (recycling process required): 0.9 tonnes x 0.5 tCO₂e/t = +0.45 tCO₂e
- Net Module D Benefit: -2.25 + 0.45 = -1.80 tCO₂e

Importantly, under the recycled content method, Module D is *always* reported separately from the main inventory (A1-C5) and not netted off against the calculated impacts.

2.7. System process map

Aims of developing a system process map

Due to the complex nature of an OSW development, practitioners shall produce a process map outlining the relevant activities included in the system boundary. The process map will be used by the practitioner to:

- Understand the product system.
- Identify data owners (organisational, supply chain, other).
- Highlight exclusions.
- Recognise allocation.
- Assign emissions sources to life cycle stages and information modules [see 2.4.2].

System process mapping

A generic process map has been created for this guidance. Figure 3 represents a simplified generic example of the processes and activities included in the system boundary [see 2.4.3] for list of relevant activities) across the life cycle of an OSW development, colour-coded by life cycle stage. This generic process map should be amended by the practitioner where required, based on specific activities associated with the development under study.

As a minimum, the process map shall:

- Detail the key processes in the life cycle, including the inputs and outputs of these processes.
- Combine activities into groups, as they will be modelled, in accordance with the guidance on life cycle stages and modules.
- Highlight anything to be excluded from the footprint.
- Highlight processes owned, operated, or controlled by the organisation.
- Highlight processes owned, operated, or controlled by the organisation's suppliers.

There are many activities which have a small percentage contribution to the total expected carbon footprint; similar activities or processes may be aggregated into a single representative node for representation in the process map, to improve visual interpretability. For example, in Figure 3, the supplier manufacture and assembly of infrastructure assets and components node could be expanded to show the constituent infrastructure assets, such as WTGs, foundations, cables, etc [see Table 10 and Appendix 1 A Table 1 for a full list of relevant life cycle activities].

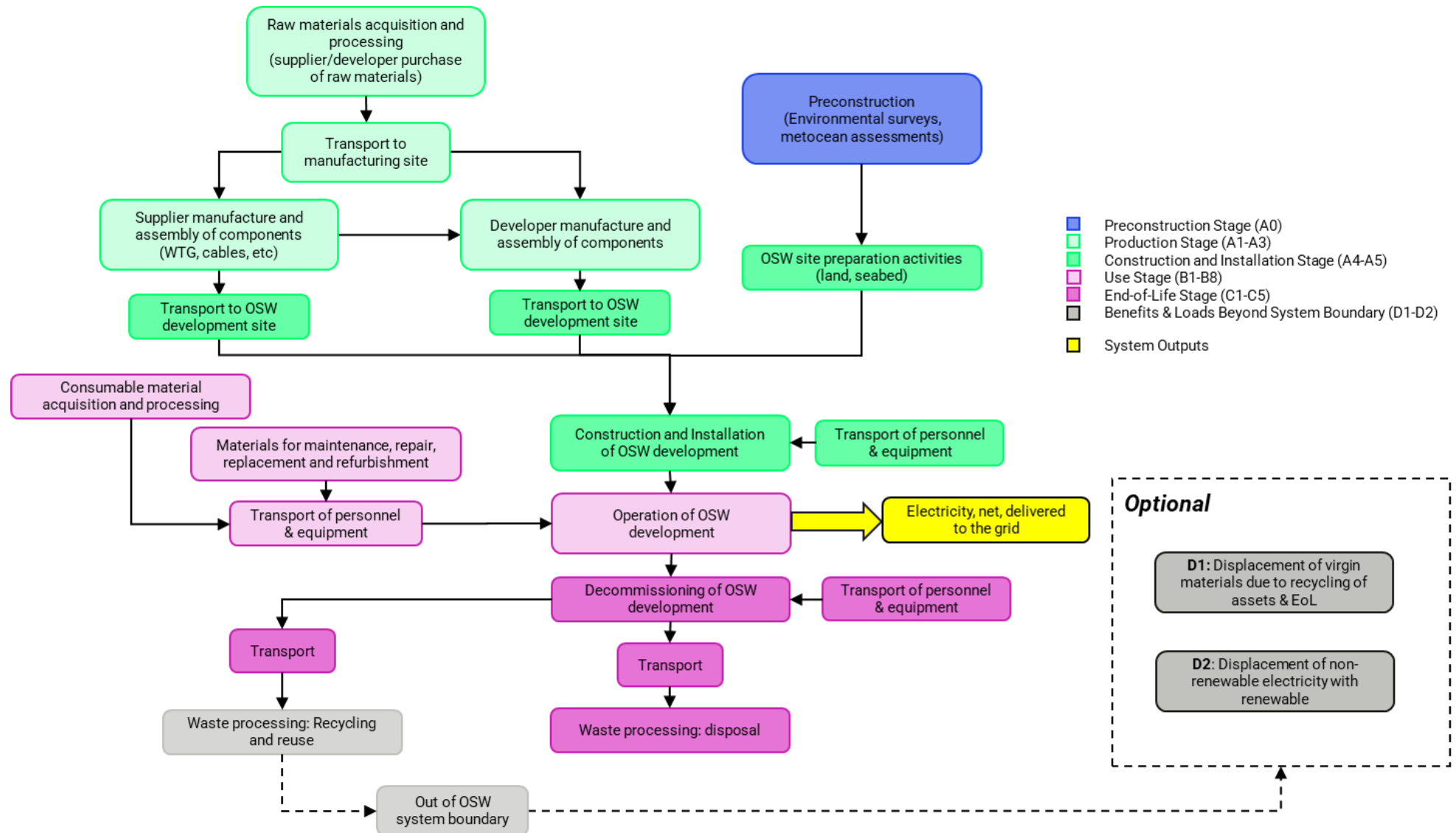


Figure 3: Generic system process map for an OSW development highlighting the life cycle stages and modules as described in 2.4

2.8. PCF impact assessment methodology

The impact of the emissions and removals produced by the OSW development shall be assessed using the most recent characterisation factors given by the IPCC for GWP of GHGs over a 100-year time horizon (GWP100), in accordance with the requirements of ISO 14067 and the GHGP Product Standard.

When collecting emission factors for the assessment [see 3.3], an assessment will be made as part of the data quality framework to assess instances where different impact methods and associated characterisation factors (e.g. CML, EF3.1, ReCiPe, TRACI, etc) have been used in the calculation of emissions factors collected from primary sources such as supplier EPDs.

2.9. Classification of activities and emission sources

This guidance describes two standard taxonomy systems for classifying the activities included in the system boundary [see 2.4.3] for OSW developments. Consistent classification is important as it allows assessments to be compared and analysed on a like-for-kind basis, ensuring that the results are useful and easily interpreted in line with the primary aims of the guidance [see 1.2].

2.9.1. Asset Taxonomy

Practitioners shall further classify assets and components included in the system boundary in accordance with the taxonomy provided in Table 15. When estimating and reporting the emissions, the practitioner shall use the asset taxonomy and label activities according to the relevant asset and component to which the activity relates to. This includes activities spanning the relevant life cycle stages and information modules, to help the practitioner to identify and report on emissions hotspots in terms of the core assets and components of an OSW development.

In general, for all assets (e.g. a WTG), there may be emissions generating activities across the life cycle stages and modules described in 2.4.2, and these activities should be assigned to an asset according to the taxonomy in Table 15, e.g. in the case of the WTG:

- Emissions associated with material extraction, transport to the upstream manufacturing site (supplier site) and WTG manufacturing [Modules A1-A3].
- Emissions associated with fuel and energy use by vehicles, vessels, aircraft, and equipment during transportation to OSW development site, and construction, installation of the WTG using installation vessels [Modules A4-A5].
- Emissions associated with the operation and maintenance of the WTG [Modules B1-B8].
- Emissions associated with decommissioning, transportation, and end-of-life treatment of the WTG materials [Modules C1-C5].

Furthermore, where data can be disaggregated, the practitioner should classify the activities according to the relevant components defined in Table 15. Where there is not sufficient data to disaggregate activities at the sub-component level, the practitioner may report activities according to the asset classification only. The practitioner may add new asset and component categories to the taxonomy where more detail is required or available, e.g. through the introduction of new technologies in OSW development.

Table 15: OSW industry PCF guidance asset taxonomy

L1: Assets	L2: Components
1. WTG	a. Nacelle and internals
	b. Blades, hub, and rotor system
	c. Tower
	d. Transformer
2. Fixed foundation	a. Monopile
	b. Jacket
	c. Transition piece
	d. Other fixed foundation technologies
3. Floating foundation	a. Platform
	b. Mooring
	c. Anchors
	d. Other floating foundation technologies
4. Cables	a. Inter array cables
	b. Export cables
5. Offshore substation	a. Transformers
	b. Switchgear
	c. Facilities
	d. Structure
6. Onshore substation	a. Transformers
	b. Switchgear
	c. Facilities
	d. Structure
7. Operations base	a. Site buildings
	b. Roads
	c. Vessel berths
8. Construction and installation assets	a. Turbine Installation vessel
	b. Foundation installation vessel
	c. Substation installation vessel
	d. Cable installation vessel
	e. Onshore plant and machinery
9. Operations and maintenance assets	a. Service operations vessels
	b. Crew transfer vessels
	c. Helicopters, drones or other
10. Other	a. Practitioner defined asset category

2.9.2. Activity taxonomy

Practitioners shall further classify all the emissions generating activities and processes included in the system boundary assessments in accordance with the taxonomy provided in Table 16. Alongside the asset taxonomy [Table 15], this guidance proposes a consistent use of an activity taxonomy to allow for consistent application of emission factors [see 3.3], and the disclosure of the carbon footprint by activity type..

Table 16: OSW industry PCF guidance activity taxonomy

L1: Activity category	L2: Activity subcategory
1. Direct emissions and removals	a. Fugitive emissions
	b. Process emissions
2. Freight and transportation	a. Air freight and transportation
	b. Rail freight and transportation
	c. Road freight and transportation
	d. Sea freight and transportation
3. Fuels and electricity	a. Biofuels life cycle
	b. Electricity life cycle
	c. Gaseous fuels life cycle
	d. Liquid fuels life cycle
	e. Solid fuels life cycle
4. Fully manufactured assets and components	a. Assets
	b. Subcomponents
5. Manufacturing processes	a. Coating and galvanising processes
	b. Joining and welding processes
	c. Material processing
	d. Other manufacturing processes
6. Materials	a. Aluminium
	b. Biogenic materials
	c. Carbon fibre
	d. Concrete
	e. Copper
	f. Fibreglass
	g. Oils and Lubricants
	h. Polymers
	i. Steel
	j. Complex composites
	k. Other materials
7. Waste treatment	a. Incineration
	b. Landfill
	c. Processing, sorting for recycling and reuse
8. Other	a. Practitioner defined activity category

3. Practical accounting guidance

3.1. Assessment steps

This section provides detailed guidance on the key steps for a practitioner seeking to calculate the carbon footprint of an OSW development using this guidance. By following the steps defined in this section sequentially using the guidance provided, the practitioner can produce a PCF assessment for the purposes of reporting and disclosing the carbon footprint of a specified OSW development.

Assessment steps:

- 1. Defining the assessment criteria**
- 2. Data collection for the assessment**
 - Activity data collection
 - Emissions factor collection
- 3. Carbon footprint assessment**
 - Calculating the reference flow
 - Calculating emissions from life cycle stages
 - Calculating biogenic carbon emissions
 - Calculating biogenic carbon content
 - Calculating land use change emissions
- 4. Data quality and uncertainty assessment**
- 5. OSW product emissions report consolidation and reporting**

The assessment steps are the same for an operational PCF or a design-stage PCF [see Table 1]. The primary differences in the method for the assessments are the cut-off criteria [see Table 12] and the associated data quality and uncertainty [see 4].

3.2. Defining the assessment criteria

The practitioner should first define the assessment criteria for the PCF assessment of the OSW development in accordance with the guidance [see 2] as stated in Table 17. The practitioner should state the assessment criteria in accordance with the definitions provided; however, assessment criteria definitions may be adjusted where specific characteristics of the OSW development under study or the goal and scope of the assessment require additional context to be included. An example could be where the OSW development has specific technological or operational specifications which require additional description.

Table 17: OSW guidance assessment criteria

Standard assessment criteria	
Scope of assessment	A PCF assessment of OSW development, [DEVELOPMENT NAME], built for renewable electricity generation, covering the full life cycle of the infrastructure development.
Product system under study	The product system under study is one OSW development, also referred to as an OSW 'farm' or 'electrical generation plant'. The product system covers the whole OSW farm life cycle – from development to decommissioning.
System function	The function of the OSW development is the generation of electrical energy (electricity) and delivery at the PoI with the grid at the onshore substation, whereafter it is transmitted and distributed to the end consumer.
Functional unit	The functional unit of the assessment shall be 1 kWh of electricity, net, generated at [OSW DEVELOPMENT NAME] and delivered at the PoI with the grid at the onshore substation, with a xMW installed capacity, x% capacity factor, x years' service life.
System boundary	The system boundary shall include all life cycle activities associated with the infrastructure development, including preconstruction, extraction of materials, manufacture of assets and components, construction and installation, operation, decommissioning, and end-of-life. The boundary includes all the infrastructure assets and development activities described in Appendix 1. The system boundary ends at the point at which electricity is delivered at the PoI with the grid at the onshore substation.
Reference flow	The reference flow (outputs) shall be defined as the total quantity of electricity (kWh) generated by the OSW development over its service life and delivered at the PoI with the grid at the onshore substation.

3.3. Data collection

Data collection is the most resource-intensive step of the PCF assessment. Having identified all attributable activities within the system boundary for the OSW development, the practitioner must now collect activity data and emissions factors to describe these activities. A list of mandatory activities for inclusion in the system boundary is described in Table 10, and a more detailed list of relevant assets and activities is provided in Appendix 1, broken down by life cycle stage and module as defined in 2.4.2 to provide a more granular view of the emissions-generating activities and increase the usefulness of assessment results in decision-making.

3.3.1. Activity data

Activity data in a PCF calculation may be defined as quantitative information about the activities identified in the system boundary. Once all the relevant activities to be included in the system boundary [see 2.4.1] have been identified, the practitioner must now collect activity data to represent them. Some typical kinds of activity data that are relevant to OSW development PCF are listed in Box 3.1. The GHG protocol product standard further classifies activity data based on its nature as either process activity data or financial activity data, which are defined in Table 18.

Box 3.1: Typical sources of activity data for OSW PCF assessments

- Suppliers or engineering teams may provide data on quantities (kg, tonnes, M³, etc) of materials used in the OSW development in assets, components, and construction.
- Engineering, operations, and maintenance teams may provide quantities of fuels (litres, tonnes, etc) and energy (kWh, MJ, etc) used in the construction, operation and maintenance of the OSW development.
- Procurement teams may provide data on financial spend (£, €, \$, etc.) on materials and energy for OSW development activities and relevant conversion factors (kg per £, litre per €, etc).

Table 18: Activity data classifications as per GHGP Product Standard

Process data	Financial data
Process activity data includes quantitative measurements of the physical activities that result in GHG emissions and removals, such as the quantity of physical inputs into an activity in the product system. In the case of an OSW development, process data may include the quantities of materials in physical units (tonnes, kg, litres, etc) used in the manufacturing of WTGs and cables, or fuels used in vessels for construction or maintenance.	Financial activity data includes monetary measurements of the activities that result in GHG emissions and removals, such as the financial transactions associated with an activity. In the case of an OSW development, financial data may include the total amount of money spent on materials for the manufacture of WTGs and cables, or on fuels used in vessels for construction or maintenance.

Activity data used in the assessment should be process data, meaning that each activity described in the system boundary should be described by data units that are a physical representation of the activity. Where only financial data is available to represent an activity, it should be converted to process data by means of a suitable conversion factor. Example 3.1 shows how a practitioner may convert financial activity data into process activity data by means of a suitable conversion factor.

Example 3.1: Converting financial data into process data for an OSW development

Developer A spends 100,000 units of currency on the procurement of concrete used in the fabrication of floating foundations for a new OSW development but does not collect process data on the quantity of concrete purchased. Developer A should convert the financial data to process data using a sourced conversion factor (units of currency/quantity of process).

Developer A sources a conversion factor from an industry database stating that the average regional cost of concrete per tonne is 100 units of currency, and converts the financial data to process data:

$$(financial\ data, 100,000\ UoC) / (conversion\ factor, 100\ UoC/tonne) = process\ data\ (100\ tonnes)$$

3.3.1.1. Primary and secondary activity data

The GHG protocol product standard also classifies activity data based on its source, as either primary activity data or secondary activity data, which are defined in Table 19.

