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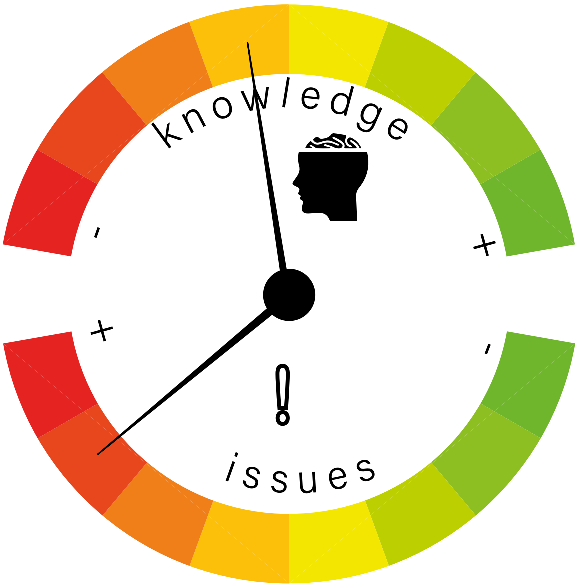
How does Life Cycle Assessment (LCA) evaluate and contribute to the mitigation of the environmental impacts of offshore wind farms?

Bulletin n°13

September 2025

COME3T



Question deemed by the experts to be “a major issue given the need to conduct environmental LCA for offshore wind farm projects while the level of knowledge remains limited in particular given the difficulty in accessing data relating to the supply chain of raw materials and to inventories”.

Please cite this document as follows:
Henry S., Creus J., Nunes M., Rincé L., Rousseaux P. and Schlesinger-Martinat J.
How does Life Cycle Assessment (LCA) evaluate and help to reduce the environmental impacts of offshore wind farms?
COME3T Bulletin n°13
Plouzané: France Energies Marines, 2025, 24 pages
Published: September 2025

Legal deposit upon publication.
Layout: France Energies Marines
Graphic design of figures: Siegrid Design
Translation: Alba traduction

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Introduction

Against the current backdrop of climate change, France aims to achieve carbon neutrality by 2050 and diversify its energy mix. One of the objectives of the energy transition is to decarbonise energy generation, in particular by reducing the share of fossil fuels. 64.7 % of the electricity produced in France in 2023 was already carbon-free and was largely the result of the high proportion of nuclear energy in France's electricity mix [20]. However, in response to the need to diversify the energy mix, the French Climate and Energy law (2019) set a target of reducing the share of nuclear power in its electricity production to 50%, triggering the shutdown of 14 reactors by 2035 [18]. Within this context, the development of offshore wind energy is being encouraged within the French energy mix. While offshore wind energy alone could not meet the whole of the country's electricity demand, it is an energy production method with low greenhouse gas (GHG) emissions.

The Life Cycle Assessment (LCA) of an offshore wind farm assesses the farm's environmental performance by considering all the life cycle stages and by studying various environmental impact categories. In accordance with the principles of sustainable development, a life cycle assessment can be conducted on three aspects: environmental, social and economic impacts. This bulletin will focus only on the environmental life cycle assessment.

The first part of this bulletin sets out the key concepts in environmental life cycle assessment. The standard framework for life cycle assessment and the associated methodological aspects are detailed. In the second part, an example of a life cycle assessment for an offshore wind farm is presented. This is followed by a section focusing on the end-of-life and recycling of materials. Finally, the limitations of this approach are outlined and recommendations are made on the use of life cycle assessment for offshore wind in the final section[1].

In short

Environmental LCA is an assessment tool used to quantify the potential environmental impacts at each stage in a system's life cycle. It is used to identify the life cycle stages that have the greatest impact on the environment in order to (i) evaluate a system's environmental impact, (ii) propose more environmentally-friendly systems by examining the main sources of impact, (iii) provide information on a system's environmental impacts and (iv) guide public policies and businesses in their environmental impact mitigation strategy (low-carbon strategy, etc.). LCA is a standardised method that can be applied to all types of systems, including offshore wind farms.

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[1] To ensure greater clarity, the diagrams presented in this bulletin do not take into account the wide range of foundations and floats that can be used in the design of bottom-fixed and floating offshore wind farms.

Key concepts

What is an environmental Life Cycle Assessment or LCA?

Life cycle assessment (LCA) is an assessment tool used to quantify the **potential environmental impacts** at each stage in a system's life cycle **(Fig. 1)** [10, 21]. LCA is a **standardised method** (ISO 14040 and ISO 14044) [12, 13] based on a two-fold approach: **multi-stage** (addressing the different life cycle stages) and **multi-criteria** (covering multiple environmental impacts). During each pre-identified stage of the life cycle, raw materials and energy (water, oil, gas, ores, fuel, electricity, etc.) are used and are referred to as "inputs" **(Fig. 1, in light blue)**. Conversely, everything that is emitted by the system (material residues, production waste, wastewater, pollution, etc.) is referred to as **outputs** **(Fig. 1, in dark blue)**. By studying the input and output flows, the **potential environmental impacts** of the system can be quantified [21].

These environmental impacts are quantified using different **impact indicators** [7], 16 of which are recommended by the European Union **(Fig. 1, in green)** [22]. Under the "climate change" indicator, the system's contribution to greenhouse gas emissions (in particular CO_2), expressed in $kgCO_2e$, is considered [7].

