Review of Existing Tools

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List of Acronyms

Acronym	Full term	Description
AA	Appropriate Assessment	Assessment required under the Habitats Directive
CIA	Cumulative Impact Assessment	Assessment of the combined effects of multiple projects and activities over space and time
EIA	Environmental Impact Assessment	Project-level assessment required under EU legislation
Espoo Convention	Convention on Environmental Impact Assessment in a Transboundary Context	International convention requiring assessment and consultation where projects or plans may have cross-border environmental impacts
GES	Good Environmental Status	Environmental objective defined under the Marine Strategy Framework Directive
LCA	Life Cycle Assessment	Analytical method used to assess environmental impacts across the full life cycle of a product, system, or project
MSFD	Marine Strategy Framework Directive	EU Directive (2008/56/EC) establishing a framework for achieving Good Environmental Status of marine waters through ecosystem-based management
MSP	Marine Spatial Planning	Process of analysing and allocating marine space to balance ecological, economic, and social objectives
Nature 2000	European ecological network of protected areas	Network of protected sites designated under the Habitats and Birds Directives
OWF	Offshore Wind Farm	Wind energy installations located in marine environments, including associated infrastructure
SEA	Strategic Environmental Assessment	Assessment applied to plans and programmes, regulated through the SEA Directive
SIA	Social Impact Assessment	Assessment of social and socio-economic impacts
WFD	Water Framework Directive	EU directive (2000/60/EC) requiring protection and improvement of water bodies and prevention of deterioration in ecological and chemical status

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Keywords list

- Environmental sciences
- Environmental Impact Assessment (EIA)
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Executive Summary and Conclusions

1.1. Purpose and scope

This deliverable (D6.1) provides a decision-oriented review of tools used to assess and support sustainability in offshore wind (OWF) planning and design. It contributes to the SUSTAINOW project by clarifying existing tools, their function in practice and their sustainability scope.

The analysis combines:

- A conceptual framing of decision-making in OWF development.
- A mapping of assessment tools used in general practice and across selected countries (Estonia, Portugal, Spain, and Denmark).
- A systematic assessment of the sustainability scope of these tools.
- A review of related tools under development in European research and innovation projects.

The objective is to identify how and to what extent existing tools support sustainability outcomes, and to provide a structured basis for identifying gaps and opportunities for improved decision support in subsequent work packages.

1.2. Conceptual framing: OWF phases and decision-making

The report adopts a life-cycle perspective structured around seven phases: site selection, tendering, project design, construction, operation, repowering, and decommissioning[1]. Across these phases, decision-making is characterised by varying:

- Levels of strategic influence.
- Degrees of reversibility.
- Capacity to affect long-term sustainability outcomes.

Early phases—particularly site selection and tendering—are identified as having the highest leverage, as they define key spatial, technical, and institutional boundary conditions. Later phases are more constrained but remain important for implementation, optimisation, and adaptive management. Repowering and decommissioning are highlighted as increasingly

[1] The seven phases are used here as they are aligned with the project description. There are substantial differences across national systems in EU, and as an example, In Estonia, licensing, superficies agreements, and environmental impact assessment (EIA) procedures are centrally administered and do not align neatly with a strictly tender-based phase.

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relevant phases, particularly in relation to circularity and long-term environmental performance.

This life-cycle and decision-oriented framework is used throughout the report to structure the analysis of tools and their contribution to sustainability.

1.3. Assessment tools in OWF practice

The report identifies and analyses a set of core assessment tools applied in OWF planning and development. An overview of these tools is provided in table 1:

<table>
<tr><th>Category</th><th>Tool name and abbreviation</th><th colspan="4">Sections in D6.1</th></tr>
<tr><td>Holistic assessment tools</td><td>Environmental Impact assessments (EIA)
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Assessment under the water framework directive (WFD) and marine spatial framework directive (MSFD)
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<tr><td>Additional technical or analytical tools for OWF development</td><td>Examples: Modelling tools, GIS-based tools, economic analyses, feasibility studies.</td><td></td><td></td><td></td></tr>
<tr><td>Upcoming tools under development in research projects</td><td>Examples: Data spaces, multi-use platforms, digital twins</td><td></td><td></td><td></td><td>6 Research</td></tr>
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Table 1 Overview of tools analysed in the deliverable.