Table 19: Defining primary and secondary sources of emission factors

Primary activity data	Secondary activity data
Primary activity data refers to activity data collected by the practitioner that is measured directly by the organisation or entity with operational control of the activity. This is the most accurate type of activity data, as it is directly measured, collected in a timely manner, and can be controlled and verified by the practitioner organisation.	Secondary activity data refers to activity data collected by the practitioner that is not directly measured by the organisation that has operational control of the activity and is instead obtained from other sources such as assumptions, generic industry databases, scientific literature, or other proxy sources. It can also include primary financial data that is converted to process data, as this is not classified as a direct measurement of the emissions-generating processes associated with an activity.

Table 20: Types of primary and secondary activity data used in an OSW development PCF

Primary activity data examples	Secondary activity data examples
1. Data collected directly from the developer’s suppliers, such as quantities of materials used in the production of OSW assets and subcomponents (e.g. X tonnes of steel, aluminium, copper used in the WTG). 2. Data collected from the developer’s own operations or engineering teams, such as fuel, energy, and material quantities used in maintenance and repair activities for the OSW development.	1. Data collected from academic literature on the average quantity of energy and materials required for maintenance activities per installed capacity. 2. Data collected as financial spend on materials and energy for an activity, which has been converted using an average factor to estimate a total process quantity. 3. Proxy data on the quantity of fuels used by a developer in the operations and maintenance of another OSW development in their portfolio of similar size. 4. Data taken from an industry database on the quantity of materials used in the production of OSW development assets.

Box 3.2: Labelling activity data using the asset and material taxonomy

To ensure consistency and comparability of PCF assessments completed using this guidance, the practitioner shall label each activity data point using the asset taxonomy for OSW defined in Table 12. This will enable the practitioner to report and analyse hotspots related to specific assets and components after completing the assessment and ensure comparability of product carbon footprint assessments conducted for OSW development using this guidance.

Industry specific databases for secondary activity data in the OSW sector

Several industry databases track and publish information relating to OSW developments and may be utilised as a source of secondary data in the absence of primary data:

- 4C Offshore Global Offshore Wind Farm Database
- Westwood Global Energy Group: Wind Logix
- Renewable Consulting Group GRIP Database
- Wood Mackenzie Offshore Wind Service Database

3.3.2. Emission factors (EFs)

Emission factors in a PCF calculation may be defined as quantitative information on the emissions intensity (kgCO₂e/unit of activity) of activities identified in the system boundary. Emission factors are typically derived from the results of other PCF or LCA assessments that have been undertaken to study activities within the system boundary.

Emission factors may be collected from a variety of sources, including primary LCA or PCF assessments conducted by organisations, industry average databases (e.g. Ecoinvent, Sphera MLC), government national inventories, and academic literature. Due to the methodological variability across the different sources of EFs, the practitioner must ensure they understand the system boundary of the EFs they use in the assessment to ensure it is an accurate representation of the activity under study. Accuracy of representation relies on several criteria, such as the boundary of the EF (cradle-to-gate, cradle-to-grave, etc) the regional specificity, technological specificity, and completeness [see 3.8]. Example 3.3 shows how a misalignment in the boundary of an emission factor may affect the assessment in practice.

3.3.2.1. Primary and secondary emission factors

Emission factors may also be classified by their source as either primary or secondary, as defined in Table 21 and Table 22.

Table 21: Defining primary and secondary sources of emission factors

Primary emission factors	Secondary emission factors
A primary emission factor refers to an emission factor derived from a PCF or LCA study that has been undertaken for specific activities within the system boundary using primary activity data. They are typically produced by the organisation or entity that has operational control over the activity, e.g. the supplier of a WTG provides the results of an LCA they conducted for their product. Primary emission factors are typically the most accurate type as they are based on real-life process data quantities, which may be measured and verified by the company with operational control of the activity.	A secondary emission factor refers to an emissions factor derived from a generic PCF or LCA study that has been sourced from secondary sources such as average industry databases, academic literature, proxy suppliers, and government databases. They are typically produced using average industry data and do not represent the unique carbon intensity associated with a specific supplier or product, e.g. the LCA for an average WTG based on an average material composition. They may be less accurate than primary emission factors but are used widely for activities where it is not practical to measure or calculate primary emission factors. Proxy emission factors are a subcategory of secondary emission factors.

Table 22: Types of primary and secondary emission factors used in an OSW development PCF

Primary emission factor examples	Secondary emission factor examples
1. Supplier-specific emission factor from a PCF Assessment: (kgCO₂e/unit of biofuel) for biofuel consumption in operations and maintenance (O&M) vehicles calculated in accordance with the ISO 14067 or GHG Protocol. 2. Supplier-specific emission factor from an EPD (kgCO₂e/unit of cables) for cables procured, calculated by the supplier in an underlying LCA in accordance with ISO 14040/14044 and disclosed in an EPD. 3. Supplier-specific emission factor from an LCA study (kgCO₂e/unit of electricity) for electricity procured by the developer from the grid during the construction and installation phase, produced in accordance with ISO 14040/14044 and disclosed in an LCA assessment report.	1. Generic emission factor calculated by a commercial partner (kgCO₂e/unit of cables) for cables procured, calculated by the supplier in accordance with ISO 14040/14044 and disclosed in a database (i.e. Ecoinvent, Sphera MLC). 2. Generic regional emission factor (kgCO₂e/unit of electricity) for electricity procured by the developer from the grid in a region during the construction and installation phase, produced in accordance with ISO 14040/14044 and disclosed in a governmental or industry database (BEIS, IEA). 3. Generic emission factor (kgCO₂e/unit of diesel) for fuel consumption in O&M vehicles calculated in accordance with the ISO 14067 by government agencies.

3.3.2.2. Secondary emission factor databases

Secondary emission factor databases⁴ are commonly used in PCF and LCA due to a lack of availability of primary emission factors for activities within the system boundary. Where different developers use different databases, this introduces a source of uncertainty that makes assessments more difficult to compare due to methodological differences between the way in which the industry databases are developed. Many of the available secondary databases can integrate with existing PCF and LCA software tools and become dominant within organisations or sectors based on usability and familiarity. The practitioner should therefore carefully consider which is the most appropriate secondary database for the assessment, considering consistency and comparability within the OSW development sector. Furthermore, when using secondary data, it is best practice to use data from only one secondary database to ensure methodological consistency across the assessment.

Several industry databases publish secondary emission factors that may be relevant to a PCF assessment for OSW development.

- Ecoinvent

⁴ The concept of a 'secondary emission factor database' comes from the Partnership for Carbon Transparency (PACT) methodology document.

- Sphera MLC (formerly GaBi)
- Global Logistics Council
- National emissions inventories
- ICE database
- Carbon Minds database

Example 3.2: Ensuring the selected emission factor has the correct boundary

The practitioner is collecting an emission factor for concrete used in the construction of the onshore substation structure in an OSW development as part of the production life cycle stage (A1-A3). The practitioner collects the emission factor from their tier 1 supplier in the form of an EPD, produced in accordance with ISO 14040/ISO 14044 and EN 15804, which discloses an emission factor (LCIA score for climate change) for the concrete in kg CO₂e per tonne.

Separately, the practitioner collects an emission factor for diesel used in the transportation of the concrete to the site to assess the emissions associated with the construction and installation life cycle stage (A4-A5). The practitioner collects the emission factor from a government database, produced in accordance with ISO 14040/ISO 14044, which discloses emission factors (LCIA score for climate change) for standard fuels in kg CO₂e per litre.

During verification, the verifier reviews the concrete EPD and sees that the boundary for the assessment is cradle-to-grave, and that the value used for the emission factor included GHG emissions from activities related to the downstream transportation of the concrete, which the supplier had included using average regional transportation profiles.

This means that due to a boundary error, the practitioner had incorrectly included emissions related to transportation (A4-A5) in the boundary of their production and manufacturing assessment (A1-A3) and created an instance of double counting in the assessment.

3.3.2.3. Data hierarchy for emission factors

The selection of emission factors is a critical step in the PCF assessment and directly influences the accuracy and comparability of the results. Each emission factor is the result of a previous assessment (e.g., PCF, LCA) that has associated uncertainty based on the parameters, methods, and models used in the assessment [see 3.8.2].

Within the two main categories of primary and secondary emission factors, there are several subcategories that may be used to estimate the emissions associated with an activity within the system boundary. Primary emission factors, which come directly from the supplier and are produced using measured or observed data from the relevant processes, are of the highest quality. However, the quality of primary emission factors varies significantly depending on the methodologies and data employed by the supplier to make their assessment and the quality of the report from which the primary emission factor is extracted. For example, a primary factor extracted from a full PCF or LCA assessment report may be of higher quality than one extracted from an EPD database, as the practitioner can fully review

the methodology to ensure the boundary of the emission factor aligns with the activity being footprinted.

Secondary emission factors also vary significantly in quality and can come from a variety of sources. These are typically drawn from industry databases but may also come from academic literature, government databases, and in some instances, suppliers. Emission factors derived from supplier or manufacturer assessment reports (e.g., PCF, LCA, EPD) can be classified as secondary as well as primary, depending on how they are used in the assessment. For instance, a practitioner using an emission factor derived from a primary LCA report from Vestas as a proxy to estimate the emissions associated with a turbine purchased from another supplier would be using a secondary emission factor, as the source is secondary to the specific OSW development under study.

Figure 4 provides a standard emission factor hierarchy which should be considered by the practitioner. It also provides an indicative representativeness scale to show how the distinct categories of factors may be more relevant to the specific activity being footprinted. For more detailed guidance, see 3.8.

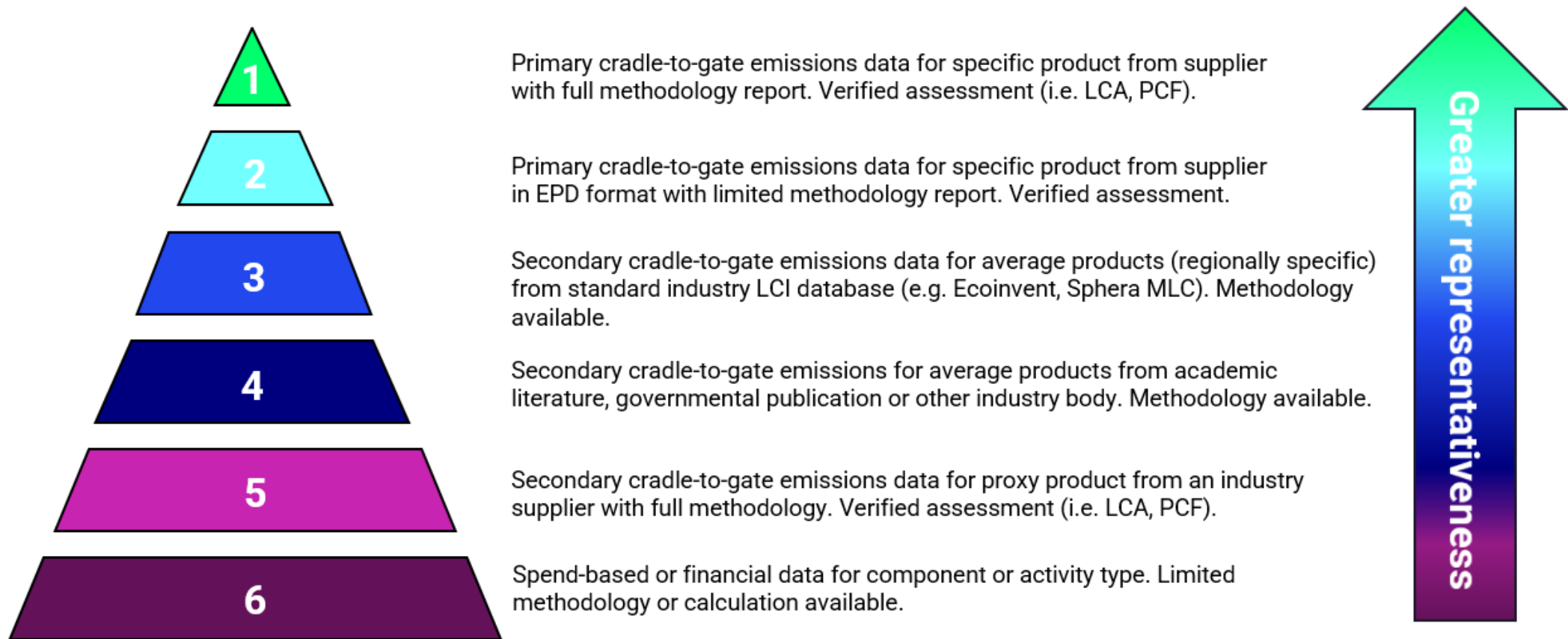


Figure 4: Emission factor hierarchy defined by this guidance

3.3.2.4. Extracting emission factors from primary sources, including PCF, LCA and EPD reports

Primary emission factors for the activities described in the system boundary may be extracted from PCF, LCA, and EPD reports collected from publicly available databases or directly from suppliers. The underlying assessments may be conducted by equipment manufacturers or service providers to allow their customers an understanding of the environmental impacts of their product or service, often as a means of comparing its impact against competitors. To ensure these emission factors are representative of the activities in the system boundary and are of high quality, the practitioner should collect metadata from the assessment report to describe the emission factor, which improves the transparency of the assessment and provides stakeholders with confidence in the results. A list of the relevant metadata to be collected by the practitioner alongside the primary emission factor data is shown in Table 23.

Table 23: Primary emission factor metadata and data to be collected

Type of Data	Datapoint
Emission factor metadata	Emission factor source (e.g. supplier provided)
	Native database ID number
	Database version number
	Assessment report type (e.g. PCF, LCA, EPD)
	Activity description (e.g. steel production)
	UN CPC 2.1 code (e.g. 412 – products of iron of steel)
	Emission factor boundary (e.g. cradle-to-gate)
	Secondary database used (e.g. Ecoinvent)
	Impact methodology used (e.g. IPCC 2021, EF 3.1, etc)
	Impact indicator (e.g. GWP 100)
	Reporting standard used (e.g. GHGP, ISO 1400/44)
	PCR used (if applicable)
	Verified (yes/no)
	Valid until (MM-YY)
Emission factor	Emission factor name (e.g. heavy plate steel)
	Geography (e.g. global)
	Emission factor unit (e.g. tonnes)
	Climate change: fossil (kgCO ₂ e/unit)
	Climate change: biogenic (kgCO ₂ e/unit)
	Climate change: land use (kgCO ₂ e/unit)
	Climate change: total (kgCO ₂ e/unit)

3.3.3. General guidance for handling data and filling data gaps

Primary data collection and quality control

To ensure primary data is traceable and accurate, practitioners should establish a formal data collection process with suppliers. While a specific format for primary data is not required, the practitioner should ensure that:

- **Allocation rule:** The primary data point should align with the allocation method (Recycled content), where it doesn't, the practitioner may still use the data but must clearly disclose the misalignment and expected impact on results.
- **Assurance check:** There is evidence or an audit trail: (e.g., verification status of LCA or PCF, invoices, meter readings, or BMS logs) to support primary where required.
- **Mass/Energy balance check:** Ensure inputs roughly equal outputs (e.g., does the weight of material inputs in the WTG align the total weight of the product minus scrap rates?).
- **Sense check:** Compare values against standard industry benchmarks (e.g., does the fuel consumption match the vessel engine rating multiplied by active hours?).

Secondary data collection and quality control

When selecting datasets from Life Cycle Inventory (LCI) databases (e.g., ecoinvent, Sphera MLC), the practitioner shall apply the following hierarchy to ensure consistency with this guidance:

- **Allocation rule:** Practitioners shall select the dataset system model that aligns with the 'Recycled Content' method (see Section 2.6.3). For ecoinvent users, this corresponds to the "Allocation, cut-off by classification" system model. Datasets using "APOS" (Allocation at Point of Substitution) or "Consequential" models should be avoided.
- **Geography check:** Practitioners shall select the most granular geography available in the following order: Specific Country > Region (e.g., RER/Europe) > Global (GLO/RoW).
- **Technology check:** Practitioners shall select the most appropriate technological description for the process, differentiating, for example, between steel produced in a conventional blast furnace process, and steel produced from scrap in an electric arc furnace.

Handling data gaps

Where specific data (primary or secondary) is unavailable, the practitioner must treat the data gap according to the following hierarchy, documenting the approach in the PER:

- **Proxy data:** Use data from a similar asset or activity in place of the data, with a clearly disclosed method for extrapolating or interpolating the data to the OSW activity (e.g., using a "15MW WTG" dataset as a proxy for a "14MW WTG", scaled linearly, according to a defined method).
- **Financial estimation:** Use the "Spend-based" method (Section 3.3.1) to convert financial cost to emissions using an environmentally extended input-output (EEIO) factor.
- **Conservative estimate:** Use a worst-case assumption based on referenced literature.
- **Exclusion:** If the activity is expected to be immaterial [see section 2.4.7], it may be excluded. If it is material but no data exists, it shall be reported as a "Data gap" in the limitations section of the PER.