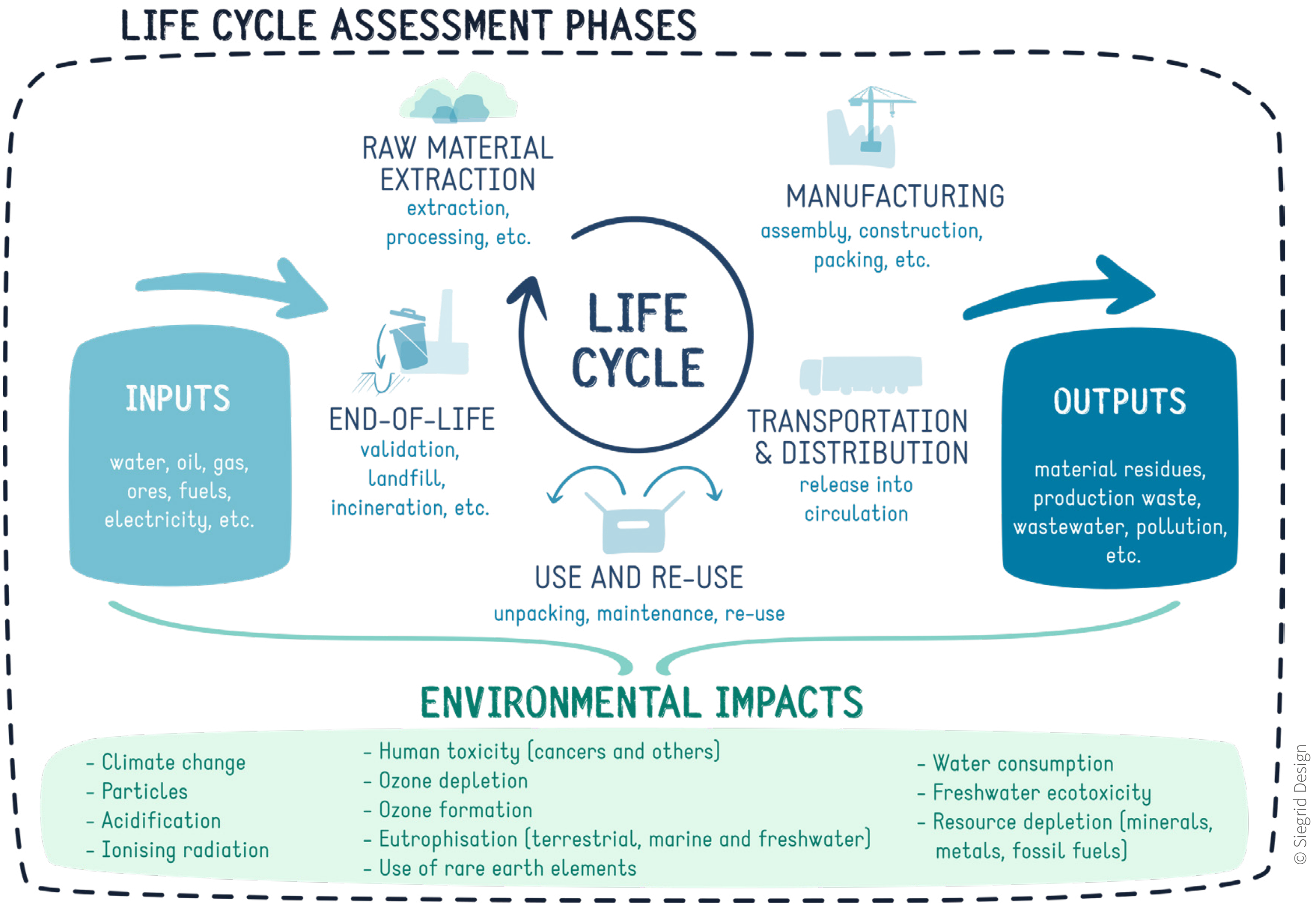

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Fig. 1 *Method for evaluating environmental impacts via a life cycle assessment offering a multi-stage and multi-criteria approach. Based on [1]*

Why conduct an environmental LCA?

The primary advantage of conducting an LCA is that it provides an **overview** of the environmental impacts. By considering all the stages in a system's life cycle and the associated flows (inputs and outputs), LCA highlights the **life cycle stages with the greatest impact** for the environment. Based on this information, **improvement opportunities** can be suggested and it may be possible to **mitigate the environmental impacts** of a given system, but, above all, any instances of **impact transfer** can be identified [1].

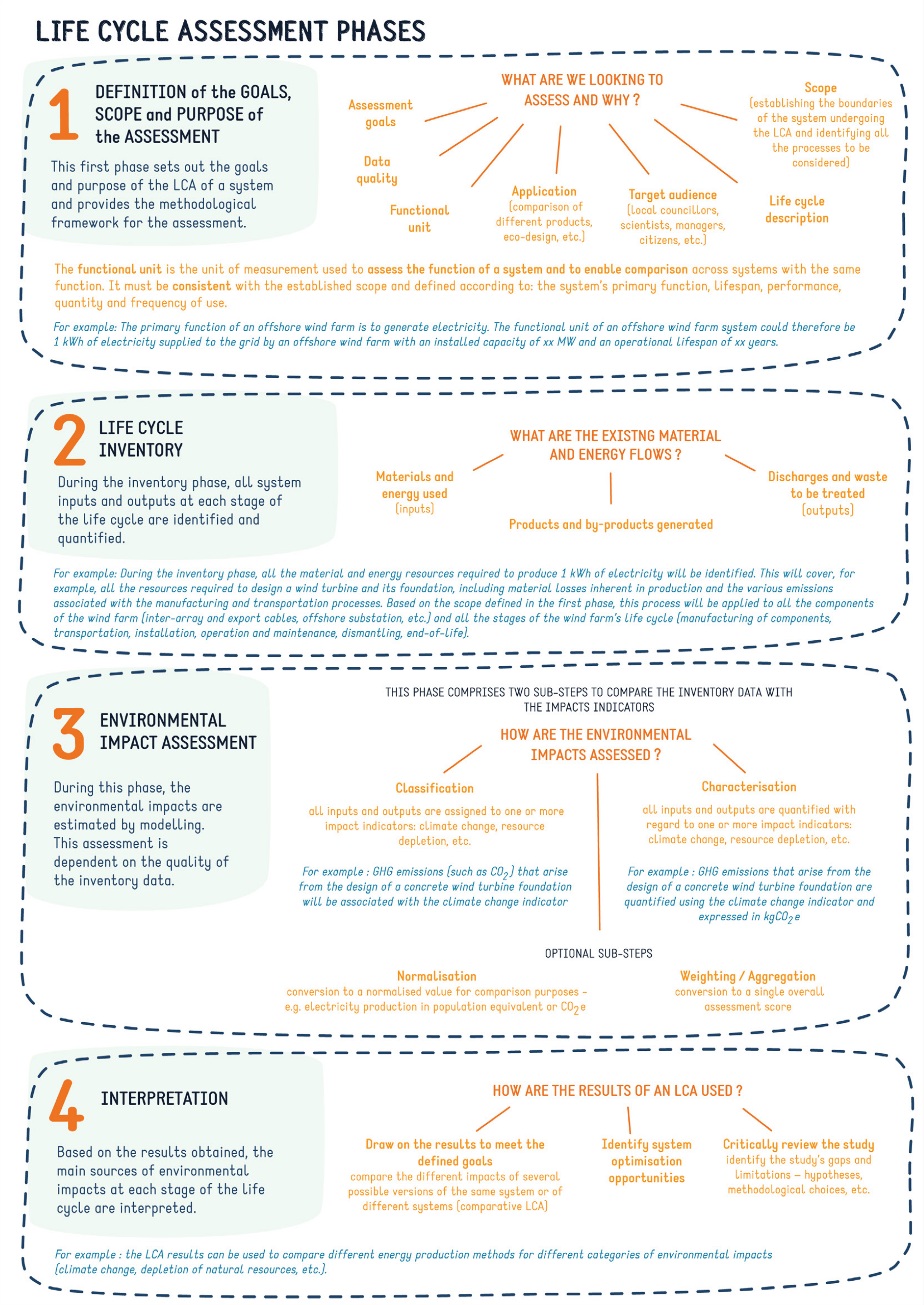
Impact transfer (or pollution transfer) refers to the transfer of environmental impacts from one stage of the life cycle to another or from one environmental impact category to another. For instance, the use of an electric car may reduce the impact of fossil fuel consumption during the usage stage. However, during the manufacturing stage, this same electric car will require more raw material resources, in particular to produce its batteries. In the case of the "electric car" system, there is therefore impact transfer between two life cycle stages (usage to manufacturing) and two environmental categories ("climate change" to "mineral resource depletion").