These tools operate within a multi-level regulatory framework, primarily defined by EU directives and international conventions, complemented by national implementation practices.

A key finding is that SEA and EIA constitute the backbone of assessment practice, while several other assessments—particularly those related to biodiversity, water, and marine ecosystems—are typically embedded within SEA and EIA processes rather than applied independently.

OWFs are treated under the EIA Directive as integrated projects encompassing turbines, cables, and onshore infrastructure across Annex I and II categories, reflecting a holistic "centre

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of gravity" approach that aligns with SUSTAINOW's focus on system-level assessment tools. However, while this integrated approach is contemplated in the EIA Directive, its transfer into national legal frameworks and permitting practices may vary between countries.

The analysis also confirms that EU directives are largely procedural in nature, requiring the identification and assessment of impacts but not prescribing specific methods or data. As a result, there is considerable variation in implementation across countries and projects.

Cross-country comparison indicates both convergence and variation:

- A shared reliance on SEA and EIA across all cases.
- Differences in the sequencing and integration of tools.
- Limited and uneven application of LCA and SIA.
- Variable treatment of cumulative and transboundary effects.

1.4. Sustainability scope of assessment tools

The sustainability scope of the identified tools is analysed using two complementary perspectives:

1. Coverage of sustainability factors, based on the environmental concept embedded in SEA and EIA legislation.
2. Contribution to mitigation and enhancement, reflecting how tools influence sustainability outcomes.

Coverage of sustainability factors

The analysis shows that existing tools collectively address a broad range of environmental, social, and socio-economic factors, including biodiversity, climate, water, human health, and socio-economic activities.

This analytical framework builds on the environmental concept defined in EU SEA and EIA directives and further operationalised in recent methodological developments (e.g. Kørnøv et al., 2023; Ravn-Boess et al., 2026), including its implementation in the Danish Environmental Assessment (EA) tool. This concept reflects an integrated understanding of sustainability, spanning environmental, social, and socio-economic dimensions. Using this definition as a basis ensures that the analysis is anchored in existing regulatory practice and directly relevant to how offshore wind development is planned, assessed, and permitted across Europe.

The analysis shows that the currently legislatively required tools differ in nature: Some of the tools have a narrow focus in terms of sustainability (e.g. assessments required by the Habitats Directive and the Water Framework Directive), whereas other tools have a broad scope (e.g. the EIA and SEA directives).

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Mitigation and enhancement

The analysis identifies a clear distinction between mitigation-oriented and enhancement-oriented contributions to sustainability.

Across the assessed tools:

- Mitigation is systematically embedded and often mandatory, particularly within SEA, EIA, and directive-based assessments.
- Enhancement is not systematically required and is addressed inconsistently, typically depending on project-specific approaches or voluntary tools.

Regulatory tools are therefore effective in:

- Identifying and reducing negative impacts.
- Ensuring compliance with environmental standards.
- Managing risks.

However, they appear less effective in:

- Systematically identifying opportunities for positive sustainability outcomes.
- Supporting proactive improvements.
- Enabling system-level optimisation.

Tools such as LCA and SIA demonstrate potential to support enhancement through lifecycle optimisation and social value creation, but their application remains limited and not structurally embedded in decision-making processes.

1.5. Key findings and identified gaps

The combined analysis across life-cycle phases, tools, and sustainability scope highlights several key findings:

- Strong institutionalisation of mitigation, supported by mandatory regulatory frameworks
- Regulatory requirements for key assessment tools ensure attention to a system perspective on OWF and related infrastructures, including cables and onshore changes.
- Limited and uneven integration of enhancement, with no consistent requirement across tools.
- Fragmentation between regulatory and voluntary tools, limiting integrated decision support.
- Variability in the treatment of cumulative, transboundary, and lifecycle impacts.
- Limited coverage of later life-cycle phases, particularly repowering and decommissioning.

These findings indicate that current assessment practice is well-developed in terms of impact identification and mitigation, but less effective in supporting proactive and systemic sustainability outcomes.