Example 3.3: Practical application of data handling principles

A practitioner is calculating the carbon footprint for the installation of a monopile foundation. The assessment requires collecting primary data for the installation vessel, selecting secondary data for the steel structure, and handling a missing datapoint for a specific grouting material.

1. Primary data collection (Foundation installation vessel fuel)

The installation contractor provides a primary activity data report stating 55,000 litres of marine fuel oil (MGO) were consumed during the operation.

- **Assurance check:** The practitioner requests the Bunker Delivery Note (BDN) and daily vessel logs to verify the figure.
- **Sense Check:** The practitioner calculates a benchmark:
 - *Engine rating (5,000 kW) × Active Hours (48 hrs) × specific fuel consumption (approx. 0.22 L/kWh) = 52,800 litres.*
 - *Result:* The reported 55,000 litres is within ~5% of the benchmark (likely due to auxiliary engine use or idling), so the data is accepted as accurate.

2. Secondary data selection (Steel monopile) The practitioner needs a secondary emission factor dataset for 800 tonnes of steel used in the monopile. They search a secondary database and find three options.

- *Option A:* Steel, low-alloyed {Global} - APOS, U
- *Option B:* Steel, low-alloyed {European Union} - Cut-off,
- *Option C:* Steel, low-alloyed {Global} - Cut-off

Selection process:

- **Allocation rule:** Option A is rejected because it uses the "APOS" model. Options B and C use "Cut-off" (Recycled Content), which aligns with the guidance.
- **Geography check:** Option B ({RER} - Europe) is selected over Option C ({GLO} - Global) because the steel was sourced from a European supplier, making {RER} the more granular and accurate geography.

3. Handling data gaps (Novel grouting material) The project used 15 tonnes of a proprietary high-strength grout, but no specific EPD or LCI dataset exists for this brand.

- **Hierarchy application (proxy data):** The practitioner searches for a proxy. They find a dataset for "Generic portland cement mortar" (0.9 kgCO₂e/kg).
- **Adjustment:** Knowing the proprietary grout contains polymer additives, the practitioner applies a linear scaling factor of 1.2x (based on internal engineering comparisons of similar materials) to estimate the impact.
- **Calculation:** 15,000 kg × (0.9 kgCO₂e/kg × 1.2) = 16,200 kgCO₂e.
- **Reporting:** This is documented in the PER as "Data Gap filled using scaled proxy"

3.4. Calculation guidance: Modules A-C

3.4.1. Background information on emissions calculations

Following data collection [see 3.3] the practitioner shall quantify the carbon footprint for all activities included in the system boundary. A simple calculation structure for PCF emissions is provided in Figure 5.

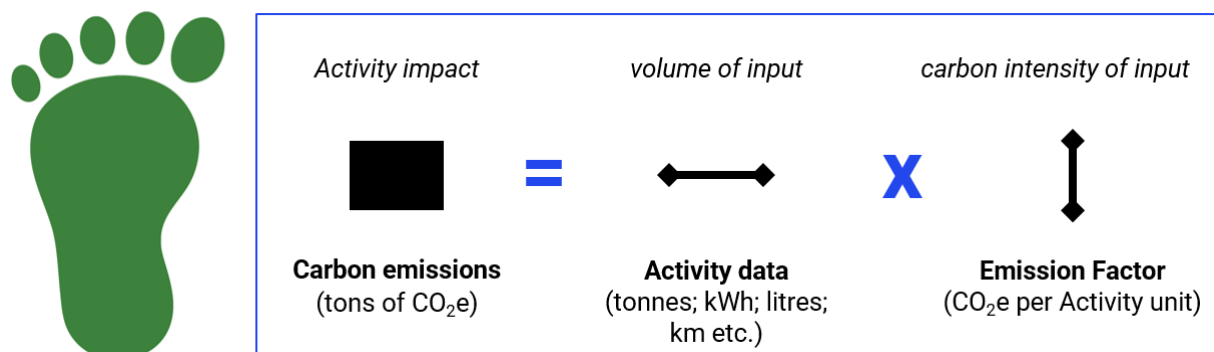


Figure 5: Simple calculation structure for PCF emissions

Table 24 provides examples of the activity data and emission factor combinations that may be relevant for quantifying the emissions of different OSW development activities, categorised by life cycle stage. For a comprehensive list of relevant OSW activities, refer to Appendix 1.

Table 24: Examples of activity data and emission factor combinations for standard activities across the OSW development life cycle

Life cycle stage	Activity description	Activity data example	Emission factor example
Preconstruction (A0)	Emission associated with environmental surveys conducted in survey vessels	Quantity of fuels in vessels (kg, litres, tonnes) or cost (€, £, \$) of service and conversion factor (fuel consumption/unit currency)	Primary/secondary emission factor for fuel used in survey vessels (kgCO ₂ e/kg, litre, tonne, etc)
Production (A1-A3)	Emissions associated with manufacturing of assets (e.g. WTG, cables, foundations, etc) and components (e.g. blades, array cables, transition piece, etc),	Model and quantity of asset/components or material composition and quantity (kg, tonnes) or cost currency (€, £, \$) and conversion factor (quantity/unit currency).	Primary emission factor for asset/components from supplier (kgCO ₂ e/asset) or primary/secondary emission factor for materials used (kgCO ₂ e/kg, tonne, etc).

Construction and installation stage (A4-A5)	Emissions associated with fuel and energy used to transport assets and components to site.	Quantity of fuels in transportation (kg, litres, tonnes) or weight distance of transportation leg (tonne kilometres)	Primary/secondary emission factor for fuel, used in transportation (kgCO ₂ e/kg, litre, tonne, etc) or secondary emission factor for weight distance by vessel/vehicle type (kgCO ₂ e/tonne.km)
Construction and installation stage (A4-A5)	Emissions associated with fuel used by turbine installation vessel during installation	Quantity of fuels combusted during construction (kg, litres, tonnes) or cost (€, £, \$) of fuel and conversion factor (fuels/unit currency)	Primary/secondary emission factor for fuel used in construction (kgCO ₂ e/kg, litre, tonne, etc)
Use stage (B1-B8)	Emissions associated with production of replacement components for maintenance of the turbine	Quantity of parts purchased, part type and model or material type and quantity (kg, tonne) or cost of parts in currency (€, £, \$) and conversion factor (quantity/unit currency)	Primary emission factor per component from supplier (kgCO ₂ e/part) or secondary emission factor per material used (kgCO ₂ e/kg, tonne, etc)
Use stage (B1-B8)	Emissions associated with regular maintenance activities for OSW development using service operation vessels	Quantity of fuels combusted during operations (kg, litres, tonnes) or cost (€, £, \$) of fuel and conversion factor (fuels/unit currency)	Primary/secondary emission factor for fuel used in construction (kgCO ₂ e/kg, litre, tonne, etc)
End-of-life stage (C1-C5)	Emissions associated with fuels used in decommissioning vessels, and vehicles transporting waste materials to waste processing site	Quantity of fuels in vessels (kg, litres, tonnes) or weight distance of transportation (tonne kilometres) or cost (€, £, \$) of service and conversion factor (fuels/unit currency)	Primary/secondary emission factor for fuel, used in decommissioning (kgCO ₂ e/kg/litre/tonnes, etc) or secondary emission factor for weight distance by vessel/vehicle type (kgCO ₂ e/tonne.km)
End-of-life stage (C1-C5)	Emissions associated with end-of-life treatment and disposal of materials	Quantity of waste material being disposed of in physical units (kg, litres, tonnes) and waste fate (disposal, landfill etc)	Primary/secondary emission factor by waste type and waste fate (kgCO ₂ e/kg, litre, tonne etc)

Box 3.3: Asset and component approach or material composition approach?

In the production stage (A1-A3), it is essential to choose the most appropriate methodology to accurately measure emissions associated with the production and procurement of OSW development assets and components. There are two primary approaches for this purpose: the asset and component approach and the material composition approach. This guidance will help you understand the differences and provide recommendations on when to apply each. In practice, practitioners may need to combine both approaches depending on data availability related to a specific asset or component.

1. Asset and component approach

The asset and component approach involves evaluating the emissions associated with fully manufactured and procured assets or components. This method covers the entire cradle-to-gate life cycle, including raw material extraction, material processing, manufacturing, and transportation up to the supplier's gate.

This approach is particularly useful when dealing with large, complex infrastructure assets, such as WTGs, foundations, and cables, where primary data from the supplier may be available. The asset and component approach leverages data from supplier PCFs, LCAs, or environmental product declarations to estimate the emissions associated with the complete asset or component.

This method provides a holistic view of the emissions associated with the entire asset or component, accounting for all relevant processes and materials. It relies on detailed data from suppliers, ensuring accuracy and reducing the need for estimations based on generic factors. By evaluating the entire asset, this approach avoids the potential inconsistencies that might arise from aggregating emissions from multiple materials or processes. However, this approach may not provide the level of detail required to disaggregate results by material group or type.

2. Material composition approach

The material composition approach involves calculating emissions based on the individual materials used in the production of an asset or component. It is particularly applicable when detailed emissions data for the full asset is unavailable or when the asset is composed of materials that can easily be assessed separately.

This approach is most appropriate when dealing with simpler assets, such as foundations, or when a specific focus on material-related emissions is necessary. For instance, if only steel or concrete quantities are known for a foundation, the material composition approach would involve calculating emissions based on the production of these materials alone, using relevant emission factors.

This method allows for emissions estimation even in the absence of comprehensive data from the supplier on the full asset, making it suitable for early-stage assessments or when working with less detailed supplier information. It provides a clear understanding of how different materials contribute to overall emissions, which can be useful for targeting emissions reduction strategies in specific areas. However, when using the material composition approach, the practitioner will need to separately assess the remaining activities, including manufacturing processes (e.g., the electricity, gas, fuel needed for processes such as welding, joining, assembly) and upstream transportation.

3.4.2. Location- and market-based approaches to calculating emissions from electricity

There are two distinct approaches within carbon footprinting to calculate emissions related to consumption of electricity. The Greenhouse Gas Protocol defines these as the following:

- Location-based method – this method reflects the average emissions intensity of the grid where energy consumption occurs
- Market-based method – this method reflects the emissions intensity of the electricity that a company has chosen for their electricity contracting and supply

Either method may be used in the OSW PCF, if it is applied correctly and transparently disclosed.

The location-based method requires a grid specific combustion emission factor to be used, that is representative of the country of consumption. The well-to-tank (WTT), transmission & distribution (T&D) and well-to-tank transmission & distributions (WTT T&D) emissions shall also be included. The market-based method (where certificate-backed renewables are being procured) does not require calculation and inclusion of the well-to-tank emissions in GHG Protocol requirements.

The market-based method has multiple emission factors that can be used within the calculation, with varying levels of precision. These emission factors can include energy attribute certificates, contracts, supplier/utility emission rates, residual mix and grid-average emission factors. Please see Table 6.3 of the Greenhouse Gas Protocol Scope 2 guidance for further requirements and examples on each type of market-based emission factor. This method should be used if the practitioner wants to reflect the use of renewable energy within the OSW PCF.

3.5. Calculation guidance: Module D

3.5.1. Module D1: Calculating net benefits and loads (emissions or avoidance) for materials leaving the OSW development

Module D1 is an optional life cycle information module that allows practitioners to account for the net emissions impact beyond the system boundary of materials that are recovered (recycling, reuse, or energy recovery) at end-of-life for the OSW development; e.g. steel recovered from the WTG towers at end-of-life and recycled to become an input for new product systems (see 2.4.1). The approach outlined in this section draws on guidance from *ISO 21931-2* [11], and *RICS: Whole life carbon assessment for the build environment* [5].

Firstly, the practitioner should estimate the total amount of recycled material or energy that will be produced from materials leaving the OSW development at end-of-life, based on the referenced recycling and recovery scenarios using the formulae on Table 25.

Table 25: Module D1, recovered material and energy flow formulae

Recovered material and energy flow output flow formulae	
Material flow	Net material recovery output flow (kg, tonnes, etc) = Total flow of waste materials leaving OSW development (quantity per material type) × material recycling rate for material by geography (%)

Energy flow	Net energy recovery output flow (kWh, MWh, etc) = Total flow of waste materials leaving OSW development (quantity per material type) × energy recovery rate for material by geography × net calorific value of material (energy/quantity of material) × electrical generation efficiency of recovery plant (%)
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Once the practitioner has estimated the net output material or energy flows, they may estimate the benefits or loads associated with the flows at the 'point of substitution', which is the point at which they become available to a new product system and are substituted for other material or energy inputs. For example, the steel that has been recycled from the OSW development is used in the production of a new WTG tower and becomes a substitute for the use of virgin steel produced from conventional steelmaking processes. The benefits or loads may then be expressed in terms of net emissions and can be estimated by calculating the difference between the emission factors of the recycled product and the new product according to the Module D1 calculation formula stated in Table 26.

Table 26: Module D1, net emissions calculation formula

Formula for estimating the net impact (benefits or loads) associated with waste materials leaving the system boundary for the OSW development after end-of-life	
	Module D1, net emissions = Substitute material or energy recovered from OSW development (quantity) × Forecasted substitute material or energy emissions factor (kgCO₂e/unit) – Substituted material or energy not used in subsequent system (quantity) × Forecasted substituted material or energy emissions factor (kgCO₂e/unit)

It is important to note that the emissions calculated using the D1 formula represent a specific scenario of material recycling or energy recovery chosen by the practitioner. This assessment is highly uncertain in the case of an OSW development as assumptions must be made about the recycling and recovery rates of specific materials at the end of the life cycle of the development, which is far into the future.

Furthermore, the calculation of net emissions impact associated with recycling and recovery at end-of-life is highly uncertain as it involves creating a forecasted scenario for the impact of waste treatment processes at some point in the future, which in the case of OSW developments may be further than 25 years away. Using emission factors associated with virgin and recovered materials and energy today may not represent a good proxy of the impact of equivalent materials or energy in the future, as global material flows and waste treatment systems change. For example, when we use a virgin steel material emissions factor as the best available data to represent the substituted material in our Module D1

calculation, this assumes a scenario in which the carbon intensity of virgin steel in 25 years is equal to that of today. If carbon capture, utilisation and storage were to become a widespread technology in steelmaking, the emissions impact of recycled material may be greater than that of virgin steel, resulting in a net load, rather than a net benefit. For these reasons, Module D1 is optional, and shall not be reported as a net with the mandatory life cycle stages (A1-C5).

For any estimation of Module D1, the practitioner shall clearly state their calculation parameters in their OSW PER (see 4).

3.5.2. Module D2: Calculating net emissions from electricity exported by the OSW development.

Module D2 is an optional life cycle information module that enables practitioners to account for the net emissions impact beyond the system boundary of electricity exported from the development, e.g. example, the potential emissions impact arising from the displacement of non-renewable, or other grid electricity with renewable electricity exported from the OSW development over its life cycle.

Firstly, the practitioner must estimate the forecasted annual export quantities of electricity from the development, using the reference flow parameters (see 2.5.1) and the formula provided in Table 27.

Table 27: Module D2, exported electricity flow formula

Formula for estimating annual export of electricity from the OSW development
Annual export of electricity (kWh/year) = Reference flow (kWh) ÷ service life (years)

Once the practitioner has estimated the annual volumes of electricity exported from the OSW development, they may estimate the benefits or loads associated with the export at the 'point of substitution', which is defined as the point at which the electricity exported substitutes another form of electricity generation on the grid. For example, the electricity that is exported from the OSW development may become a substitute for electricity produced by a local combined cycle gas turbine plant, which generates electricity with a much larger carbon intensity and is powered down for longer periods due to the electricity generated by the OSW development. There is significant uncertainty over the extent to which new sources of renewable electricity displace non-renewable sources of electricity, or simply add to overall electricity supply, meeting a continually growing demand for electricity [14]. The actual displacement expected is referred to as 'marginal displacement', which means the estimated actual volume of electricity displacement when also factoring in the regional growth in demand. Furthermore, the impact of marginally displaced electricity will change over the course of the lifetime of the OSW development, as the grid decarbonises, which means that the net impact total should be calculated as a sum of the annual impact. The benefits or loads associated with the exported electricity may be calculated by estimating the marginal displacement volume for each year of operation and the forecasted emissions intensity of the displaced electricity in that year, according to the Module D2 calculation formula provided in Table 28 .