The other advantage of LCA is that it can be applied to all types of systems: products (electric cars, photovoltaic panels, ballpoint pens, computers, etc.) and services (electronic equipment repairs, wind farm operation, etc.) [1]. LCA can be used to reduce the environmental impact of a system by choosing the most environmentally-friendly options during the **system design stage** [27]. This is **complementary tool** to other environmental impact methods and studies, which take better account of local priorities [1].

How are environmental LCAs conducted?

There is a standardised framework for conducting an LCA that is broken down into four main steps **(Fig. 2)**.

ISO 14040 and 14044 standards recommend carrying out a critical review to ensure that the method and data used are objective and transparent. The interpretation of the results must also be consistent with the objectives and limitations identified. The purpose of the review process is not to verify or validate the framework or the results, nor to pass judgement on how the results are used. It is an objective critical review of the LCA with regard to the framework set out in the ISO standards. This review should be carried out by a panel that is independent from the commissioning party and the practitioner [21, 27].



LIFE CYCLE ASSESSMENT PHASES

1 DEFINITION of the GOALS, SCOPE and PURPOSE of the ASSESSMENT

This first phase sets out the goals and purpose of the LCA of a system and provides the methodological framework for the assessment.

WHAT ARE WE LOOKING TO ASSESS AND WHY ?

- **Assessment goals**
- **Data quality**
- **Functional unit**
- **Application** (comparison of different products, eco-design, etc.)
- **Target audience** (local councillors, scientists, managers, citizens, etc.)
- **Life cycle description**
- **Scope** (establishing the boundaries of the system undergoing the LCA and identifying all the processes to be considered)

The **functional unit** is the unit of measurement used to **assess the function of a system and to enable comparison** across systems with the same function. It must be **consistent** with the established scope and defined according to: the system's primary function, lifespan, performance, quantity and frequency of use.

For example: The primary function of an offshore wind farm is to generate electricity. The functional unit of an offshore wind farm system could therefore be 1 kWh of electricity supplied to the grid by an offshore wind farm with an installed capacity of xx MW and an operational lifespan of xx years.

2 LIFE CYCLE INVENTORY

During the inventory phase, all system inputs and outputs at each stage of the life cycle are identified and quantified.

WHAT ARE THE EXISTNG MATERIAL AND ENERGY FLOWS ?

- **Materials and energy used** (inputs)
- **Products and by-products generated**
- **Discharges and waste to be treated** (outputs)

For example: During the inventory phase, all the material and energy resources required to produce 1 kWh of electricity will be identified. This will cover, for example, all the resources required to design a wind turbine and its foundation, including material losses inherent in production and the various emissions associated with the manufacturing and transportation processes. Based on the scope defined in the first phase, this process will be applied to all the components of the wind farm (inter-array and export cables, offshore substation, etc.) and all the stages of the wind farm's life cycle (manufacturing of components, transportation, installation, operation and maintenance, dismantling, end-of-life).

3 ENVIRONMENTAL IMPACT ASSESSMENT

During this phase, the environmental impacts are estimated by modelling. This assessment is dependent on the quality of the inventory data.

THIS PHASE COMPRISES TWO SUB-STEPS TO COMPARE THE INVENTORY DATA WITH THE IMPACTS INDICATORS

HOW ARE THE ENVIRONMENTAL IMPACTS ASSESSED ?

Classification

all inputs and outputs are assigned to one or more impact indicators: climate change, resource depletion, etc.

For example : GHG emissions (such as CO_2) that arise from the design of a concrete wind turbine foundation will be associated with the climate change indicator

Characterisation

all inputs and outputs are quantified with regard to one or more impact indicators: climate change, resource depletion, etc.

For example : GHG emissions that arise from the design of a concrete wind turbine foundation are quantified using the climate change indicator and expressed in $kgCO_2e$

OPTIONAL SUB-STEPS

Normalisation

conversion to a normalised value for comparison purposes – e.g. electricity production in population equivalent or CO_2e

Weighting / Aggregation

conversion to a single overall assessment score

4 INTERPRETATION

Based on the results obtained, the main sources of environmental impacts at each stage of the life cycle are interpreted.

HOW ARE THE RESULTS OF AN LCA USED ?

- **Draw on the results to meet the defined goals** compare the different impacts of several possible versions of the same system or of different systems (comparative LCA)
- **Identify system optimisation opportunities**
- **Critically review the study** identify the study's gaps and limitations – hypotheses, methodological choices, etc.

For example : the LCA results can be used to compare different energy production methods for different categories of environmental impacts (climate change, depletion of natural resources, etc.).

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Fig. 2 *Representation of the four phases involved in carrying out a life cycle assessment of a system in accordance with ISO 14040 and 14044, based on [12, 13]*

What is the purpose of an environmental LCA?

The main purposes of an environmental LCA are to:

- **Assess a product from an environmental perspective**

The LCA analyses all the stages in a system's life cycle in order to assess the large-scale environmental impacts and to highlight the stage(s) that potentially generate the highest environmental impacts [1], as well as to identify and quantify any impact transfer with a view to mitigating or even eliminating these impacts. Measures designed to reduce these impacts can thus be implemented (reducing or substituting the use of certain resources for resources with lower impact, etc.) [21].