Basis for further work

The results of this deliverable provide a structured basis for subsequent project activities, particularly in relation to:

- Identifying priority areas for improving decision support.
- Developing approaches that better integrate enhancement alongside mitigation.
- Strengthening the use of lifecycle and system-oriented assessments.
- Improving the integration of tools across life-cycle phases and decision levels.

The overall life-cycle framework provides a useful and conceptually clear picture for understanding OW development processes. However, in practice, planning and permitting processes are often iterative and overlapping rather than strictly sequential. Permitting, environmental assessment, technical optimisation, and stakeholder negotiations may evolve in parallel and continue across multiple phases. Acknowledging this complexity strengthens the practical applicability of the framework and highlights the need for flexible and adaptive assessment approaches.

Overall, the analysis points to the need for a transition from a predominantly impact mitigation framework towards a more balanced approach, where assessment tools also support the identification and realisation of positive sustainability outcomes.

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2. Introduction

2.1. Background and rationale

The large-scale expansion of offshore wind farms (OWFs) is a central pillar of European strategies for climate neutrality, energy security, and reduced dependence on fossil fuels. Offshore wind is expected to play a decisive role in achieving long-term decarbonisation targets, with European capacity is projected to increase substantially by mid-century (European Commission, 2020; Stranddorf et al., 2025).

At the same time, the rapid scaling of OWFs introduces new pressures on already intensively used and ecologically sensitive marine environments, where cumulative human impacts are significant and often insufficiently understood (Siqueira-Gay et al., 2025). Offshore wind development increasingly interacts with complex marine ecosystems, existing maritime activities (e.g. fisheries, shipping), and coastal communities, giving rise to contested trade-offs across environmental, social, and economic domains. Importantly, these trade-offs are not only biophysical but also socio-political, involving stakeholder conflicts, distributional concerns, and issues of social acceptance that can critically influence project feasibility and timelines (Skiniti et al., 2026).

As a result, OWF planning and development involve inherently multi-dimensional decision-making processes in which environmental protection, social and socio-economic considerations, and technical and economic feasibility must be balanced under conditions of uncertainty. These challenges are further amplified by the need to coordinate across spatial scales and governance scales, including sectoral policies, marine spatial planning, and project-level implementation.

Importantly, these considerations are not addressed at a single decision point but evolve across multiple planning and development phases, from strategic spatial planning and site selection to project-level design, consenting, and end-of-life management. Decisions taken at early, strategic stages tend to establish boundary conditions that constrain subsequent options and may have long-term or irreversible implications for sustainability outcomes. This path dependency is well recognised in the literature, which emphasises the importance of early-stage assessment instruments, such as Strategic Environmental Assessment, in shaping downstream project decisions and avoiding lock-in of suboptimal solutions (Josimovic et al., 2021; Siqueira-Gay et al., 2025). At the same time, emerging evidence indicates that later lifecycle stages, including decommissioning, introduce additional trade-offs, further underlining the importance of adopting a life-cycle and systems perspective when assessing sustainability in offshore wind development (Stranddorf et al., 2026; Ferreira et al., 2023; Thomassen et al., 2025).

A wide range of tools is currently used to inform these decisions. These include regulatory assessment instruments such as Strategic Environmental Assessment (SEA), Environmental

Impact Assessment (EIA), and cumulative effects assessment, as well as analytical approaches such as Life Cycle Assessment (LCA), social and socio-economic assessments, and spatial modelling tools. In parallel, European research and innovation projects are developing new methods and tools intended to strengthen sustainability assessment and decision support in offshore wind planning, with the aim of enabling more holistic and evidence-based decision-making (Ferreira et al., 2023).

Despite this diversity, the overall tool landscape remains fragmented. Tools differ substantially in scope, level of integration, data requirements, and - critically – their timing and influence within decision-making processes. Studies point to considerable variability in how environmental assessment requirements are implemented across jurisdictions, with implications for both the consistency of sustainability outcomes and the predictability of planning processes (McMaster et al., 2021; Dibo et al., 2025). Moreover, even where formal requirements such as SEA are in place, their effectiveness can be constrained by non-systematic application, limited integration across planning levels, and insufficient consideration of cumulative and long-term impacts (Siqueira-Gay et al., 2025). For example, SEA undertaken at the national or regional planning level may not always be effectively linked to subsequent project-level EIAs, resulting in fragmented consideration of cumulative pressures, grid infrastructure interactions, or long-term impacts across multiple OW developments.