Table 28: Module D2, net emissions calculation formula

Formula for calculating the net impact (benefits or loads) associated with electricity exported by the OSW development over the life cycle	
Module D2, net emissions = $\sum_{i=\text{year}}^n \left(\begin{aligned} &\text{Annual export of electricity (kWh/year)} \\ &\times \text{Annual marginal displacement factor for operational year (\%)} \\ &\times \text{Forecasted substituted electricity generation factor (kgCO}_2\text{e/kWh)} \end{aligned} \right)$	

The annual emission factors for the substituted grid electricity should be forecasted for each year of the service life using referenced grid decarbonisation scenarios (national government, IEA, etc) to reflect the expected reduction in carbon intensity of grid electricity as more renewable capacity is added.

While the calculation above describes an annual assessment, the practitioner should be aware that OSW generation profiles are highly seasonal (typically generating more electricity in winter months). Similarly, the marginal emissions intensity of the grid varies throughout the year depending on demand and generation mix.

To provide a more thorough and accurate assessment of Module D2, the practitioner should calculate the marginal displacement monthly where data allows, although it is acknowledged that this type of assessment presents difficulties in data collection and is highly uncertain. This ensures that the specific marginal grid intensity during high-production months is accurately reflected, rather than applying a flat annual average which may over- or underestimate the benefit.

Given the high level of uncertainty regarding future scenarios, particularly for Module D, it is important to be conservative in all calculations. To address this, scenario-based reporting should be considered, utilising official data and forecasts to present a range of potential outcomes rather than a single fixed result. For any estimation of Module D2, the practitioner shall clearly state their calculation parameters in their OSW PER [see 4].

3.6. Accounting for biogenic emissions and removals

Biogenic emissions and removals are GHG emissions and removals that are associated with biological processes, such as the growth and decay of organic materials from plants or animals. In PCF assessment, biogenic emissions and removals should be accounted for separately from other types of emissions and removals, including 'fossil' and 'land-use change'.

In the context of OSW development, there are several activities included in the system boundary (refer to Table 10) that may result in biogenic emissions or removals, and the impacts shall be stated separately. Some activities where biogenic emissions or removals may occur for an OSW development are:

- Any activity that has generated emissions from the combustion of biofuels as a source of energy. Biofuels also have associated removals, through the growth of the organic fuel feedstock, and emissions where the fuel is combusted.
- Any material used in the construction and installation of the wind farm that comes from a biogenic source (e.g. balsa wood used in blade manufacturing) and removed carbon from the atmosphere during growth.
- Biogenic removals may also arise due to technological measures undertaken to promote the growth of marine organisms on below sea-level OSW development infrastructure.

Biogenic emissions and removals can be quantified by the practitioner by using an activity-based approach, applying biogenic indicator result which may be available in some sources of emission factors. For example, standard secondary emission factor databases [see 3.3.2.2], will provide total aggregated climate change impact, and the disaggregated impacts by fossil, biogenic and land-use change emission sources, which enables easier calculation of biogenic emissions. Many primary emission factors, derived from industry PCF, LCA or EPD reports have also begun to publish the disaggregated impacts.

Biogenic emissions and removals in the system boundary should be calculated and reported separately in the PER. Where the disaggregated impacts are not available in the emission factor collected for the study, the practitioner may report the aggregated total but must state this clearly in the assumptions.

3.7. Accounting for emissions and removals associated with direct land use change

Direct land use change (dLUC) occurs when the demand for a specific land use to enable OSW development results in a direct change in carbon stocks on that land. In PCF assessment, emissions and removals from dLUC should be accounted for separately from other types of emissions and removals, including 'fossil' and 'biogenic'.

In the context of OSW development, there are several activities included in the system boundary [see Table 10] that may result in dLUC, and the impacts of this shall be stated separately. Some activities where land-use change impacts may occur for an OSW development are:

- Any activity related to the construction of the OSW development that results in land-use change and alterations to existing carbon stocks on land. For example, forest clearances or other land conversion for the purpose of constructing the onshore substation, operations base, or other onshore infrastructure.
- Any activity related to the construction of the OSW development that results in land-use change and alterations to carbon stocks at sea. For example, clearances of mangrove, seagrass meadows or alteration of salt marshes to install foundations, cables, or other below sea level infrastructure.
- Sea-based carbon stocks may also change due to increasing sedimentary organic carbon stocks arising from the creation of marine habitats on below sea-level OSW development infrastructure [12].

There are several methods for assessing dLUC impacts, including direct measurement (soil/seabed carbon testing), or calculation through activity-based calculation (primary or secondary PCF and LCA data), model-based calculation, or remote sensing calculation approaches. dLUC impacts may be quantified by the practitioner according to the activity-based approach by using the land-use change indicator result which may be available in some sources of emission factors. For example, standard secondary emission factor databases [see 3.3.2.2], should provide total aggregated climate change impact and the disaggregated impacts by fossil, biogenic and land-use change emission sources, which enable calculation of land-use change emissions. Furthermore, these databases often include activities related to standard land-use changes such as deforestation or afforestation. Many primary emission factors, derived from industry PCF, LCA or EPD reports have also started to include the disaggregated impacts.

Land based dLUC in the system boundary should be calculated and reported separately in the OSW PER. Where the disaggregated impacts are not available in the emission factors collected for the study, the practitioner may report the aggregated total but must state this clearly in the assumptions. Sea-based dLUC change may be more difficult to quantify as it is currently less well understood than land-based dLUC. Where the practitioner finds that sea-based dLUC has occurred but has difficulties quantifying it due to lack of data availability, they should at a minimum provide a qualitative description of the sea-based dLUC that has occurred within the system boundary in the OSW PER.

3.8. Data quality and uncertainty

Assessing data quality and uncertainty is a crucial step in the PCF assessment process. After identifying all relevant activities and gathering the corresponding activity data and emission factors [see 3.3 for guidance on data collection], the practitioner should evaluate the quality of the data. A thorough data quality assessment enables the practitioner and other stakeholders to identify potential weaknesses in the data and understand their impact on the assessment results.

The guidance draws on the requirements of ISO 14067 and the GHGP Product Standard to define a method for assessing data quality and uncertainty. This guidance also introduces additional criteria to differentiate between data quality and uncertainty assessments based on the timing of the assessment [see 1.4.2 for further guidance on the aims of design-stage and operational assessments].

3.8.1. Data quality

The following steps outline a method for analysing and maximising data quality for the assessment, harmonising the requirements from ISO 14067 and the GHG Protocol Product Standard:

1. Develop a robust data management plan and clearly document it in the assessment assumptions.
2. Identify all data needed and data types.
3. Collect high-quality data to represent the activities relevant to the OSW development.
4. Assess data quality using the pedigree matrix provided in Table 31.

Data quality for different types of assessments

This guidance sets out guidance for two main types of assessment, which may be further subcategorised to inform our understanding of data availability:

1. Design-stage PCF assessment of an OSW development that is not yet operational.
 - Assessment during strategic design
 - Assessment during concept design
 - Assessment during technical design
 - Assessment during construction
 - Assessment during post-completion
2. PCF assessment of an OSW development that is fully operational.
 - Assessment during in-use
 - Assessment after end-of-life

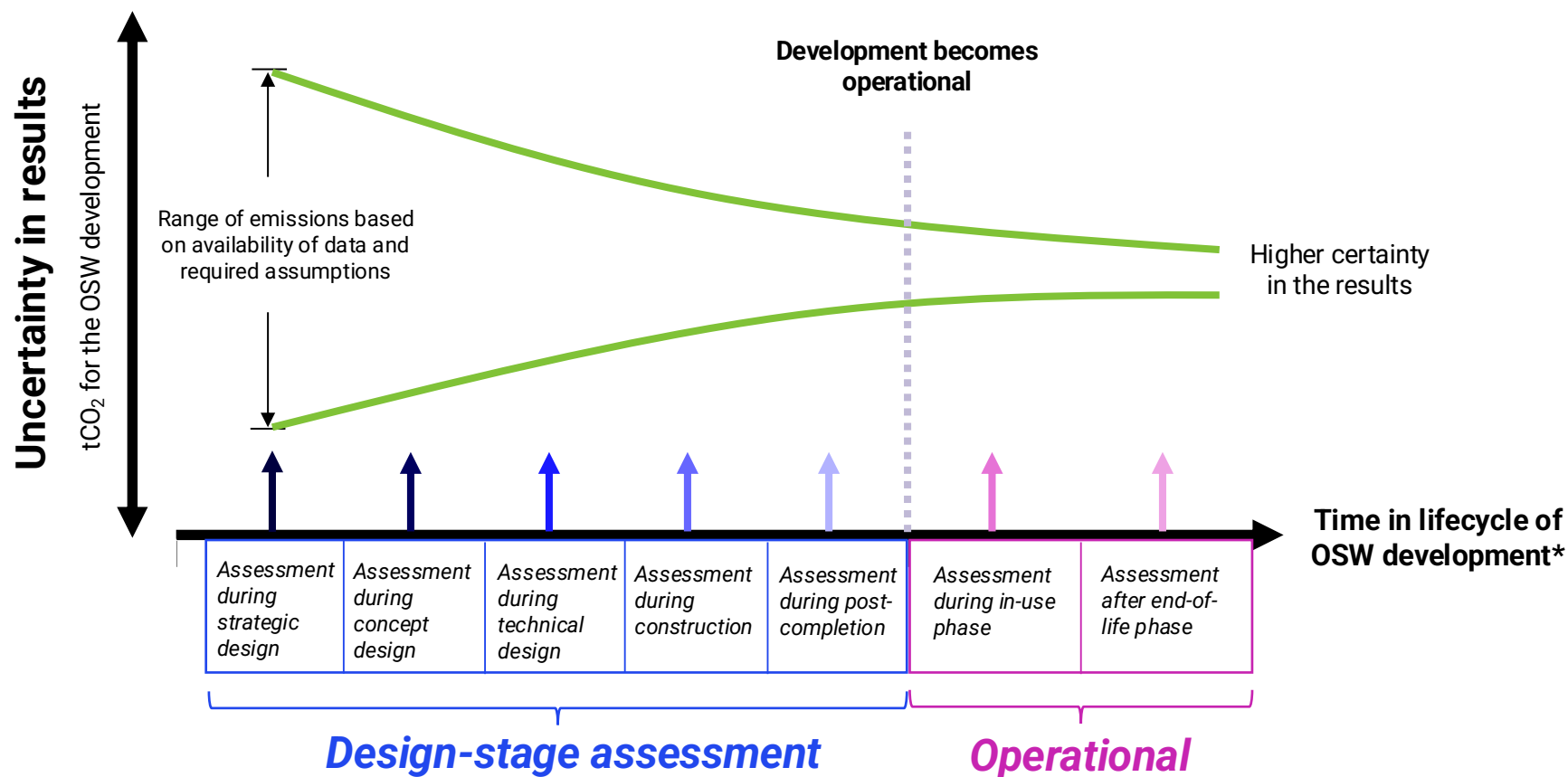
Each of these assessments occurs at distinct phases in the OSW development life cycle and may be conducted for varying purposes. Consequently, the data quality assessment must account for the inherent differences between these assessment types and the availability of data.

For assessments of operational developments, a considerable proportion of the total life cycle activities in terms of emissions materiality (A1-A3, covering emissions from production stage) have already occurred and therefore primary data should be available to be used by the practitioner. For design-stage or forward-looking assessments, data availability may be poor, and primary data may not be available as several of the activities may have not yet occurred.

Table 29: Guidance’s data quality requirements by life cycle stage and assessment type

Life cycle stage	Data requirements for a Design-stage PCF	Data requirements for an Operational PCF
Preconstruction Stage (A0)	The practitioner should collect primary data for preconstruction activities where they have already occurred, or secondary data where they have not. Data from similar and comparable projects should be used as a proxy where possible.	The practitioner should collect primary data for all preconstruction activities.
Production Stage (A1-A3)	The practitioner should collect primary data for production activities where a detailed technical design exists, or secondary data where no detailed design is available. Data from similar and comparable projects should be used as a proxy where possible.	The practitioner should collect primary data for production activities, including all core assets.
Construction and Installation Stage (A4-A5)	The practitioner should collect primary data where available, and secondary data for other construction and installation activities, documenting any assumptions. Data from similar and comparable projects should be used as a proxy where possible.	The practitioner should collect primary data for all construction and installation activities.
Use of infrastructure Stage (B1-B8)	The practitioner should collect secondary data for use-stage activities based on literature averages (industrial or academic), documenting any assumptions. Data from similar and comparable projects should be used as a proxy where possible.	The practitioner should collect primary data for use-stage activities and extrapolate operational data to cover the full operational life cycle, documenting any assumptions. The practitioner may use secondary data where primary data is not available or easily extrapolated, documenting any assumptions.

End of Life of infrastructure stage (C1-C5)	The practitioner should collect secondary data for end-of-life activities based on literature averages (industrial or academic), documenting any assumptions.	The practitioner should collect primary data if available, or secondary data for end-of-life activities based on literature averages (industrial or academic), documenting any assumptions.
Reference flow parameters	The practitioner should collect secondary data for reference flow parameters, including capacity factor and service life.	The practitioner should collect primary data for reference flow parameters, including capacity factor and service life.



*The timeline presented is not proportional to full lifecycle of OSW development. The diagram uses a modified timeline to visually represent the different phases of the lifecycle.

Figure 6: Indicative uncertainty range for assessments at distinct phases of the OSW development

Data quality indicators (DQI) for qualitative assessment of OSW PCF data quality

ISO 14067 and the GHGP Product Standard both address data quality through the assessment of various qualitative parameters or ‘indicators’. While the description of these indicators differs between the standards, they cover the same aspects. Table 30 harmonises the indicators and provides a unified description of their meaning.

Table 30: Harmonising data quality indicators from ISO 14067 and GHGP Product Standard

ISO 14067 indicators	GHGP Product Standard indicators	OSW industry PCF guidance parameter description
Technology coverage	Technological representativeness	Practitioner confidence in how well the data represents the actual technological activities within the boundary.
Time related coverage	Temporal representativeness	Practitioner confidence in how accurately the data reflects the actual time when the activity occurred.
Geographical coverage	Geographical representativeness	Practitioner confidence in how accurately the data represents the actual location (geography) where the activity took place.
Completeness	Completeness	The percentage of the total flow for a data point that is either measured or estimated.
Sources of data	Reliability	Practitioner confidence in the underlying methods, data, and assumptions that form the basis of a data point.

The GHGP Product Standard provides further guidance on how to make the assessment in terms of a pedigree matrix, which is interpreted specifically for this guidance in Table 31. The pedigree matrix allows practitioners to systematically rate each data point across the indicators and then convert the qualitative ratings into a quantitative measure of confidence. This quantitative measure can be used to estimate the uncertainty associated with the data point.

The PCF standards recommend that for each data point used in the OSW PCF assessment, including both activity data and emission factors, the practitioner should make a qualitative assessment of each indicator.

Materiality and hotspot prioritisation for data quality and uncertainty analysis

To ensure the data quality assessment is efficient and focuses on the most significant drivers of the PCF, the practitioner shall adopt a significance-based approach. Rather than applying equal effort to all data points, the practitioner shall prioritise achieving 'Very Good' or 'Good' data quality ratings for the development's emissions hotspots.

Based on typical offshore wind profiles, the practitioner shall prioritise high-quality primary data for the following hotspots:

- Production (A1-A3) activities including materials and manufacturing emissions: specifically for the core infrastructure assets:
 - Wind Turbine Generators (WTG)
 - Foundations (fixed or floating),
 - Cables (inter-array and export
 - Substations
- **Construction and installation (A4-A5):** Specifically, fuel consumption for major transportation and installation vehicles and vessels:
 - Vessels and vehicles used in transportation of core infrastructure assets to site.
 - Turbine installation vessel
 - Foundation installation vessel
 - Cable laying vessels
 - Substation installation vessels

The operational (B1-B8) and end-of-life (C1-C5) stages are important hotspots for the total PCF inventory, but will typically be measured using parameters of lower data quality because they rely on forecasting activities that will occur decades into the future, rather than measuring events that have already happened, or will happen in the near-term future.

For ancillary life cycle stages or activities with low materiality (e.g., preconstruction surveys, minor consumables or low-impact operational activities), the practitioner may accept lower data quality scores or use secondary data with broader assumptions, provided this does not materially misrepresent the total footprint.

Appendix 1, Table 2, column 5 may be used by practitioners as an indicative guide for prioritising data collection for activities and assets which are expected to be most significant to the footprint.

Table 31: Data quality pedigree matrix for this guidance.