- **Eco-design systems**

Eco-design involves designing systems in a way that reduces their environmental footprint at each stage in the life cycle, in particular by focusing on the main sources of impact. It helps to develop more environmentally-friendly systems, by focusing on reducing the consumption of natural resources and mitigating environmental impacts throughout the life cycle. It is a preventive approach, which can be essential when used for commercial, environmental and strategic purposes (supply security, etc.) [1].

- **Inform and communicate**

Providing information and communicating the results of the LCA are an integral part of the standards (ISO 14040 and 14044), which specify the need to define the objectives and main reasons for conducting an LCA. By communicating about the potential environmental impacts and improving the understanding of these impacts, the LCA raises awareness and provides information on the environmental issues associated with the system’s life cycle [1]. The results can also be used to define environmental certification systems, such as ecolabels, to help consumers identify the most environmentally-friendly products [21].

- **Support decision-making**

Finally, concrete use can be made of the results to feed into and guide public policies, such as France’s low-carbon strategy or companies’ environmental strategies [1].

LCA to assess the environmental impacts of offshore wind farms

In this section, the four main phases of the life cycle assessment of an offshore wind farm are presented, based on the results of two studies and projects:

- The "Vestas" study, which proposes an environmental LCA of electricity production from a 990 MW offshore wind farm composed of Vestas V236 turbines with a unit capacity of 15 MW on a bottom-fixed monopile foundation [5];
- The LIF-OWI project, whose main objective was to develop a methodological framework for environmental and societal LCA applied to offshore wind energy [19].

While the results of the Vestas study cannot be directly transposed to French offshore wind farms and their grid connections, they do provide information on the material breakdown for each life cycle stage and for each offshore wind farm component (foundation, tower, turbine blade, etc.).

Definition of the goals, scope and purpose of the assessment

Every offshore wind farm has its own specificities in relation to:

- The offshore wind farm technology and design: number, type and size of wind turbines, foundations or floats, direct or alternating current connection, installation technique, lifespan, etc.;
- The farm siting: water depth, distance from the coast, wind speed, etc.

The **results will therefore be specific to the technological choices made** for the offshore wind farm and to the **local geographical characteristics**. Furthermore, every LCA study comprises its own methodological specificities and assumptions, which will also affect the results [1].

The different stages in the **life cycle** of an offshore wind farm and its grid connection **(Fig. 3)** used in this bulletin are taken from the LIF-OWI project, which proposes an adapted version of the five stages set out in ISO 14040 and 14044 standards. The scope of the study, the function and the functional unit are closely linked and may vary depending on the objectives of the study. The table below provides a few examples of configurations for an environmental LCA for offshore wind energy **(Tab. 1)**.

Scope of the study	Function	Functional unit
Wind turbine	Electricity production	1 kWh of electricity produced by a turbine
Wind farm	Electricity production	1 kWh of electricity produced by a xx MW wind farm
Wind farm + grid connection	Electricity production and transmission to the grid	1 kWh of electricity transmitted to the grid by a xx MW wind farm

Tab. 1 *Example of scope, function and functional unit configurations to conduct an environmental LCA of an offshore wind farm. Based on [1]*

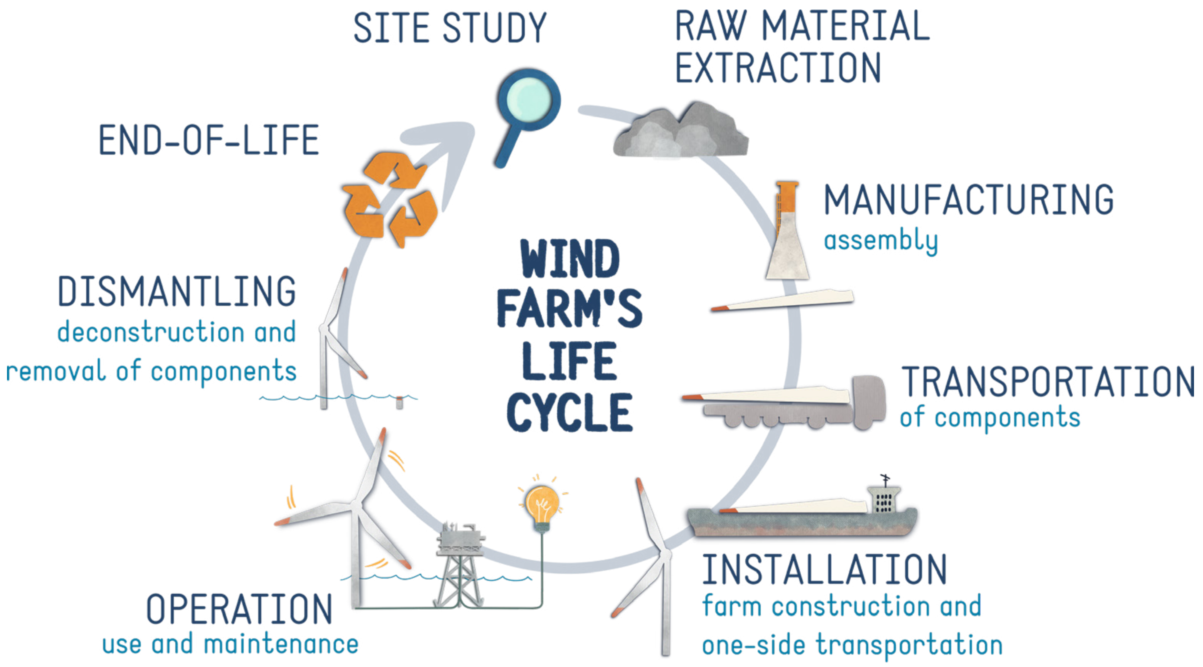

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Fig. 3 *Stages in the life cycle of an offshore wind farm. Based on the results of the LIF-OWI project [19]*

Inventory

To conduct an environmental LCA, all of the system's inputs and outputs must be identified and quantified. This is achieved by carrying out an inventory to identify and quantify all the materials and energy sources required for all the components of the offshore wind farm (turbines, foundations, etc.) at each stage of the life cycle (from the extraction of raw materials to dismantling).