Consequently, sustainability considerations are often addressed unevenly across decision phases, impact categories, and governance levels. In particular, early strategic decisions with high leverage for sustainability outcomes are not always supported by tools capable of capturing cumulative, cross-sectoral, or system-level effects. They are not consistently embedded in decision processes in a way that ensures their influence on downstream project choices. This creates a structural mismatch between where key decisions are made, and their robust analytical support is available.

Against this background, there is a need for a decision-oriented review of existing tools, focusing not only on their analytical scope, but on how, when and to what extent they inform decision-making in practice. Such a perspective is essential for identifying gaps and opportunities for better integration across tools, decision phases and governance levels, and ultimately for strengthening the contribution of assessment frameworks to sustainable offshore wind development.

2.2. Objectives and scope of D6.1

The overall objective of Deliverable D6.1 is to provide a structured, practice-based, and decision-oriented review of existing tools used – or currently under development – to assess and support sustainability in OWF planning and development. The review supports the development of SUSTAINOW decision-support tools by clarifying the current state of practice and identifying key functionalities and scope in existing approaches.

More specifically, the deliverable aims to:

- Identify and characterise key tools currently used in offshore wind planning and design practice, with particular attention to those applied by SUSTAINOW consortium partners involved in development of OWF.
- Analyse how these tools support sustainability-related decisions across different phases of the OWF life cycle.
- Review relevant tools under development in European research and innovation projects.
- Assess the extent to which environmental, social, and economic sustainability dimensions are addressed.

The scope of the deliverable is limited to tools relevant for planning and early design of OWFs. Detailed engineering tools, construction management systems, and operational monitoring tools are considered only insofar as they inform planning-related decisions.

The review focuses on tools applicable within a European regulatory and planning context, rather than providing a detailed comparison of national legal procedures.

2.3. Structure of the deliverable

Section 2 introduces a decision-centred framework, structuring offshore wind development into life-cycle phases and identifying key decision types relevant for sustainability.

Section 3 reviews existing tools used in practice and analyses how they are embedded in decision-making processes across phases and national contexts.

Section 4 examines the sustainability scope of these tools, including the extent to which environmental, social and socio-economic dimensions are addressed, as well as the balance between impact mitigation and value creation through enhancement.

Section 5 maps ongoing research and innovation activities and identifies emerging tools and methodological developments relevant to offshore sustainability assessment.

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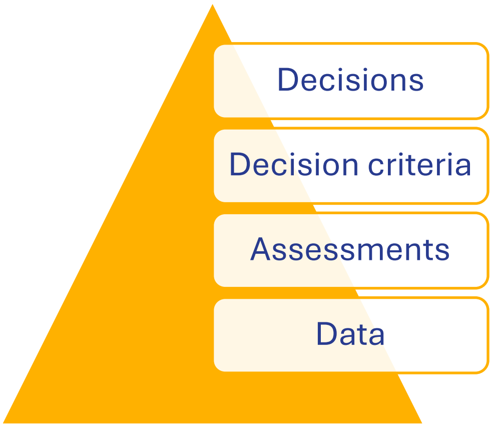
3. OWF phases and decision making

Planning and development of OWFs unfolds through a sequence of interrelated life-cycle phases, each characterised by distinct objectives, actors, institutional settings, and decision logics. Decisions taken in one phase shape the conditions under which subsequent phases unfold and may have long-term, cumulative, or irreversible implications for sustainability outcomes. Understanding where and how key decisions are taken across the OWF life cycle is therefore essential for identifying where decision-support tools can most effectively contribute to sustainability.

This section introduces the decision-centred framework that underpins Deliverable D6.1 and SUSTAINOW. Rather than focusing on assessments or analytical methods in isolation, the framework emphasises decisions as the points at which sustainability is ultimately enabled, constrained, or traded off. The section provides a structured overview of OWF life-cycle phases, the nature of decisions taken within each phase, and their relevance for sustainability considerations. This framework serves as the analytical reference for the subsequent review of tools (Sections 3 and 4) and for the assessment of sustainability potential (Section 5).