	Technology	Time	Geography	Completeness	Source reliability
Very Good	Datapoint represents the exact technology used in OSW development (e.g. steel, S355, produced by BOF)	Datapoint was produced less than 3 years from actual time of OSW development activity.	Datapoint represents the exact country where the OSW development activity took place (e.g. copper, produced in Germany).	Datapoint represents complete boundary for OSW development activity (e.g. primary data is available for fuel consumption in all vessels)	Verified, high quality process data based on measurements and other primary data (e.g. quantity of aluminium for cables in kg, tonnes, measured by manufacturer)
Good	Datapoint represents a similar technology used in OSW development (e.g. steel, low-alloyed, produced by BOF)	Datapoint was produced less than 6 years from time of OSW development activity	Datapoint represents the region where the OSW development activity took place (e.g. copper, produced in Europe)	Datapoint represents more than half of the boundary with minor extrapolation (e.g. primary data for fuel consumption for 80% of vessel working days and extrapolated the rest)	Verified, data partially based on assumptions or other secondary data. (e.g. quantity of aluminium, in kg, tonnes, based on technical specifications)
Fair	Datapoint represents an average technology used in OSW development (e.g. steel, average type/grade)	Datapoint was produced less than ten years from time of OSW activity	Datapoint represents a different region used as a proxy for OSW activity (e.g. copper produced in Japan, as a proxy for copper produced in Germany)	Datapoint represents less than half of the boundary with significant extrapolation (e.g. primary data for fuel consumption for 20% of vessel working days and extrapolated the rest)	Non-verified, low-quality data based on stated assumptions or other qualified estimate (e.g. quantity of aluminium, in kg, tonnes, based on other similar cables)
Poor	Datapoint does not represent a specific technology (e.g. metals, unknown)	Datapoint was produced more than ten years from time of OSW activity or has not yet occurred (including Design-stage PCF)	Datapoint does not describe a geographical area, or area is unknown (e.g. copper, unknown production geography.)	Datapoint represents less than 5% of total activity (e.g. primary data for fuel consumption for 1% of vessel working days and extrapolated the rest)	Non-verified data based on unqualified estimates (e.g. quantity of aluminium, converted from financial cost, based on a guess for average cable)

Calculating the combined data quality score for activity data and emission factors datapoints

Having assigned indicator ratings to the footprint data [see 3.3 for further guidance on data collection] the practitioner should use the values in Table 32 to calculate the combined data quality score for each relevant datapoint.

Table 32: Data quality indicator values and data quality weighting factors

	Technology	Time	Geography	Completeness	Source reliability
Very good	0.9	0.9	0.9	0.9	0.9
Good	0.7	0.7	0.7	0.7	0.7
Fair	0.5	0.5	0.5	0.5	0.5
Poor	0.2	0.2	0.2	0.2	0.2
DQ weighting factor	5.5	2.0	0.1	0.4	2.0

Each indicator is assigned a rating value, ranging from 0.2 for poor quality, to 0.9 for high quality, which corresponds to the pedigree matrix qualifications. The value is then weighted using the 'Data Quality Weighting' factor. These factors reflect the relative contribution of each of the indicators to our confidence in the datapoint and are derived as mathematically proportional to the maximum variance (σ^2) in the Ecoinvent pedigree methodology and the GHGP quantitative inventory uncertainty guidance [15]. For example, a higher weighting for technology [Table 32] than geography means that the rating for technology has a greater effect on the overall quality of the datapoint than the rating for geography. The weighted average data quality score should be calculated as the weighted average of the indicator rating values according to the following equation.

$$\text{Weighted average data quality score} = \frac{\sum_{i=1}^{\text{indicators}} (\text{DQ weighting factor} \times \text{indicator rating values})}{\sum_i^{\text{indicators}} (\text{DQ weighting factor})}$$

The combined data quality score shall be rounded down to the nearest rating category value (very good – poor) to determine the combined rating for the datapoint and presented according to the traffic light system presented in Table 33. Practitioners may add more granular rating categories where necessary to improve the description and communication of data quality.

Table 33: Weighted average data quality rating traffic light system for this guidance

Weighted average DQ score	Data quality rating
>0.8	Very good
0.6 - 0.79	Good
0.4 - 0.59	Fair
<0.4	Poor

Assessing data quality for a design-stage PCF of a planned or future development

There is no inherent difference in how the practitioner should evaluate data quality for a PCF of an operational development versus a design-stage PCF of a future or planned development. The pedigree matrix outlined in Table 31 can be used for both types of assessments. Generally, data quality assessments of design-stage PCFs will result in lower weighted average DQ scores. This is because many activities may not have occurred yet, or their exact details may be unknown. Consequently, while the data quality may represent the best available information to the practitioner at the time, it is often rated lower, as it relies on assumptions or estimations about future activities. This is particularly evident in the 'Time' indicator, where data related to design-stage activities that have not yet occurred will be scored as 'Poor', leading to a lower weighted data quality score for that activity or life cycle stage. Methodological differences in the uncertainty assessment for operational versus design-stage PCFs are discussed in 3.8.2.

Box 3.4: How are the DQ weighting factors derived?

Empirical derivation from literature:

The weighting factors in Version 2 are derived mathematically from the Ecoinvent pedigree matrix methodology and the GHGP Quantitative Inventory Uncertainty Guidance. They represent the relative contribution of each indicator to the total variance (σ^2) of a dataset. According to the standard pedigree matrix, 'Technological' discrepancies introduce the highest variance (approx. 60% of total uncertainty), while 'Geographical' discrepancies introduce the lowest. The weighting factors have been normalised to sum to 10 to simplify the calculation while maintaining this strict statistical proportionality.

Sector-specific context:

It is acknowledged that in the specific context of offshore wind, where logistics and grid intensity are critical, geography is often viewed as highly material; however, this guidance retains the low weighting factor (0.1) for geography to ensure the assessment remains strictly consistent with the statistical variance defined in the underlying scientific literature.

Practical application for data collection:

These weighting factors provide a clear hierarchy for practitioners when selecting secondary data. Since Technology (5.5) exerts a significantly stronger influence on the final uncertainty score than Geography (0.1), practitioners should prioritise sourcing data that accurately represents the specific technology or production route (e.g., specific steel grade or furnace type) over data that perfectly matches the location but relies on generic or proxy technologies.

3.8.2. Uncertainty assessment

Carbon footprint measurements, including PCF, OCF, or LCA, inherently carry uncertainty due to the parameters and methods used in the assessment. Effectively assessing and communicating this uncertainty is crucial for ensuring that stakeholders can trust the insights derived from the assessment. This, in turn, enables stakeholders to plan interventions to reduce the carbon footprint of an OSW development with confidence that these interventions will achieve the desired impact on the measured carbon footprint.

There are several types of uncertainty relevant to PCF assessments described in both ISO 14067 and the GHGP Product Standard. These uncertainties can be broadly categorised as parameter uncertainty, model uncertainty, and scenario uncertainty. Table 34 provides a harmonised description of these uncertainties for this guidance. Additionally, each type of uncertainty may be best evaluated using different methods defined by the standards: qualitative and quantitative uncertainty assessment, and sensitivity analysis.

Table 34: Harmonising uncertainty type descriptions from ISO 14067 and the GHGP Product Standard

Uncertainty type	Offshore wind industry product carbon footprint guidance uncertainty description	Typical evaluation method
Parameter Uncertainty	Uncertainty from the direct parameters used in the assessment to calculate the PCF: • Activity data • Emission factors • Conversion factors	Quantitative uncertainty assessment and optional sensitivity analysis
Scenario uncertainty	Uncertainty in methodological choices or scenarios used in the assessment: • Allocation methods • Use-phase or end-of-life scenarios. • Reference flow assumptions	Sensitivity analysis
Model uncertainty	Uncertainty from the models used to derive the PCF measurement. This may include uncertainty inherent in the impact methodology (model) chosen for the assessment, which is an indirect parameter of the PCF calculation. This guidance requires the use of IPCC characterisation factors, which should result in a consistent model uncertainty across the PCF that cannot be reduced through actions taken by the developer or practitioner to improve data quality. Assessing model uncertainty is not required by this guidance but may be communicated qualitatively.	Qualitative uncertainty

Quantitative parameter uncertainty assessment using the pedigree matrix

The purpose of a quantitative parameter uncertainty assessment is to try to quantify the level of confidence that a value used for a parameter is what the practitioner has stated it to be, and how the uncertainty in the parameters used in the assessment (both activity data and emission factor) may be propagated to the resulting carbon footprint.

The pedigree matrix approach described in 3.8.1 may be used to translate the qualitative data quality assessment into a quantitative estimate of the uncertainty for the parameter, expressed as a lognormal distribution, using the uncertainty scaling factors presented in the GHG Protocol's *Quantitative Inventory Uncertainty* guidance [15] which have been cited for this guidance. The data quality indicator score assigned by the practitioner should be matched to the uncertainty scaling factor presented in Table 35 for each relevant parameter. The GHGP assumes lognormal distribution to quantify parameter uncertainty as it prevents the potential for uncertainty ranges including negative values for activity data and emission factor parameters, which is not possible. This guidance also recommends an approach for presenting the lognormal uncertainty.

Table 35: Uncertainty scaling factors for assessing parameter uncertainty based on DQI ratings

	U1: Technology	U2: Time	U3: Geography	U4: Completeness	U5: Source reliability
Very good	1.00	1.00	1.00	1.00	1.00
Good	1.20	1.10	1.02	1.05	1.10
Fair	1.50	1.20	1.05	1.10	1.20
Poor	2.0	1.5	1.10	1.20	1.50

Having made the data quality assessment, the practitioner may estimate the uncertainty of the parameter, expressed the geometric standard deviation (95% confidence interval) using the following equation described in the *GHGP Quantitative Inventory Uncertainty* guidance:

Parameter uncertainty expressed as Geometric Standard Deviation (GSD)= $SD_{g95} \approx \sigma_{g2} =$

$$\exp(\sqrt{(\ln(U_1))^2 + (\ln(U_2))^2 + (\ln(U_3))^2 + (\ln(U_4))^2 + (\ln(U_5))^2 + (\ln(U_b))^2})}$$

Where:

- U_1 = uncertainty factor of Technology
- U_2 = uncertainty factor of Time
- U_3 = uncertainty factor of Geography
- U_4 = uncertainty factor of Completeness
- U_5 = uncertainty factor of Source Reliability
- U_b = basic uncertainty factor for Activity Type

The practitioner should assign the indicator uncertainty scalar values for $U_1 - U_5$ from Table 35 corresponding to the DQI rating assigned in the data quality assessment [Table 32]. The practitioner must also assess another uncertainty component, the 'basic uncertainty', which is an additional inherent uncertainty source which represents the uncertainty associated with specific activity types, defined by the GHGP. The basic uncertainty values have been cited from *GHGP Quantitative Inventory Uncertainty* and applied to the standard OSW industry PCF guidance activity categories defined in the asset taxonomy provided in Table 16.

Table 36: Basic uncertainty scaling factors for OSW development activities

L1: Activity category	Basic uncertainty scaling factor
Direct emissions and removals	1.05
Freight and transportation	2.00
Electricity and fuels	1.05
Manufactured assets	1.05
Manufactured components	1.05
Manufacturing processes	1.05
Materials	1.05
Waste treatment	1.05

When the practitioner has calculated the geometric standard deviation for the parameter, they may now use the following process to express the range of uncertainty for the parameter value (geometric mean) with a 95% confidence interval:

1. **Determine the Logarithmic Mean (μ):** This is the natural logarithm of the parameter being assessed ($\mu = \ln(\text{AD value, EF value})$)
2. **Calculate the Logarithmic Standard Deviation (σ):** This is the natural logarithm of the GSD calculated for the parameter using the pedigree matrix ($\sigma = \ln(\text{GSD})$)
3. **Apply the Z-Score for a 95% Confidence Interval and calculate the confidence bounds:** For a 95% confidence level, the Z-scores are ± 1.96
 - Lower bound on log scale (LB) $= \mu - (z \times \sigma)$
 - Upper bound on log scale (LB) $= \mu + (z \times \sigma)$
4. **Exponentiation: After determining the lower and upper bounds on the logarithmic scale, these may be exponentiated to return to the parameter scale.**
 - $e^{\text{Lower bound on log scale}}$
 - $e^{\text{Upper bound on log scale}}$
5. **Uncertainty Range Expression: The uncertainty range should be expressed as a plus-minus value around the parameter value, based on the difference between the bounds and the parameter value.**

$$\begin{aligned} & \text{Parameter uncertainty range} \\ & = \text{parameter value} \pm (\text{Upper bound-parameter value}), (\text{parameter value-Lower bound}) \end{aligned}$$

Propagating parameter uncertainty

Propagating parameter uncertainty is the method by which the uncertainty range assessed for each of the individual parameters that make up a PCF assessment is combined to determine the overall uncertainty in the footprint result. There are several approaches for propagating uncertainty. This

guidance recommends the use of Monte Carlo simulation for uncertainty propagation. This method involves random sampling, where the values for parameters (activity data, emission factors) are varied at random within the ranges assessed using the quantitative parameter uncertainty approach.

Uncertainty analysis in design-stage and operational PCF assessments

Practitioners should complete uncertainty analysis for any assessment, design-stage or operational which will be the basis for a public disclosure.

There is likely to be significantly more uncertainty in a design-stage assessment compared to an assessment of an operational development due to a lack of primary data available to the practitioner for activities that have not yet occurred, this phenomenon is represented visually in Figure 6. There is no fundamental difference in how data quality and uncertainty should be assessed for operational and design-stage assessments. However, the data quality is likely to be assessed to be worse in design-stage assessments, as many of the data quality indicators are likely to be scored as “average” or “poor”, and this will be reflected in the quantitative parameter uncertainty estimated.

Example 3.5: Calculating quantitative parameter uncertainty?

A practitioner is calculating the footprint of secondary steel used in the transition pieces. The calculation involves two parameters:

1. **Activity Data (Quantity):** Estimated at 10,000 tonnes. Derived from an early-stage "Preliminary Design" bill of materials (BOM).
2. **Emission Factor (Intensity):** 2.0 kgCO₂e/kg. Derived from a "Good" quality secondary industry database (e.g., Ecoinvent) representing European steel average.

Step 1: Assess data quality (pedigree matrix) The practitioner scores both parameters against the indicators in Table 31 and assigns the corresponding uncertainty scalars from Table 35:

Indicator	Activity Data (Quantity)	Scalar (U)	Emission Factor (Intensity)	Scalar (U)
U1 Technology	Very Good: Data describes the exact material type (Steel (x grade)).	1	Good: Represents similar technology (blast furnace) but not supplier specific.	1.2
U2 Time	Good: Recent design data (<6 years).	1.1	Very Good: Recent database (<3 years).	1
U3 Geography	Very good: Specific to the project site.	1	Fair: European average used as proxy for specific country.	1.05
U4 Completeness	Fair: Early design estimate; <50% of detail finalised.	1.1	Good: Database represents >50% of market.	1.05
U5 Reliability	Fair: Unverified internal engineering estimate.	1.2	Good: Verified third-party database.	1.1

Step 2: Identify Basic Uncertainty (U_b)

Using Table 36, the practitioner identifies the activity category for both as "Materials", which has a basic uncertainty factor of 1.05.

Step 3: Calculate Geometric Standard Deviation (GSD) using formula:

- Activity Data GSD: $\exp(0.230) \approx 1.26$ (Driven by uncertainty in completeness and reliability of the early design)
- Emission Factor GSD: $\exp(0.219) \approx 1.25$ (Driven by uncertainty in technology and geography representativeness of the secondary data)

Step 4: Calculating the 95% Confidence Interval Using the Lognormal distribution properties (Z-score = 1.96), the practitioner calculates the uncertainty range for each parameter.

- **Activity Data (10,000 tonnes):**
 - Uncertainty Range: 6,370 – 15,700 tonnes
 - *Interpretation:* The actual steel quantity required could vary significantly as the design matures.
- **Emission Factor (2.0 kgCO₂e/kg):**
 - Uncertainty Range: 1.30 – 3.07 kgCO₂e/kg
 - *Interpretation:* The true carbon intensity falls within this band based on the proxy data used.

3.8.3. Sensitivity analysis

Sensitivity analysis is a method of estimating or quantifying the effects of methodological choices made or data used to inform the value of parameters in the PCF. For example, consider the reference flow parameters used to calculate reference flow [see 2.5.1 for guidance on the reference flow calculation]. The practitioner may provide a value for the lifetime of the OSW development or a value for the capacity factor based on assumptions about the operating conditions for a specific development. The values chosen for these parameters greatly influence the result of the PCF in terms of the functional unit, yet there is a lot of uncertainty in these values.

Sensitivity analysis for reference flow parameters

As these parameters simply represent a potential operational scenario chosen by the practitioner, sensitivity analysis shall be undertaken for the reference flow parameters to allow for simple interpretation and comparison of the results. The practitioner shall assess the results of the PCF per functional unit using their stated reference flow parameter values alongside default values.