The inventory of inputs (materials and energy excluding spare parts and associated logistics – transport, maintenance, etc.) in the Vestas study is presented, as an example, in **Figure 4** [5]. While the types of inputs and outputs are generally similar from one farm to another, **each inventory is specific and can vary greatly depending on the characteristics of the wind farm:** foundation type, turbine size, water depth, etc.

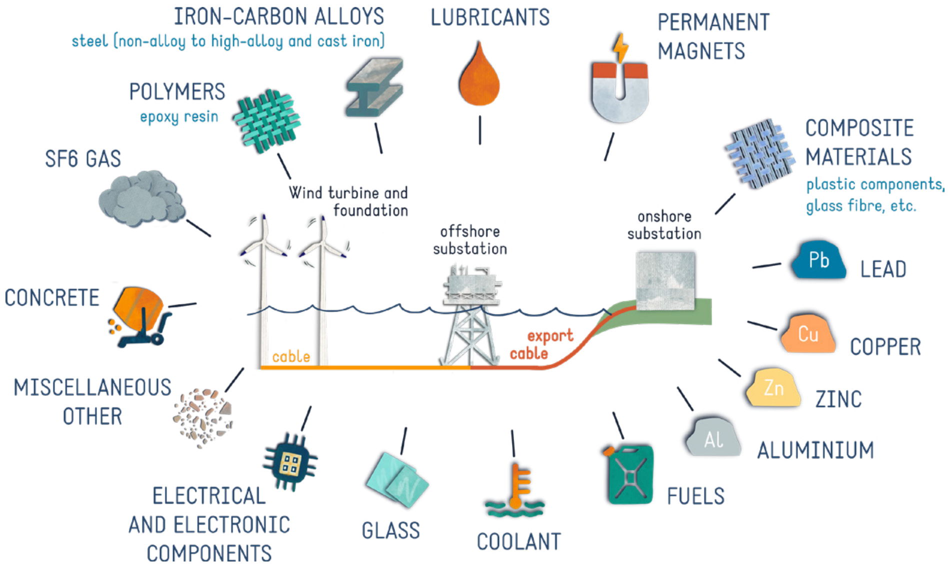

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Fig. 4 *Overview of materials used throughout the life cycle of the 990 MW bottom-fixed monopile foundation offshore wind farm in the North Sea and its grid connection. SF6 gas is an artificial gas used as an insulating gas in high-voltage electrical equipment. Based on the results of the Vestas study [5]*

By providing quantified data, the inventory offers insight into the quantities of materials used for each component (and sub-component) of an offshore wind farm and its grid connection **(Fig. 5)** [1, 5].

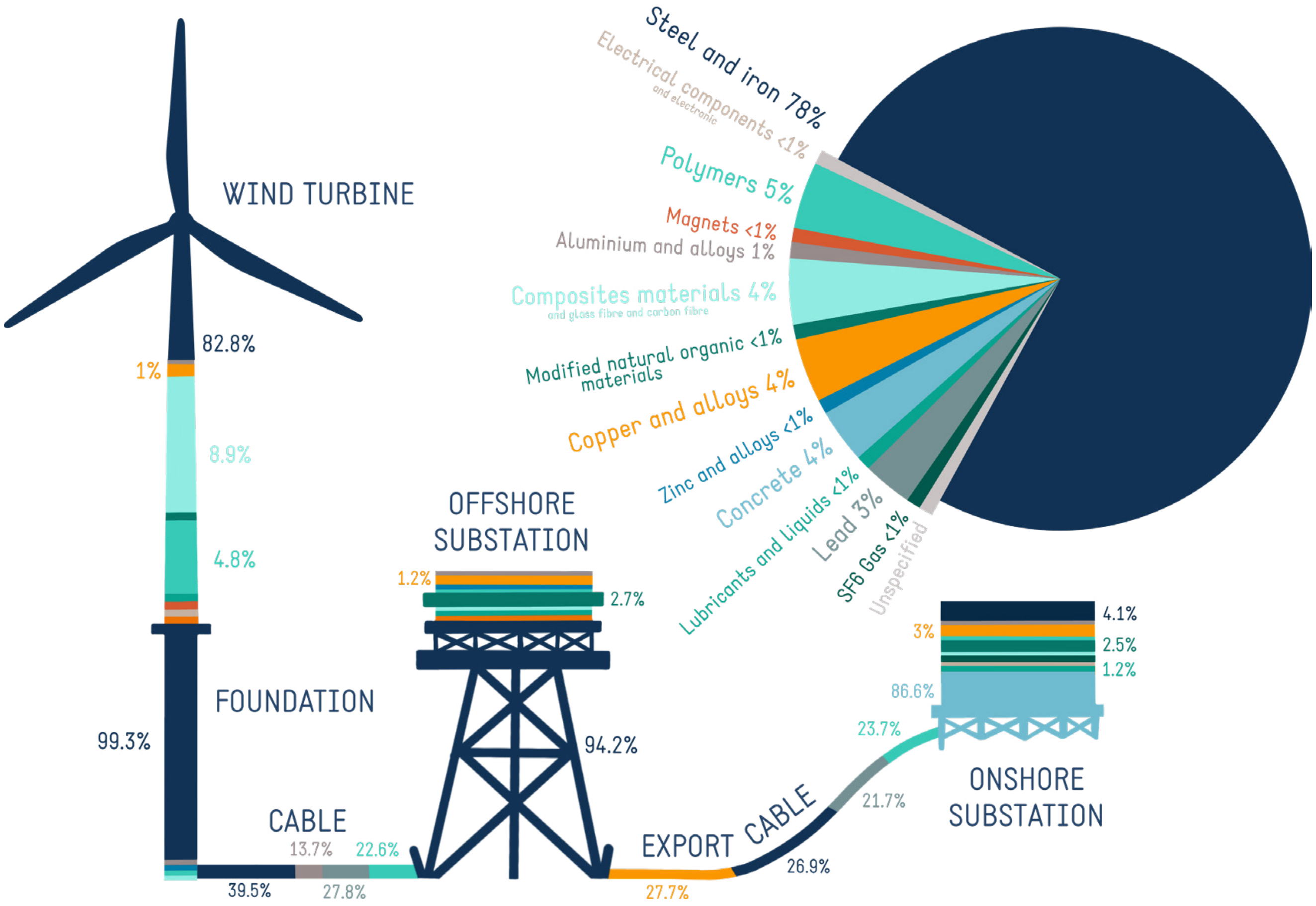

Fig. 5 *Example of the material breakdown by mass for the components and sub-components of the 990 MW bottom-fixed offshore wind farm (monopile foundation) and its grid connection as presented in the Vestas study. On the left is the material breakdown for each component (e.g. for the wind turbine, the material breakdown is provided for the wind turbine as a whole, and not for each of the sub-components – blades, nacelle, etc.); on the right, the overall material breakdown by mass is presented. Based on the results of the Vestas study [5]*