3.1. Understanding decisions in OWF planning and development

In this deliverable, **decisions are understood as deliberate choices or commitments** made by planning authorities, developers, or other responsible actors that determine the spatial, technical, procedural, or institutional configuration of an OWF.



This definition distinguishes decisions from:

- **Data**, which provide the basis for assessments.
- **Assessment methods**, which generate knowledge about impacts.
- **Criteria**, which structure how alternatives are evaluated.

Figure 1 Decisions in OWF planning and development based on data, assessments, and decision criteria. (Source: Kørnøv & Lyhne, 2026).

Decisions are the points at which alternatives are selected and where sustainability outcomes are ultimately enabled, constrained or traded off.

Adopting a decision-centred perspective shifts the analytical focus:

- From what tools analyse to where sustainability is determined

This distinction is central to the SUSTAINOW approach, as it allows the identification of high-leverage decision points across the OWF life cycle and enables a direct linkage between decisions, decision-support tools, and data needs. It also provides a basis for differentiating decisions according to their sustainability potential, depending on timing, scope, and reversibility.

The effectiveness of assessment tools not only depends on their analytical robustness, but on their ability to inform decisions at the right time, at the right level, and in a form that is actionable for decision-makers.

3.2. OWF life-cycle phases

The following description of OWF life cycle phases and related decisions is based on a comprehensive review of scientific literature (Kørnøv and Lyhne, 2026). The OWF life cycle is structured into seven phases:

- Site selection
- Tender
- Project design
- Construction
- Operation
- Repowering
- Decommissioning

Although this report is based on a conceptual understanding of seven phases, there are substantial differences across national systems in EU, where permitting and licensing processes are embedded differently across national systems and may overlap with both tendering and design phases. As an example, In Estonia, licensing, superficies agreements, and environmental impact assessment (EIA) procedures are centrally administered and do not align neatly with a strictly tender-based phase.

Across these phases, decision characteristics differ significantly in terms of:

- Strategic importance
- Reversibility
- Uncertainty
- Scope of impacts

A key insight is that:

> **Early-phase decisions (especially site selection and tendering) have the highest leverage for sustainability outcomes, while later phases primary enable optimisation, mitigation, and adaptation within predefined constraints.**

The **site selection phase** involves early, strategic decisions that define the spatial and institutional conditions for OWF development. Choices regarding the delineation of areas, exclusion of conflicting uses, resource assessment, regulatory feasibility, and social acceptance establish the foundation for all subsequent phases. Decisions at this stage are typically characterised by high strategic importance and limited reversibility, making them particularly influential for long-term sustainability outcomes.

The **tender phase** translates strategic planning intentions into binding conditions for project development. Decisions taken here determine who develops the OWF, under which contractual and financial arrangements, and with which technical and sustainability commitments. Tender criteria and award mechanisms can strongly shape sustainability performance by embedding requirements related to environmental mitigation, circularity, social responsibility, and innovation.

The **project design phase** focuses on translating site allocation and tender commitments into a concrete technical, spatial, and organisational configuration of the OWF. Decisions regarding turbine selection, foundation concepts, layout optimisation, electrical infrastructure, and permitting strategies define the physical form of the project and condition construction, operation, and repowering options. At this stage, trade-offs between energy performance, costs, environmental impacts, and social considerations become particularly salient.

The **construction phase** involves decisions related to implementation methods, sequencing, logistics, and environmental impact mitigation. While many design parameters are fixed at this stage, construction decisions can still significantly influence environmental disturbance, resource efficiency, safety, and local impacts. Construction-phase decisions are often operational in nature but can have cumulative and long-term effects.

The **operation phase** encompasses long-term and recurrent decisions related to maintenance strategies, resource allocation, monitoring, data use, and performance management. These decisions determine energy yield, operational costs, safety, and ongoing environmental performance over the operational lifetime of the OWF. Although operational decisions are adaptive, they are often constrained by earlier design and construction choices.