Table 37: Sensitivity analysis for the reference flow parameters

Reference flow parameter	Unit	Practitioner values	Default value for sensitivity analysis
Assumed capacity factor	%	Practitioner determines the value for the reference flow parameters based on operational assumptions for the OSW development under study and justifies their values [see 2.5.1]. To ensure comparability with other assessments, they also calculate the reference flow using the default values provided in this guidance.	42%
Assumed service life	Years		25 years

Sensitivity analysis for design and scenario choices

In addition to the reference flow parameters, the practitioner should conduct sensitivity analysis on key design and scenario choices, particularly for design-stage assessments (Strategic, Concept, and Technical Design). This analysis allows the practitioner to evaluate the potential carbon reduction impact of specific interventions and supports decision-making by quantifying the trade-offs between different technological or supply chain options.

Where specific design decisions have not yet been finalized, or where the practitioner wishes to demonstrate the potential impact of decarbonisation strategies, a comparison should be made between a "Baseline scenario" (standard industry practice) and an "Alternative scenario" which might represent a scenario where the design has been optimised for carbon intensity, cost, or another key metric.

The results of these sensitivity analyses should be reported alongside the main carbon footprint results to highlight the potential variation in the total PCF based on design maturity and supply chain choices.

Box 3.5: Common design-stage sensitivity scenarios for OSW development

Design choice category	Baseline scenario example	Alternative scenario example
Production of materials	Use of conventional primary steel for foundations (2.5kgCO _{2e} /kg).	Use of electric arc furnace (EAF) or low-carbon steel (0.8kgCO _{2e} /kg).
Construction & installation	Installation vessels running on Marine Gas Oil (MGO).	Installation vessels running on Biodiesel (HVO) or Methanol.
Foundation design	Standard XXL Monopile design.	Jacket foundation or Suction Bucket Jacket design.
Cable material	Copper conductor cables.	Aluminium conductor cables.
Dismantling & Waste	Standard cut-and-lift removal with 90% recycling rate for steel.	Full removal or partial removal scenarios; chemical recycling of composite blade waste.

3.8.4. Primary Data Share (PDS)

To ensure transparency regarding the reliance on specific supply chain data versus generic databases, practitioners shall calculate and report the Primary Data Share (PDS) of the PCF. This metric is defined in accordance with the WBCSD PACT Pathfinder Framework [6] and is described in table.

The PDS represents the proportion of the total Global Warming Potential (GWP) impact that is calculated using primary data. It is calculated using the formula in Table 38. For definitions of primary and secondary data, please refer to section 3.3.

Table 38: Formula for measuring primary data share

Primary data share is measured as the total quantity of emissions across all life cycle stages estimated using primary data as a proportion of total GHG emissions	
PDS (%) = $\sum \frac{(GHG\ Emissions\ calculated\ using\ Primary\ Data)}{Total\ GHG\ emissions\ for\ PCF} \times 100$	

While the goal in any assessment should be to ensure as much primary data as possible, it is recognised that data availability varies depending on the type of assessment (Operational vs Design-stage PCF) and the life cycle stage (Production vs End-of-life). It is recommended that for operational PCF, the recommended PDS target is >50%, with high PDS specifically in the Production (A1-A5) and Construction and Installation (A4-A5) life cycle stages.

3.8.5. Limitations of the study

To ensure sufficient context and transparency for the reader of the OSW PCF, it is crucial that the practitioner discloses any limitations of the assessment. These limitations should be clearly explained, addressed to the extent possible, and factored into the interpretation of the results. Typical limitations include, but are not limited to:

- Poor data quality
- Assumptions used
- Data collection processes
- Allocation methods
- Limited development of the calculation, sensitivity analysis and uncertainty assessment.

The level of detail regarding these limitations should reflect the assessment's type and purpose. For instance, a design-stage PCF inherently possesses more limitations than an operational PCF, and a publicly disclosed PCF requires more transparency than an internal assessment.

4. Reporting and disclosure

The Offshore wind industry product carbon footprinting guidance reporting and disclosure requirements are defined in accordance with ISO 14067 and the GHGP Product Standard. The practitioner may use the OSW PER templates provided in Appendix 2 to disclose the results of their assessment. The overall goal of the OSW PER is to provide a clear and interpretable set of results that provides stakeholders with the information required to plan effective decarbonisation interventions.

The following requirements should be followed by a practitioner completing an OSW PER:

- The disclosure shall include all relevant information, including results, data quality, methods, assumptions, and limitations of the PCF assessment.
- The information shall be presented in sufficient detail to allow the reader to interpret and understand the complexities and trade-offs inherent in the PCF assessment.
- The disclosure should be completed in a transparent manner consistent with the stated goals of the PCF assessment.
- The disclosure must be accurate and not misleading.

The OSW PER should be:

- Reasonable in length.
- Written with a reasonable level of detail for the intended audience.
- Made available in the public domain where possible, depending on the stated goals of the assessment.

4.1. Units and quantities for reporting

The following guidance should be followed to standardise units so that PCFs are comparable. Specific guidance on units is not provided in ISO 14067 or the GHGP Product Standard, so additional requirements are provided, paraphrasing the *EPD International General Program Instructions* v5.0.0 [16] which provides useful guidance on the use of units and quantities.

- The International System of Units (SI units) should be used, e.g., kilograms (kg), Joules (J) and metres (m).
- Reasonable multiples of SI units may be used in the PCF to improve readability, e.g., grams (g) or megajoules (MJ). The following exceptions apply:
 - Resources used for energy input (primary energy) should be expressed as kilowatt-hours (kWh) or megajoules (MJ), including renewable energy sources.
 - Time should be expressed in the unit that is most practical for the assessment, e.g., hours (reference flow calculation), or years (lifetime of OSW development).
- The results of the OSW PCF assessment should be expressed in the units prescribed by the impact assessment methods, e.g. kgCO₂e/kWh, but may also be reported in multiples for example, gCO₂e/kWh, to improve readability.
- Use three significant figures and ensure the number of significant digits is appropriate and consistent.
- The product emissions report shall not contain blank cells, or '0' unless the life cycle module, asset category or activity category has been evaluated to be zero.
- If a module or category is not relevant to the system, or excluded based on materiality and data availability, the report cells should contain 'NA' or 'excluded,' along with a justification.

4.2. Reporting and disclosing results

This section outlines the standard information that must be reported and disclosed at the end of the assessment. It is accompanied by a series of standard reporting templates provided in Appendix 2. Practitioners may use the provided templates or create their own, but they must report the results of the assessment in line with the requirements outlined below.

4.2.1. Reporting the assessment details and criteria

The OSW PER shall outline details about the assessed development and shall describe the methodologies and data used to calculate the results. A standard template for disclosing the details of the assessment is provided in Appendix 2, Table 1.

4.2.2. Reporting the assessment results by functional unit and other selected intensity metrics

The results of the PCF should be reported in either gCO₂e or kgCO₂e per functional unit to three significant figures. Results should be rounded to obtain the correct number of significant figures. The following calculation shall be used to report results. The parameters of the reference flow calculation shall be clearly stated and justified where they diverge from the default values described in 2.5. A reporting template is provided in Appendix 2, Table 2

- Installed capacity (MW)
- Assumed capacity factor (%)
- Assumed service life (Years)

The practitioner should also qualitatively describe the assumed performance conditions (i.e., wind speed) for the wind farm from which their capacity factor is derived.

4.2.3. Reporting the assessment results by types of GHG emissions and removals

The results shall be reported separately in terms of emissions and removal types defined in 2.4.8. Each of the reporting templates in Appendix 2 provides separate columns for each of the types of emissions and removals.

- Fossil GHG emissions and removals
- Biogenic GHG emissions and removals
- dLUC GHG emissions and removals
- Total emissions (sum of fossil, biogenic and dLUC emissions and removals)

4.2.4. Reporting in the assessments results by life cycle stages and modules, and assets and activities

Life cycle stages and modules

The results should be reported separately in terms of tCO₂e (absolute value) for each of the life cycle stages and modules outlined in 2.4.2 of the guidance, to allow for ease of interpretation and to identify the most emissions-intensive life cycle stages of the OSW development. A reporting template is provided in Appendix 2, Table 3. Where the practitioner cannot separate the emissions totals for some life cycle modules, such as A1-A3, the results for the life cycle stage may be reported as a single total. This may occur when the practitioner has used cradle-to-gate emissions factors that aggregate the whole life cycle stage.

The results for total emission by life cycle stage (e.g. Total production (A1-A3)) should also include a disclosure of the lower and upper estimates for quantitative uncertainty using the analysis method described in section 3.8.2.

Asset and activity taxonomies

The results should be reported separately in terms of tCO₂e (absolute value) for both the OSW asset taxonomy and the OSW activity taxonomy described in 2.9 of the guidance, to allow for ease of interpretation and to identify the most emissions-intensive assets and activities in the OSW development life cycle. Reporting templates are provided in Appendix 2, Table 4, and Appendix 2, Table 5. Where the practitioner cannot separate the emissions totals for some assets, such as WTG, into the constituent components (Nacelle and internals, blades, hub and rotor system, tower, etc.), the results for the asset category may be reported as a single total. This may occur when the practitioner has a single emissions factor for the full asset, such as an emission factor for one WTG.

4.2.4 Optional reporting for the OSW PCF assessment

Module D

Optional results for the calculation of Module D [see 2.4.4] shall be reported by the practitioner separately from the results of the mandatory life cycle stages and module. The practitioner shall not calculate or report a net of the life cycle stages A1-C5 and Module D to use as a basis for reporting the results, either on an absolute basis or in terms of the functional unit.

Carbon credits or other offsets procured by the developer to mitigate the impact of the OSW development

Where the developer or another stakeholder has procured verified carbon credits or offsets to offset some of the GHG impact of the OSW development for hard-to-abate activities, these may be described in the OSW PER but shall be reported separately from the results of the assessment. The practitioner shall not calculate or report a net of the results for the absolute carbon footprint of the OSW development combined with the purchased credits or offsets.

4.3. Critical review

For a LCA, a critical review is the conformity assessment approach according to ISO 14040 and ISO 14044. The critical review process provides an additional level of confidence as it makes the individual reviewer personally responsible for the work. As LCAs are intended to be used in comparisons and/or be disclosed to the public, the critical review process is designed to improve the robustness and credibility of the study.

A critical review is not mandatory; the practitioner may wish to conduct a critical review. Where this process is carried out, it shall be done in accordance with ISO 14044 and ISO 14040.

The guidance strongly recommends that a critical review of the OSW PCF is carried out where the results are being used for internal purposes only and a third-party verification for assessments that will inform a public disclosure.

4.4. Verification

Verification is not a mandatory requirement for PCF assessments made using this guidance, however, it is strongly recommended, particularly where the assessment will be used as the basis for a public disclosure. This section describes the benefits of, and the process for, a verification of a footprint calculated in compliance to this methodology document.

The benefits of verification include but are not limited to:

- **Information accuracy** – third-party verification provides stakeholders with confidence that the reported information represents a true and fair account of the carbon footprint of the development. A verification verifies the parameters and final value to be correct. The verification ensures that a company does not overstate, nor understate the footprint.
- **Ensuring completeness** – the steps taken in verification means that all relevant activities emission sources are accounted for within the footprint.
- **Providing confidence** – as the verifiers are impartial, verification provides stakeholders, businesses and consumers with confidence that a footprint has been calculated and reported correctly. For stakeholders, especially those involved in the public consultation part of the tender process, verification shows transparency, openness and that due diligence has been taken. For businesses, it ensures that they are focussing on the most material areas in their decarbonisation journey and environmental management plan (EMP) part of the tender process. For consumers, it helps them make informed decisions.
- **Supporting the auction process** – a carbon footprint assessment may become common within the prequalification and bid submission of the auction process for an OSW development, verification or validation provides greater confidence with the results of the assessment.
- **Preparation for mandatory verification in future or market trend change** – the disclosure landscape is constantly evolving, therefore verifying a footprint and familiarising oneself with the verification the process can prepare the practitioner for future legislative change or market trends which may require third-party verification.

The first step that needs to be taken to get a PCF verified is to submit a request for proposal (RFP) or select a verification body. Before the verification takes place, the assessment parameters need to be selected. These include but are not limited to:

- **Type of engagement (verification or validation)** – a verification engagement evaluates greenhouse gas statements based on historical data, whereas a validation engagement assesses the assumptions, limitations, and methods supporting forecasts of future activities. Therefore, verification is required for operational PCF assessments, while validation is required for design-stage PCF assessments.
- **Accounting standards** – the accounting methodology to be assessed against. The core standards referenced in Section 1.5 and this guidance document is recommended. The accounting standards shall be clear in any communications made.
- **Verification standard** – the requirements for the verification body to conform to while conducting the verification. The recommended verification standard is *ISO 14064-3: Specification with guidance for the verification and validation of greenhouse gas statements*. Different verifications standards may be used; however, this shall be clear in any communications made.
- **Level of assurance** – the degree of confidence in the greenhouse gas statement or footprint. It is recommended to request a reasonable level of assurance, as the nature and extent of the verification activities have been designed to provide a higher (but not absolute) level of confidence in the footprint, compared to a limited level of assurance.

Upon commencement of assurance, the practitioner shall provide the required documentation (e.g., data, methodology and any other relevant supporting information) for the OSW development PCF as well as primary evidence to support the activity data and emission factors used in the footprint. The verifier may, depending on the chosen verification standard, conduct a site visit and/or interview to ensure that data gathering processes and emissions sources are complete and representative of the assessment being verified. If the verification is successful, some verifiers may require ongoing monitoring to ensure continued compliance. The practitioner shall disclose the results of the verification or validation process, where verification or validation has been undertaken.

Appendix 1: Full list of emissions sources and activities to be included in the system boundary for an OSW development

Appendix 1 serves as supplementary guidance to support the calculation of a PCF for an OSW development and should be used in conjunction with the guidance provided in Section 3.

Appendix 1, Table 1 provides a list of the mandatory emission sources that must be included within the system boundary for a PCF assessment of an OSW development. The relevant emission sources remain consistent regardless of the type of assessment being conducted (operational PCF or design-stage PCF; refer to Table 1 for further information). However, data availability may vary, particularly when specific activities have not yet occurred at the time of the assessment, resulting in the absence of primary data for the practitioner. Appendix 1, Table 1 begins by describing each relevant emission source or 'activity' within the system boundary, based on the activity taxonomy provided in Table 16. It also provides examples of where these emissions might arise in an OSW development and recommends the appropriate emission factors to use.

Following this, Appendix 1, Table 2 provides list of specific development activities that should be included in the PCF assessment where they occur in the development being studied, organised by life cycle stage. Each OSW development will have its own set of relevant activities, determined by the design and technical specifications of the project. Where activities listed are not relevant to the development under study, they may be excluded from the assessment. Conversely, if specific activities relevant to the OSW development being studied are not included in the list, the practitioner should add them. The table references previous research conducted in The Crown Estate and Offshore Renewable Energy Catapult (OREC) '*Guide to an Offshore Wind Farm*' to summarise the activities relevant to the carbon footprint of an OSW development.

Appendix 1, Table 1: Full list of mandatory sources of emissions and recommended emission factors for a PCF assessment of an OSW development based on this guidance's activity taxonomy (Table 16).

L1: Activity category	L2: Activity subcategory	OSW development emissions source	Recommended emission factors
1. Direct emissions and removals	a. Fugitive emissions	Emissions of insulating GHGs (e.g., SF6) from substation equipment during regular operation or blow-outs.	IPCC (2021) emission factor for specific GHG (GWP100)
	b. Process emissions	Emissions of GHGs from chemical processes (e.g., use of coolants, chemicals in maintenance).	IPCC (2021) emission factor for GHG (GWP100)
2. Freight and transportation	a. Air freight and transportation	Emissions from transport of infrastructure components, parts, and maintenance personnel to site using freight planes, drones, or transport helicopters.	Emission factor for specific fuel combusted in the aircraft, typically jet fuel, or kerosene (kgCO₂e/litre, tonne, MJ, etc.) Weight distance-based emission factor for aircraft type (kgCO₂e/tonne.km) Journey-based emission factor for aircraft type (kgCO₂e/hour, LTO)
	b. Rail freight and transportation	Emissions from transport of components and materials using trains.	Emission factor for specific fuel combusted in the train, typically diesel (kgCO₂e/litre or tonne or MJ, etc.) Weight-distance based factor for train type (kgCO₂e/tonne.km)
	c. Road freight and transportation	Emissions from transport of components, materials, and maintenance personnel using trucks, lorries, vans, cars, and specialised vehicles.	Emission factor for specific fuel combusted in the vehicle, typically diesel, petrol, bio-based alternative, or electricity (kgCO ₂ e/litre or tonne or MJ, etc.)