Rare-earth elements in the permanent magnets of wind turbines

Despite what their name suggests, rare-earth elements (REE) are relatively abundant in the Earth's crust. They earned their name in the late 18th century due to the difficulty involved in extracting the ores at a time when it was believed they were present only in small quantities [2, 6, 10]. Rare-earth elements are a group of 17 metallic elements with similar chemical properties and a wide range of applications: volume/weight reduction for electric motors and generators, batteries, metallurgical alloys, medical imaging, etc. [2]. REEs are used extensively in new technologies (a smartphone contains approximately 3 g of REEs [6]) and are used in the permanent magnets of certain wind turbine generators to (i) improve electricity conversion yields, (ii) reduce structure weight and maintenance requirements, and (iii) extend the system’s lifespan. Permanent magnets typically contain three REEs (for 1 kg of permanent magnet): 29-32 % of neodymium, 3-6 % of dysprosium, <1 % of praseodymium [16]. On average, depending on the technology, the generators (which convert the wind's mechanical energy into electricity) used on wind farms contain 150 to 650 kg of permanent magnets per MW of installed capacity [16].

Assessing environmental impacts

The environmental impact assessment outlines the impact categories selected and evaluated as part of the LCA. During this phase of the LCA, the impact modelling tools and the limitations associated with methodological choices and data access conditions are also presented. In France, it is mandatory to conduct an LCA for an offshore wind farm and its grid connection as part of the environmental impact assessment process, even if it is not necessarily publicly released.

In the case of the Vestas study, the results of which are presented below, the modelling method used is the LCA method developed by the Centre for Environmental Science, Leiden University, and which is incorporated into the Sphera LCA for Experts software tool [5].

Among the impact indicators used in this study, we will focus on "climate change" and “mineral and metal resource depletion" [5].

For each indicator, the results presented below are those of the Vestas study and summarise the potential environmental impacts of the offshore wind farm and its grid connection estimated for the entire life cycle per KWh of electricity delivered to the grid.

- **“Climate change” indicator**

  This indicator assesses the potential impacts on climate change based on the warming of the Earth's surface temperature due to an increase in the concentration of greenhouse gases (GHGs) in the atmosphere. Impacts are measured in grams of CO_2 equivalent (gCO_2e) emitted. The offshore wind farm studied emits 7 gCO_2e per kWh of electricity produced. The manufacturing stage dominates the life cycle. The majority of these emissions are associated with the manufacture of the wind turbine's foundations and tower (25% and 13% respectively). The end-of-life phase also makes a significant but negative contribution to the final result (-22%) associated with avoided metal production (iron, steel, copper and aluminium in particular) thanks to recycling **(Fig. 6)**.

What does 7 gCO_2e/kWh equate to?

The contribution to global warming of the offshore wind farm studied here is similar to that of a nuclear power station (6 gCO_2e/kWh) [3]. These emission factors vary according to the characteristics of the offshore wind farm (number of turbines, unit capacity, operational lifetime, etc.). The GHG emissions of French offshore wind farms vary between 14 and 18 gCO_2 e/kWh [17]. This is lower than the GHG emissions associated with photovoltaic panels (43.9 gCO_2e/kWh), a gas-fired power plant (418 gCO_2e/kWh) or a coal-fired power plant (1058 gCO_2e/kWh) [3].

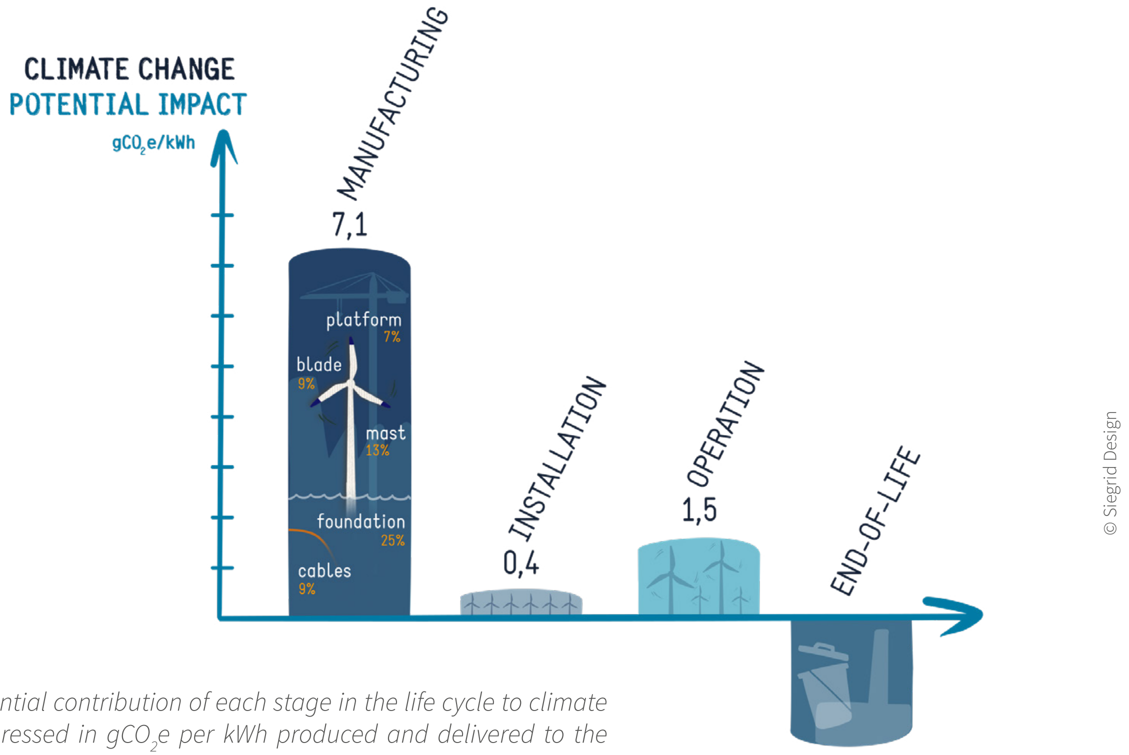

Fig. 6 *Potential contribution of each stage in the life cycle to climate change expressed in gCO_2e per kWh produced and delivered to the grid. The manufacturing stage dominates the life cycle in terms of emissions, primarily associated with the production of the foundations (25%), tower (13%), blades (9%), cables (9%) and nacelle (7%). Based on the results of the Vestas study [5]*