			Weight-distance based factor for vehicle type (kgCO ₂ e/tonne.km)
	d. Sea freight and transportation	Emissions from transport of infrastructure assets, components, materials, and personnel via sea, using freight vessels, specialist vessels (e.g., Turbine Installation).	Emission factor for specific fuel combusted in the vehicle, typically marine fuel oil, marine diesel, bio-based alternative, or electricity (kgCO ₂ e/litre or tonne or MJ, etc.) Weight-distance based for vessel type (kgCO ₂ e/tonne.km)
3. Fuels and electricity	a. Biofuels life cycle	Emissions from the production, transport, and use of biofuels for OSW operations not otherwise captured in Freight and Transportation.	Emission factor for specific biofuel combusted, may be derived from PCF or LCA report (biofuel certification) or from secondary database. Typically, biodiesel, bioethanol, biogas, etc. (kgCO ₂ e/litre or tonne or MJ, etc.)
	b. Electricity life cycle	Emissions from the production, transmission, and use of electricity imported from the grid to support OSW development operations such as onshore operation sites.	Emission factor for electricity generation for the grid region where the OSW development is operating may be derived from secondary database (kgCO ₂ e/kWh).
	c. Gaseous fuels life cycle	Emissions from the production, transport, and use of gaseous fuels to support OSW development operations such as heating onshore operation sites.	Emission factor for specific gas combusted, typically natural gas (kgCO ₂ e/litre or tonne or MJ, etc.)
	d. Liquid fuels life cycle	Emissions from the production, transport, and use of fossil-based liquid fuels for OSW operations not otherwise captured in Freight and Transportation.	Emission factor for specific fuel combusted, typically diesel, petrol, marine fuel oil, etc (kgCO ₂ e/litre or tonne or MJ, etc.)

	e. Solid fuels life cycle	Emissions from the production, transport, and use of solid fuels for OSW operations not otherwise captured in Freight and Transportation. Unlikely to be relevant.	Emission factor for specific fuel combusted, may include coal or other solid fuels (kgCO ₂ e/litre or tonne or MJ, etc.)
4. Fully manufactured assets and components	a. Assets	Emissions from the production and manufacturing of infrastructure assets procured for the OSW development (e.g. WTG, foundations, cables etc [see Table 15 for list of assets]). Covers all cradle-to-gate (supplier gate) emissions from manufacturing the asset including materials, upstream transportation, manufacturing energy use and waste.	Emission factor for the finished asset may be derived from a supplier PCF, LCA or EPD report for the asset (kgCO₂e/unit (e.g. 1 WTG specific manufacturer model, MW capacity)) Emissions factor for generic finished asset may be derived from secondary database (kgCO₂e/unit (e.g. 1 generic WTG, MW capacity)) Practitioners may combine a full asset approach for some assets (e.g. WTG, cables) with a material composition approach for others (e.g. steel quantities for foundations)
	b. Subcomponents	Emissions from the production and manufacturing of subcomponents procured for the OSW development (e.g. blades for WTG, transformers for substation, etc [see Table 15 for list of asset subcomponents]). Covers all cradle to gate (supplier gate) emissions from manufacturing the asset including materials, upstream transportation, manufacturing energy use and waste.	Emission factor for the finished subcomponent may be derived from a supplier PCF, LCA or EPD report for the asset (kgCO₂e/unit (e.g. 1 WTG blade, specific manufacturer model, material grade)) Emissions factor for generic finished asset may be derived from secondary database (kgCO₂e/unit (e.g. 1 generic WTG blade, specific manufacturer model, material grade)) Practitioners may combine a full asset approach for some assets (e.g. WTG, cables) with a

			material composition approach for others (e.g. steel quantities for foundations)
5. Manufacturing processes	a. Coating and galvanising processes	Emissions from coating, galvanizing, or other surface treatment processes used in the manufacturing of OSW components, where not already included in assessment of fully manufactured assets or components assessment. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets	Emission factor for specific coating or galvanising process used, typically derived from secondary databases (kgCO ₂ e/unit or per process step).
	b. Joining and welding processes	Emissions from welding, joining, or other assembly processes used in the manufacturing of offshore wind components, where not already included in assessment of fully manufactured assets or components assessment. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets	Emission factor for specific joining or welding process used, typically derived from secondary databases (kgCO ₂ e/unit or per process step).
	c. Material processing	Emissions from processing raw materials into components or parts for offshore wind manufacturing (e.g., cutting, forming, shaping materials), where not already included in assessment of fully manufactured assets or components assessment. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets	Emission factor for specific material processing step, typically derived from secondary databases (kgCO ₂ e/unit or per process step).

	d. Other manufacturing processes	Emissions from additional manufacturing processes not covered in other subcategories.	Emission factor for the specific manufacturing process, typically derived from secondary databases (kgCO ₂ e/unit or per process step).
6. Materials	a. Aluminium	Emissions from the production, processing, and use of aluminium, or aluminium alloys in offshore wind components, including WTG towers, nacelle, cable conductors, substation, and electrical equipment, where not already included in assessment of fully manufactured assets or components assessment. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets. Covers all cradle-to-gate (supplier gate) emissions from production of the material.	Emission factor for aluminium production (cradle-to-gate), referencing specific grade required for asset or component. Typically, derived from supplier LCA, PCF or EPD report, or secondary databases (kgCO ₂ e/kg or tonne of aluminium).
	b. Biogenic materials	Emissions from the production, processing, and use of biogenic materials (e.g., wood, natural fibres) in offshore wind components, potentially used in blades, insulation, composite materials, where not already included in assessment of fully manufactured assets or components assessment. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets. Covers all cradle-to-gate (supplier gate) emissions from production of the material.	Emission factor for biogenic material production (cradle-to-gate). Typically, derived from supplier LCA, PCF or EPD report, or secondary databases (kgCO ₂ e/kg or tonne of biogenic material).
	c. Carbon fibre	Emissions from the production, processing, and use of carbon fibre in offshore wind components, particularly in WTG blades and other high-strength,	Emission factor for carbon fibre production. Typically, derived from supplier LCA, PCF or EPD

		lightweight structures where not already included in assessment of fully manufactured assets or components assessment. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets. Covers all cradle-to-gate (supplier gate) emissions from production of the material.	report, or secondary databases (kgCO ₂ e/kg or tonne of carbon fibre).
	d. Concrete	Emissions from the production, processing, and use of concrete in offshore wind components, including foundations, platforms, and other structures, where not already included in assessment of fully manufactured assets or components assessment. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets. Covers all cradle-to-gate (supplier gate) emissions from production of the material.	Emission factor for concrete production, referencing specific concrete type and grade. Typically, derived from supplier LCA, PCF or EPD report, or secondary databases (kgCO ₂ e/kg or tonne of concrete).
	e. Copper	Emissions from the production, processing, and use of copper or copper alloys in offshore wind components, notably in cables, transformers, and other electrical equipment. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets. Covers all cradle-to-gate (supplier gate) emissions from production of the material.	Emission factor for copper production, referencing specific copper grade. Typically, derived from supplier LCA, PCF or EPD report, or secondary databases (kgCO ₂ e/kg or tonne of copper).
	f. Fibreglass	Emissions from the production, processing, and use of fibreglass in offshore wind components, particularly in WTG blades and nacelles. Typically,	Emission factor for fibreglass production. Typically derived from supplier LCA, PCF, or EPD

		relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets. Covers all cradle-to-gate (supplier gate) emissions from production of the material.	report, or secondary databases (kgCO ₂ e/kg or tonne of fibreglass).
	g. Oils and lubricants	Emissions from the production, processing, and use of oils and lubricants in offshore wind components and machinery. Covers all cradle-to-gate (supplier gate) emissions from production of the material.	Emission factor for oils and lubricants. Typically derived from supplier LCA, PCF, or EPD report, or secondary databases (kgCO ₂ e/kg or litre of oil or lubricant).
	h. Other materials	Emissions from the production, processing, and use of other materials in offshore wind components not covered in other subcategories. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets. Covers all cradle-to-gate (supplier gate) emissions from production of the material. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets. Covers all cradle-to-gate (supplier gate) emissions from production of the material.	Emission factor for other materials. Typically derived from supplier LCA, PCF, or EPD report, or secondary databases (kgCO ₂ e/kg or tonne of material).
	i. Polymers	Emissions from the production, processing, and use of polymers in offshore wind components, particularly in cables, insulation, and composite materials. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets. Covers all	Emission factor for polymer production. Typically derived from supplier LCA, PCF, or EPD report, or secondary databases (kgCO ₂ e/kg or tonne of polymer).

		cradle-to-gate (supplier gate) emissions from production of the material.	
	j. Steel	Emissions from the production, processing, and use of steel in offshore wind components, including towers, foundations, and other structural elements. Typically, relevant where practitioner uses a material composition approach to measure emissions from infrastructure assets. Covers all cradle-to-gate (supplier gate) emissions from production of the material.	Emission factor for steel production, referencing specific steel grade. Typically derived from supplier LCA, PCF, or EPD report, or secondary databases (kgCO ₂ e/kg or tonne of steel).
7. Waste treatment	a. Incineration	Emissions from the incineration, without energy recovery, of waste generated during offshore wind development life cycle activities.	Emission factor for waste incineration. Typically derived from LCA or secondary databases (kgCO ₂ e/kg or tonne of waste).
	b. Landfill	Emissions from the disposal of waste in landfills, generated during offshore wind development and operations.	Emission factor for landfill disposal. Typically derived from LCA or secondary databases (kgCO ₂ e/kg or tonne of waste).
	c. Processing, sorting for recycling and reuse	Emissions from the processing and sorting of waste for recycling and reuse, generated during offshore wind development and operations.	Emission factor for recycling and reuse processes. Typically derived from LCA or secondary databases (kgCO ₂ e/kg or tonne of waste).

Appendix 1, Table 2: List of potential development activities included, organised by life cycle stage for a PCF assessment of an offshore wind development

Life cycle stage	Emissions sources	Relevant development area	Specific development activity	Expected significance; priority; recommended data
A0: Preconstruction stage	Emissions from fuels and energy consumed in preconstruction activities and emissions from the production of preconstruction infrastructure	A0: Development and consenting services	Environmental impact assessment	Less significant; Low priority; secondary data suitable
		A0: Environmental surveys	Benthic environmental surveys	Less significant; Low priority; secondary data suitable
			Fish and shellfish surveys	
			Ornithological environmental surveys	
			Marine mammal environmental surveys	
			Onshore environmental surveys	
			Human impact studies	
		A0: Metocean assessment	Survey infrastructure, including: • Foundation • Platform • Mast • Buoys	Less significant; Low priority; secondary data suitable
			Survey sensors including: • Meteorological sensors • Anemometers • Metocean sensors • Data loggers	Less significant; Low priority; secondary data suitable
		A0: Geological and hydrological surveys	Geophysical surveys	Less significant; Low priority; secondary data suitable
			Geotechnical Surveys	
			Hydrographic surveys	

A1-A3: Production stage	Emissions from fuel and energy, and materials used in production activities for assets, sub-components and materials used in the offshore wind development. This includes extraction, transportation, and processing of materials up to supplier gate (tier 1).	A1-A3: WTG	Nacelle and internals • Bedplate • Main bearing • Main shaft • Gearbox • Generator • Power take-off • Control system • Yaw system • Yaw bearing • Nacelle auxiliary systems • Nacelle cover • Small engineering components	Highly significant; High priority; Primary data priority
			Blades, hub, and rotor system • Structural fasteners • Condition monitoring system • Hub casting • Blades • Blade bearings • Pitch system • Spinner • Rotor auxiliary systems • Fabricated steel components • Structural fasteners	Highly significant; High priority; Primary data priority
			Turbine transformer	Highly significant; High priority; Primary data priority

		A1-A3: Fixed foundations	Turbine tower • Steel • Tower internals	Highly significant; High priority; Primary data priority
			Monopile • Steel plates • Flange • Joints • Corrosion protection materials and coatings, including galvanisation materials • Scour protection materials	Highly significant; High priority; Primary data priority
			Transition piece • Crew access system and work platform • Internal platforms • Davit crane • J-tubes, l-tube or monopile entry point	Highly significant; High priority; Primary data priority
			Jacket • Steel lattice • Struts • Nodes • Pin piles • Crew access system and work platform • Internal platforms • Davit crane • J-tubes	Highly significant; High priority; Primary data priority

			- Corrosion protection materials and coatings, including galvanisation materials. - Scour protection materials	
			Other fixed foundation technologies - Gravity base - Hybrid foundations - Suction bucket foundations - Composite materials - Innovative scour protection techniques	Highly significant; High priority; Primary data priority
		A1:A3: Floating foundations	Platform - Semi-submersible (steel structure) - Spar buoy (steel structure) - Tension Leg Platform (TLP)	Highly significant; High priority; Primary data priority
			Mooring - Anchors - Mooring lines - Mooring connectors	Highly significant; High priority; Primary data priority
			Ballast - Ballast tanks - Water ballast - Concrete ballast	Highly significant; High priority; Primary data priority
			Other fixed foundation technologies - Barges - Pontoon systems - Hybrid floating structures - Alternative mooring systems	Highly significant; High priority; Primary data priority

		A1-A3: Cables	Inter array cables • Cable core • Cable outer • Cable accessories • Cable jointing	Highly significant; High priority; Primary data priority
			Export cables • Cable core • Cable outers • Cable accessories • Cable jointing	Highly significant; High priority; Primary data priority
		A1-A3: Offshore substation	Electrical systems • HVAC and HVDC systems • HVAC and DC switchgear • Transformers • Converters • Passive and active power compensation • Earthing systems • Auxiliary electrical, control and monitoring systems • Industrial waterproof enclosures • Cable trays, tracks, clamps, and supports to protect electrical items	Highly significant; High priority; Primary data priority
			Facilities • Auxiliary electrical systems • Monitoring systems • Communication system • Fire and blast protection systems	Moderately significant; Medium priority; Primary data where possible

			- Standby generator (normally for HVDC substations) - Crane - Control room and refuge - Clean and black water systems (normally for HVDC substations) - Fuel tanks (normally for HVDC substations) - Heating, ventilation and air conditioning equipment	
			Structure - Steel structure - Helideck and/or heliwinch	Highly significant; High priority; Primary data priority
		A1-A3: Onshore substation	Electrical systems - HVAC and HVDC systems - HV AC and DC switchgear - Transformers - Converters - Metering equipment - Passive and active power compensation - Earthing systems - Auxiliary electrical, control and monitoring systems Cable trays, tracks, clamps and supports to protect electrical items	Highly significant; High priority; Primary data priority
			Facilities - Auxiliary electrical systems - Communication system - Fire and blast protection systems	Moderately significant; Medium priority; Primary data where possible

			- Standby generator (normally for HVDC substations) - Control room - Clean and black water systems (normally for HVDC substations) - Fuel tanks (normally for HVDC substations) Heating, ventilation, and air conditioning equipment	
			Structure Concrete, steel and other building materials Welfare facility	Highly significant; High priority; Primary data priority
		A1-A3: Operations base	Vessel berths	Less significant; Low priority; secondary data suitable
			Warehouse	
A4-A5: Construction and installation stage	Emissions from fuel and energy consumed in the transportation of assets, sub-components and materials to the offshore wind development site and emissions and emissions from fuel	A4: Transportation to site	Workshop	
			Sea freight - Container ships - Tanker ships - Other vessels	Moderately significant; Medium priority; Primary data where possible
			Land freight - Heavy goods vehicles (HGV) - Light goods vehicles (LGV) - Freight train	Moderately significant; Medium priority; Primary data where possible
			Air freight Freight planes	Moderately significant; Medium priority; Primary data where possible

	and energy in the construction of the offshore wind development.		Construction and installation vessels that are used in the transportation of infrastructure assets to site (please refer to A5: Construction and installation at site for a list of relevant vessels).	
		A5: Construction and installation at site	Turbine installation vessel	Highly significant; High priority; Primary data priority
			Foundation installation vessel	Highly significant; High priority; Primary data priority
			Cable laying vessels	Highly significant; High priority; Primary data priority
			Substation installation vessels	Highly significant; High priority; Primary data priority
			Onshore substation installation	Highly significant; High priority; Primary data priority
			Support vessels • Barges • Crew transfer vessels • Remotely operated vehicle	Moderately significant; Medium priority; Primary data where possible
			Other offshore construction and installation vessels	Moderately significant; Medium priority; Primary data where possible
			Onshore plant and construction equipment	Less significant; Low priority; secondary data suitable
			Transport, processing, disposal of construction and installation waste	Moderately significant; Medium priority; Primary data where possible
			Land-use change (if applicable)	Highly significant; High priority; Primary data priority
	Direct emissions and removals from use		Direct, leakage or venting of greenhouse gasses.	Moderately significant; Medium priority; Primary data where possible