- **“Mineral and metal resource depletion” indicator**

  This indicator provides information on the scarcity (or potential depletion) of non-energetic natural resources used during the life cycle: iron ores, aluminium, precious metals, etc. Expressed in mass of antimony equivalents (kg.eq.Sb), this indicator accounts for the ultimate ore reserves (and not the economically feasible reserves). Once again, the manufacturing stage dominates the life cycle in terms of impacts. This is primarily driven by use of lead (55%), silver (21%), copper (10%), zinc (7%), and gold (5%), mainly from cables. Since the study assumes that the cables will remain in the seabed and not be removed at the end of its useful life, their contribution to the end-of-life metal recycling stage is relatively minor [5].

What is antimony?

Antimony is a semi-metal considered to be exhaustible at human scale. The associated indicator expresses the quantity of rare materials (metals, ores, etc.) or energy (gas, oil, etc.) consumed during the various stages of the life cycle. If the value obtained is greater than 1 (the value assigned to antimony by convention), the resource consumed is rarer than antimony. This is the case, for instance, of gold, estimated at 52 kg. eq.Sb (compared with 0.0000000524 kg. eq.Sb for iron).

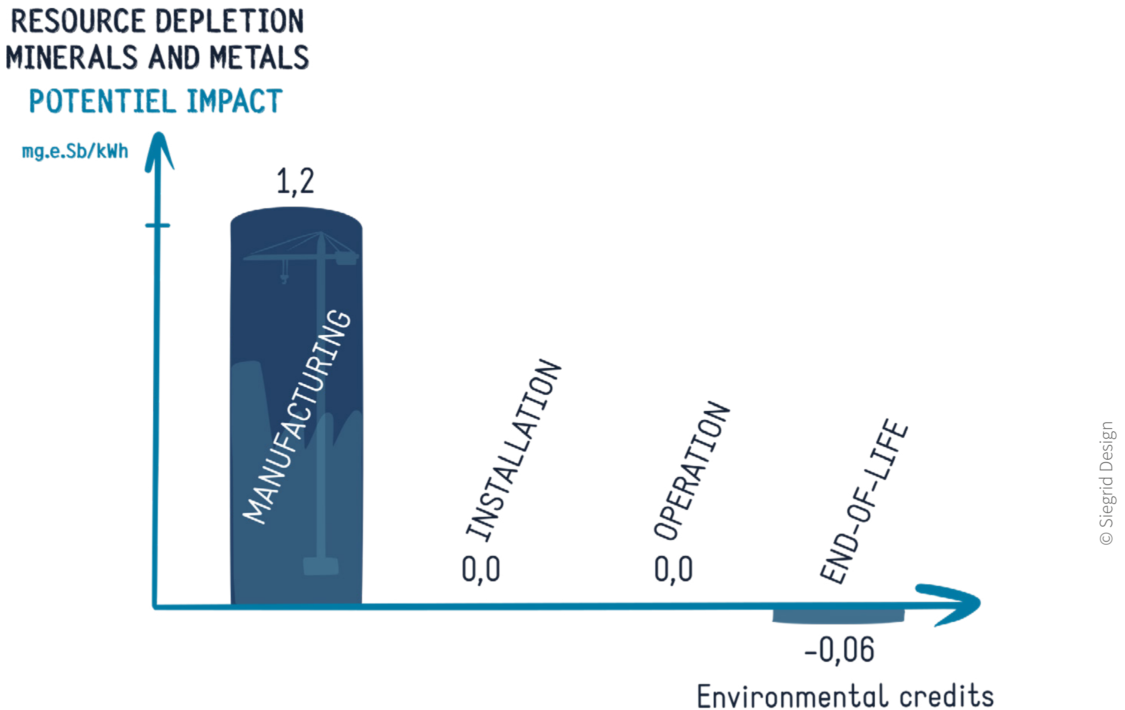

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Fig. 7 *Potential contribution of each stage in the life cycle to mineral and metal resource depletion expressed in mg.eq.Sb/kWh produced and delivered to the grid.*

Focus on material recovery

The reliability of the results of an LCA is dependent on the quality of the inventory data and the indicators used. To guarantee reliable results, it is important to carry out a sensitivity analysis and robustness assessment, as well as an independent critical review. The robustness of the estimation of end-of-life environmental impacts may be hampered by: knowledge and data gaps, difficulties in calculating potential impacts, and assumptions on the use of recycled materials in manufacturing and the extent to which materials are recycled [1].

Materials, products and structures that no longer fulfil the function for which they were produced are considered to be "waste". Their recovery at the end of their useful life is therefore an important issue. While recycling is often encouraged, it is not always virtuous for the environment if we consider the entire life cycle and the associated environmental impacts.

Various waste recovery streams exist:

- Energy recovery: non-recyclable materials are incinerated
- Material recovery: end-of-life materials are recovered, thereby reducing resource consumption. There are several forms of material recovery. **Reuse** involves reusing the material without changing its initial use. **Repurposing** involves using the material again, but not for its original purpose. Finally, with **recycling**, the raw material of an object is used to manufacture a new object [8].

• The specific case of end-of-life recovery for offshore wind farms

Decommissioning is a regulatory requirement whereby offshore wind farm and grid developers must remove the infrastructure. Depending on the wind farm, decommissioning may involve complete removal (e.g. the Fécamp wind farm and its gravity foundations) or partial removal (e.g. the Courseulles wind farm, where only the upper part of the foundations – from the seabed to the water surface – will be dismantled). If the preliminary environmental study shows that removal of the cables would have negative effects that exceed those of leaving them in place, the French State may grant an exemption [15].

Energy recovery may be possible for certain materials from offshore wind farms, such as composite blades. This material has a high calorific value (around 15,000 to 25,000 kJ/kg of ground composite, compared with 13,000 to 18,000 kJ/kg for wood, for example) [4].