B1-B8: Use of development stage	of the infrastructure, emissions from fuel and energy consumption in the infrastructure, and emissions the production of consumable materials used in the infrastructure including maintenance, repair, and replacement activities.	B1: Direct emissions and removals from the use of the infrastructure	• Insulating gas (e.g. SF6, etc.) • Refrigerant gasses • Process gasses	
			Absorption of carbon dioxide or other greenhouse through natural or technical processes • Carbonation of cementitious materials • Technological removals	Less significant; Low priority; secondary data suitable
		B2-B5: Maintenance, repair, replacement, and refurbishment activities for offshore wind development	Maintenance and repair services, including fuel and energy consumed by vessels for maintaining development infrastructure • Turbine inspection and repair • Foundation inspection and repair • Cable inspection and repair • Scour monitoring and management • Substation maintenance and service	Less significant; Low priority; secondary data suitable
			Material procurement for maintenance, repair, and refurbishment: • Finished parts and components. • Maintenance materials.	Moderately significant; Medium priority; Primary data where possible
		B6-B8 Direct use of energy, use of materials, use of water or waste generated by the offshore wind development	Consumption of grid electricity by the OSW development, or assets, during start up or down time.	Less significant; Low priority; secondary data suitable
			Consumption of fuels in backup generators used by the OSW development or assets during start up or down time	Less significant; Low priority; secondary data suitable
			Consumption of mains or utility water by the OSW development, or specific assets during operation.	Less significant; Low priority; secondary data suitable

			Transport, processing and disposal of waste generated by the OSW development during regular operation.	
C1-C5: End of life of infrastructure stage	Emissions from fuel and energy consumed in the deconstruction and demolition of the offshore wind development site, transport of waste to treatment site, processing of sorting of waste before end-of-waste state, disposal and relandscaping activities	C1: Decommissioning and deconstructing OSW development	Decommissioning and deconstruction vessel activities - All offshore and onshore infrastructure assets and components - Other decommissioning activities	Highly significant; High priority; Secondary/scenario data suitable due to time lag
		C2: Transportation of OSW development waste materials to processing facility	Sea freight - Container ships - Tanker ships - Other vessels	Less significant; Low priority; Secondary/scenario data suitable due to time lag
			Land freight - Heavy goods vehicles (HGV) - Light goods vehicles (LGV) - Freight train	Less significant; Low priority; Secondary/scenario data suitable due to time lag
			Air freight Freight planes	Less significant; Low priority; Secondary/scenario data suitable due to time lag
		C3: Waste processing and treatment	Waste processing: - Dismantling of assets components not otherwise assessed in Module C1 - Processing and sorting of recyclable materials up to end-of-waste state - Processing of non-recyclable materials before disposal	Less significant; Low priority; Secondary/scenario data suitable due to time lag

		C4: Waste disposal	Waste disposal activities • Incineration without energy recovery • Landfill	Less significant; Low priority; Secondary/scenario data suitable due to time lag
		C5: Relandscaping	Return of land and seabed to original condition • Vessels and equipment	Less significant; Low priority; Secondary/scenario data suitable due to time lag

Appendix 1, Table 3: Indicative matching of PCF life cycle activities and assets to corporate inventory (Scope 1, 2 and 3) under the operational control approach. Mapping may vary depending on the organisational structure of the developer.

PCF module	Activity and asset	Operational scenario	Corporate scope	GHG Protocol category	Comments
A1-A3	Production of major components (turbines, foundations, substations, cables)	Standard development: Developer purchases assets to build the wind farm.	Scope 3	Cat 2: Capital goods	These are treated as capital assets (CAPEX) on the developer's balance sheet.
A1-A3	Production of spare parts	Operational phase: Purchase of replacement parts during O&M.	Scope 3	Cat 1: Purchased goods & services	Consumables and parts purchased during the operational phase (OPEX) are typically category 1.
A4	Transport to site	Owned transport: Developer owns the transportation vehicles or vessels	Scope 1	Direct emissions	Fuel combustion in assets owned by the reporting company.
A4	Transport to site	Separate transport contract: Developer hires a vessel to transport components from factory to site.	Scope 3	Cat 4: Upstream transportation	The developer pays for transportation services separately from the goods themselves.
A5	Construction and installation	Owned vessel: Developer owns the installation vessel.	Scope 1	Direct emissions	Fuel combustion in assets owned by the reporting company.

A5	Construction and installation	Bareboat charter: Developer leases vessel without crew (takes operational control).	Scope 1	Direct emissions	Under the operational control approach, the lessee reports fuel use as Scope 1.
A5	Construction and installation	Time charter (leased): Developer leases vessel with crew (vessel owner retains control).	Scope 3	Cat 8: Upstream leased assets	This category applies if the asset is leased but not included in Scope 1 or 2.
A5	Construction and installation	Service contract (T&I): Developer hires a contractor to perform installation (no specific vessel lease).	Scope 3	Cat 2: Capital goods	Installation costs are usually capitalised; emissions are part of the "capital good" life cycle.
B1	Use phase (fugitive)	Operational control: SF6 or coolant leaks from substations controlled by developer.	Scope 1	Direct emissions	Fugitive emissions from equipment under the developer's operational control.
B2	Maintenance (O&M)	In-house maintenance: Developer's own technicians and vessels perform maintenance.	Scope 1 & 2	Direct emissions	Fuel for Crew Transfer Vessels (CTVs) (Scope 1) and electricity for O&M bases (Scope 2).
B2	Maintenance (O&M)	Outsourced maintenance: Third-party contractor performs O&M.	Scope 3	Cat 1: Purchased goods & services	Services purchased by the developer (OPEX).

B2	Maintenance (O&M)	Helicopter transport: Helicopter owned/operated by developer.	Scope 1	Direct emissions	Aviation fuel combustion.
B2	Maintenance (O&M)	Helicopter transport: Chartered helicopter flights.	Scope 3	Cat 6: Business travel	If used to transport employees (technicians) to work sites.
B6	Operational energy use	Grid import: Importing power from grid for standby/auxiliary services when wind is calm.	Scope 2	Purchased electricity	Electricity purchased for own consumption.
C1-C4	Decommissioning	End of life: Developer pays for dismantling and disposal.	Scope 3	Cat 5: Waste generated in operations	Emissions associated with the disposal and treatment of waste (if the developer still owns the asset).
C1-C4	Decommissioning	Asset sold prior to EoL: Wind farm sold to another entity before decommissioning.	N/A	Excluded	The liability for decommissioning (and associated emissions) transfers to the new owner.

Appendix 2: OSW product emissions report template

Appendix 2 Table 1: OSW PER template – Assessment details and criteria

Assessment details		Practitioner description	
Practitioner name			
Contact information			
Development name			
Standards applied and statement of conformity			
Name of the independent, third-party verifier (if applicable)			
Level of assurance achieved (if applicable)			
Date of verification (if applicable)			
Footprint period			
Functional unit			
Greenhouse gases considered			
Assessment methodology		Practitioner description	
OSW development description			
Assessment type (operational/design-stage)			
System boundary description			
Cut-off criteria			
Characterisation factor(s) and version(s)			
Methodology			
- Description of key methodological choices			
- Assumptions			
- Exclusions			
- Allocation – Inputs, outputs and recycling			
- Changes since previous assessment (if applicable)			
- Location- or market-based method used			
Calculation methodology by life cycle stage			
- A0: Pre-construction			
- A1-A3: Production and manufacturing			
- A4-A5: Transportation, installation, and construction			
- B1-B7: Operations and maintenance			
- C1-C4: End-of-life			
- D: Optional information outside of the system boundary			

Data management		Practitioner description
Data collection and validation process description		
Data completeness description		
Data sources used		
Data quality assessment description		
Results of uncertainty assessment and sensitivity analysis		
Primary Data Share (PDS) for the assessment (%)		
Limitations of the study		

Appendix 2, Table 2: OSW PER template – Assessment results by functional unit and other selected intensity metrics

Reporting parameter	Unit	Mandatory	Practitioner values	Sensitivity analysis
Installed capacity	MW	Yes		N/A
Assumed capacity factor	%	Yes		42%
Assumed service life, expected year of decommissioning	Years, Year 20XX	Yes		25
Assumed performance conditions	Qualitative description	Yes		N/A
Any assumed actions which will be taken to extend the service life beyond default value	Qualitative description	Yes		N/A
Calculated reference flow output (lifetime electricity delivered to grid at onshore substation)	kWh	Yes		
Total emissions	tCO ₂ e	Yes		N/A
Emissions per declared unit	kgCO ₂ e/kWh	Yes		
Other selected intensity metrics	Unit	Mandatory	Practitioner values	Sensitivity analysis
Emissions intensity per installed capacity	kgCO ₂ e/MW	No		NA
Emissions intensity per unit of investment	kgCO ₂ e/£, \$, €	No		NA
Emissions per operational year	kgCO ₂ e/year	No		NA

Appendix 2, Table 3: OSW PER – Assessment results by life cycle stage (tCO₂e)

Life cycle module	Life cycle stage	Fossil (tCO ₂ e)	Biogenic (tCO ₂ e)	Land-use change (tCO ₂ e)	Total (tCO ₂ e)	Uncertainty lower bound (tCO ₂ e)	Uncertainty upper bound (tCO ₂ e)
Pre-construction stage (A0)	A0: Pre-construction surveys						
Production and manufacturing stage (A1-A3)	A1: Material supply						
	A2: Material transport						
	A3: Manufacturing energy						
	Total (A1-A3)						
Construction stage (A4-A5)	A4: Transportation to site						
	A5: Construction						
	Total (A4-A5)						

Use of infrastructure stage (B1-B7)	B1: Use						
	B2: Maintenance						
	B3: Repair						
	B4: Replacement						
	B5: Refurbishment						
	B6: Operational energy use						
	B7: Operational water use						
	B8: User activities not covered in B1-B7						
	Total (B1-B8)						
End-of-life of infrastructure stage (C1-C5)	C1: Deconstruction and demolition						

	C2: Transport						
	C3: Waste processing						
	C4: Disposal						
	C5: Relandscaping						
	Total (C1-C5)						
Total life cycle emissions (A1-C5)	Total (A1-C5)						
Optional reporting							
Benefits and loads beyond the system boundary (D)	D1: Displacement of materials						
	D2: Displacement of non-renewable electricity						
	Total (D1-D2)						

Appendix 2, Table 4: OSW PER – Assessment results by asset and component

L1: Asset	L2: Component	Fossil (tCO ₂ e)	Biogenic (tCO ₂ e)	Land-use change (tCO ₂ e)	Total (tCO ₂ e)
Wind turbine generators (WTG)	Nacelle and internals				
	Blades, hub, and rotor system				
	Tower				
	Transformer				
	Total (WTG)				
Fixed foundation	Monopile				
	Jacket				
	Transition piece				
	Other fixed foundation technologies				
	Total (fixed foundation)				
Floating foundation	Platform				
	Mooring				
	Anchor				
	Other floating foundation technologies				
	Total (floating foundation)				
Cables	Inter array cables				
	Export cables				
	Total (cables)				
Offshore substation	Transformers				
	Switchgear				

	Facilities				
	Structure				
	Total (offshore substation)				
Operations base	Site buildings				
	Roads				
	Vessel berths				
	Total (operations base)				
Construction and installation (C&I) assets	Turbine installation vessel				
	Foundation installation vessel				
	Substation installation vessel				
	Cable installation vessel				
	Onshore plant and machinery				
	Total (C&I assets)				
Operations and maintenance (O&M assets)	Service operations vessels				
	Crew transfer vessels				
	Helicopters, drones or other				
	Total (O&M assets)				
Other	Practitioner defined category				

Annex 2, Table 5: OSW PER – Assessment results by activity and sub-category (tCO₂e)

L1: Activity	L2: Activity sub-category	Fossil (tCO ₂ e)	Biogenic (tCO ₂ e)	Land-use change (tCO ₂ e)	Total (tCO ₂ e)
Direct emissions and removals	Fugitive emissions				
	Process emissions				
	Total (direct emissions and removals)				
Freight and transportation	Air freight and transportation				
	Rail freight and transportation				
	Road freight and transportation				
	Sea freight and transportation				
	Total (freight and transportation)				
Electricity and fuels	Biofuels life cycle				
	Electricity life cycle				
	Gaseous fuels life cycle				
	Liquid fuels life cycle				
	Solid fuels life cycle				
	Total (electricity and fuels)				
Fully manufactured assets and components	Manufactured assets [see Table 11, L1]				
	Manufactured components [see Table 11, L2]				
	Total (finished goods)				
Manufacturing processes	Coating and galvanising processes				
	Joining and welding processes				

	Material processing				
	Other manufacturing processes				
	Total (manufacturing processes)				
Materials	Aluminium				
	Biogenic materials				
	Carbon fibre				
	Concrete				
	Copper				
	Fibreglass				
	Oils and lubricants				
	Other materials				
	Polymers				
	Steel				
	Total (materials)				
Waste processing and treatment	Incineration				
	Landfill				
	Processing and sorting for recycling and reuse				
	Total (waste processing and treatment)				

Appendix 3: Partnership for Carbon Transparency (PACT) alignment

The WBCSD PACT Pathfinder Framework [6] provides global guidance for the standardisation of Product Carbon Footprint (PCF) calculations and data exchange across value chains. It ensures alignment across differing guidelines and standards, enabling companies to prioritise a consistent approach for their products. By acting as a platform for transparent data reliability metrics, PACT facilitates the exchange of PCFs alongside data reliability Key Performance Indicators (KPIs), such as the Primary Data Share (PDS). Furthermore, it creates the technical infrastructure required for automated data exchange between different software solutions

This guidance is designed to assess the PCF of an infrastructure asset (the OSW development) over its full life cycle. To align this assessment with the PACT Pathfinder Framework, which focuses on the exchange of product-level data (i.e., electricity) through the supply chain, the practitioner must adjust specific assessment criteria.

To produce a PACT-aligned PCF, the practitioner shall apply the following adjustments to the assessment criteria defined in Section 2 of this guidance:

1. **Product definition:** infrastructure to electricity
 - Standard guidance approach: The product system is defined as the offshore wind development (infrastructure). The primary goal is to assess the life cycle impact of the physical assets (turbines, cables, etc.).
 - PACT-aligned approach: The product shall be defined as electricity. The focus shifts to the utility provided by the development. Consequently, the offshore wind development infrastructure is viewed not as the final product, but as the capital goods and attributable processes required to generate that electricity.
2. **System boundary:** cradle-to-grave to cradle-to gate
 - Standard guidance approach: The boundary includes the raw material extraction, construction, operation, and eventual decommissioning of the wind farm. This is considered "cradle-to-grave" because it tracks the infrastructure assets until their end-of-life.
 - PACT-aligned approach: When the product is defined as electricity, the same set of life cycle activities constitutes a cradle-to-gate boundary.
 - The "gate" is defined as the point of interconnection at the onshore substation, where electricity enters the national grid.
 - All activities related to the infrastructure (production, installation, maintenance, and decommissioning) are considered attributable upstream processes required to generate the electricity at the gate.
 - Downstream activities associated with the transmission, distribution, and consumption of the electricity in the national grid are excluded.

3. **Unit of analysis:** functional unit to declared unit
 - Standard guidance approach: Uses a functional unit (1 kWh of electricity) to describe the function of the infrastructure system over its lifetime.
 - PACT-aligned approach: Because the boundary ends at the "gate" (the onshore substation) and does not include the full downstream life cycle of the electricity usage, the unit of analysis shall be referred to as a declared unit.
 - The "declared unit" shall be: '1 kWh of electricity, net, generated and delivered at the PoI with the grid the onshore substation'
4. **Data quality and reporting:** To comply with PACT requirements, the reporting of the PCF must include specific data quality metrics to ensure transparency and technical interoperability:
 - **Primary data share (PDS):** The practitioner shall calculate and report the PDS [see Section 3.8.4], which quantifies the percentage of the footprint derived from specific primary data.
 - **Data quality rating (DQR):** The uncertainty and quality of the dataset shall be exchanged using the PACT-compliant scoring methodology as defined in Section 3.8.
 - **Technical data exchange:** Where the PCF is intended for automated exchange between software solutions, the data structure shall comply with the PACT Pathfinder Framework Data Exchange Protocol (JSON schema). This ensures that the product footprint, validity period, and uncertainty metrics can be machine-read and integrated into customer carbon accounting platforms.

Beyond the specific adjustments detailed above regarding the product definition, system boundary, and unit of analysis, all other assessment criteria defined in this guidance are considered consistent with the requirements of the PACT Pathfinder Framework [6]. Specifically, the allocation rules (Section 2.6), cut-off criteria (Section 2.4), and life cycle impact assessment (LCIA) methods (Section 2.7) align with the underlying GHG Protocol Product Life Cycle Accounting and Reporting Standard and ISO 14067, which serve as normative references for the PACT methodology. As a result, the authors find that no further adjustments are required for a PCF assessment made using the *OSW industry PCF guidance* to achieve a PACT-compliant verification.

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