Material recovery is generally the preferred method and various examples of this practice have been documented:

- **Reuse:**

Following the dismantling of two wind turbines at the Blyth offshore wind farm in England, some turbine parts were kept for reuse as spare parts [9].

- **Repurposing:**

Various initiatives and research projects have been launched to repurpose composite materials. In the city of Aalborg (Denmark), for instance, the RE-Wind project repurposed pieces of wind turbine blade into bike shelters [25]. Other initiatives aim to repurpose wind turbine blades into geotechnical structural elements – foundations, retaining walls, etc. [11].

- **End-of-life recycling:**

End-of-life recycling is considered separately from the use of recycled materials during the construction phase. For many of the materials used on offshore wind farms, such as copper and aluminium, the recycling methods are well known and the associated streams are well established. However, in the case of certain materials such as concrete or steel, recycling is more complex due to marine conditions. Onshore concrete [24] and steel are often recycled. This is not the case for chlorinated concrete or steel corroded by seawater, for which other issues are involved in recycling. In some cases, leaving the foundations (concrete and steel), colonised by marine species, in place may be an acceptable solution and have less impact on the environment than decontamination followed by recycling. Furthermore, in the case of composite materials (epoxy, fibreglass, etc.), recycling processes are not yet fully optimised [1].

- **Use of recycled materials:**

Recycling can also be addressed from the point of view of recycled material input, which will be taken into account in the LCA during the manufacturing stage. The possibility of using recycled content varies according to the materials and requires the recycled material to be of equivalent quality to the default material. In the case of mineral and metal resources such as copper, for example, the use of recycled materials greatly reduces the impact of the manufacturing stage (particularly in terms of GHG emissions) and significantly affects the results of an LCA. While recycling processes can have major environmental impacts (notably an increase in the results of indicators for atmospheric pollution, acidification or eutrophication of aquatic environments), these impacts are generally lower than the impacts generated by the manufacture of a virgin material, particularly in the case of mineral and metal resources. For certain materials, particularly those derived from an exhaustible resource, the use of recycled materials is a necessity. This is the case, for example, of gold, silver and copper, which are highly critical, or of sand and water for concrete. Recycling therefore helps to preserve resources and avoid exploiting deposits that are potentially more difficult to access, resulting in significant economic, social and environmental costs [1]. In fact, some developers are capable of manufacturing recyclable blades, such as the Siemens Gamesa models [26] used for the Courseulles-sur-mer offshore wind farm [23].

Limitations

LCA is a useful tool for identifying the potential impacts of a system and attempting to reduce these impacts, particularly through eco-design. However, as with any modelling exercise, environmental LCAs have their limitations:

- **Uncertainties and data gaps:**

Despite the existence of specific databases dedicated to LCA (such as Ecoinvent, Exiobase, Impacts or ELCD at European level), access to all the data required for LCA remains complicated, particularly in the case of industrial data (often confidential) or data that has already been aggregated. The lack of available data means that assumptions and simplifications have to be made, which can exacerbate the uncertainties associated with the use of LCA [21].

- **Robustness of assumptions and methodological choices:**

For every environmental LCA, a presentation of the method used must be provided, detailing all the choices made and assumptions made for the analysis (software used, indicators chosen, etc.) [1]. An LCA must consider the complexity of the systems studied and requires large amounts of data [1, 21]. The use of the results of an LCA, even if it has undergone a critical review, is therefore limited by the assumptions and methodological choices made.

- **Limited consideration of the spatial dimension of impacts and biodiversity:**

Environmental LCA is a good tool for estimating potential "global" impacts. However, it is less effective in assessing potential small-scale impacts (local impacts). Given the lack of scientifically robust indicators, it does not yet consider all the potentially identified environmental impacts on biodiversity. For instance, it does not consider the effects of noise or light pollution [1, 5]. Furthermore, potential impacts are more difficult to model at certain stages in the life cycle than others. This is the case of the end-of-life stage, for which the lack of precise knowledge or clearly defined streams makes it difficult to assess the potential impacts [1].

An LCA generally compares the system with a reference situation (another equivalent system, a similar but eco-designed system, etc.). When applied to energy production, it can be used to compare different production technologies (wind farms versus nuclear power, for example, or bottom-fixed versus floating wind farms). The environmental LCA’s multi-criteria and multi-stage approach does not override the need for a critical analysis of the results for decision-making purposes [14].

Conclusion

Environmental LCA is used to study the potential environmental impacts of a system as a whole. By considering all the stages in the life cycle of a system, it can be used to:

- Assess a system from an environmental perspective by identifying the stages that have the greatest impact on the environment and potential impact transfers, whatever their nature (from one life cycle stage to another, from one impact category to another).
- Support decision-making, in particular by providing useful information for comparing two systems with the same purpose (two energy production methods with the same functional unit, for instance).
- Eco-design systems by encouraging the input of recycled materials or the replacement of certain materials with others that have lower impact at different stages in the life cycle.

Environmental LCA is a standardised tool (ISO 14040 and 14044). While the interpretation of its results should consider the limitations described in this bulletin (framework of the study, assumptions and methodological choices made, data quality and accessibility, etc.), it remains the best tool for assessing a system's environmental impacts throughout its life cycle. To mitigate the environmental impacts of energy production, the use of more environmentally-friendly materials and the introduction of energy-saving measures should be encouraged.

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COME3T

COME3T is an initiative that brings together a panel of national and regional stakeholders (universities, industrial firms, consultants, regions, State services, etc.) within a steering committee that puts forward questions, based on public concerns and key environmental and socio-economic issues identified by the stakeholders, to committees of neutral, independent experts. For each topic, a committee of experts is established following a call for applications and provides information, summaries and recommendations on the environmental and socio-economic issues associated with offshore renewable energy.

https://www.france-energies-marines.org/projets/come3t/

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France Energies Marines is a research and innovation centre devoted to offshore wind energy with a recognised industrial, economic and societal impact in France and internationally. Its mission is to overcome the barriers facing the offshore wind sector. Supported by the French State, the Institute, driven by a 90-strong multi-disciplinary team and a network of international experts, underpinned by one-of-a-kind infrastructures, conducts excellence-oriented multi-partner research projects. The results of these projects are transferred to the sector in the form of research and expertise services, operating licences, know-how transfer and participation in expert committees and networks. Two of its four key research departments are devoted to the environmental and social integration of offshore wind farms.

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ISSN 2743-6942

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