The **repowering phase** represents a strategic transition point at which decisions are made about extending the life of the OWF, upgrading components, or fundamentally redesigning the installation. Repowering decisions resemble those taken in the project design phase but are shaped by existing infrastructure, regulatory conditions, and accumulated environmental and social impacts. This phase offers significant potential to improve sustainability performance compared to the original design.

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Finally, the **decommissioning phase** involves decisions related to the end-of-life management of OWF infrastructure. Choices regarding timing, scope of removal, methods, waste management, and site restoration determine the long-term environmental and social legacy of offshore wind development. Decommissioning decisions are increasingly relevant for sustainability due to their implications for circularity, ecosystem recovery, and future sea use.

To summarise these phases and highlights their implications for sustainability-oriented decision-making, Table 2 provides an overview of the general objectives and sustainability-oriented objectives associated with each phase of the OWF life cycle. The table also characterises the nature of the key decisions occurring in each phase, emphasising differences in strategic importance, reversibility, uncertainty, and operational constraints. This overview helps clarify where and how decisions across the life cycle may influence sustainability outcomes and where decision-support tools may be particularly relevant.

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Phase	General objectives	Sustainability-oriented objectives	Decision characteristics
Site selection	Identify technically, spatially, and legally feasible locations for offshore wind development.	Select locations that maximise renewable energy benefits while minimising environmental, social, and spatial conflicts.	Strategic and spatial planning decision; high sustainability influence; largely irreversible; high uncertainty; requires early environmental and spatial assessments.
Tender	Identify/Select qualified developers, contractors, and suppliers through a transparent and competitive procurement process.	Integrate sustainability, circularity, and social responsibility as key selection criteria.	Policy and procurement decision; shapes project standards and incentives; multi-actor decision; sustainability integrated through criteria and requirements.
Project design	Define technical configuration, layout, and specifications to ensure performance, safety, and compliance.	Optimise lifecycle performance, minimise impacts, and enable adaptability and future upgrades.	Technical and multi-criteria decision; iterative and model-based; trade-offs between energy production, cost, and environmental impacts.
Construction	Build the wind farm according to approved designs, standards, and schedules.	Implement construction practices that minimise environmental disturbance and ensure safe and efficient resource use.	Operational decisions under regulatory constraints; time-sensitive; focused on mitigation and compliance with approved assessments.
Operation	Operate and maintain the wind farm to ensure reliable and efficient energy production.	Maximise clean energy production while managing environmental impacts and resource use.	Long-term operational management; monitoring-based and adaptive decisions; influenced by environmental conditions and regulatory requirements.
Repowering	Assess and implement upgrades or replacements to extend or enhance performance.	Improve energy efficiency and sustainability while considering environmental impacts and economic viability.	Strategic reinvestment decision; technology-driven; evaluation of environmental effects, costs, and regulatory conditions.
Decommissioning	Safely dismantle and remove infrastructure at the end of operational life.	Minimise environmental harm, maximise material recovery, and support ecosystem restoration.	End-of-life decision; regulated process; focus on environmental restoration, circular economy, and site recovery.

Table 2 Objectives and decision characteristics across OWF life-cycle phases. (Based upon Kørnøv and Lyhne, 2026).

3.3. Decision-making as a basis for assessing sustainability potential

Not all decisions across the OWF life cycle have equal influence on sustainability outcomes. Their leverage depends on:

- Timing (early vs late phase).
- Reversibility (fixed vs adjustable decisions).
- Spatial and temporal scale.
- Ability to influence cumulative and system-level effects.

Early strategic decisions define:

- Spatial allocation
- Exclusion zones
- Development conditions

and therefore, shape the solution space within which later decision operate.

Later decisions – particularly in construction and operation – tend to focus on and enable:

- Incremental improvement
- Mitigation
- Optimisation
- Compliance

By structuring OWF planning around life-cycle phases and the key decisions associated with them, this deliverable establishes a consistent analytical framework.

In Sections 3 and 4, this framework is used to review how existing tools support decision-making in practice. In Section 5, it provides the basis for mapping sustainability potential across phases and decisions and for identifying where improved decision support can have the greatest effect.

This perspective allows for a more differentiated understanding of where improvements in tools, data, or integration could have the greatest impact on sustainability outcomes.

4. Assessment tools for sustainability used in OWF practice

This section reviews the main tools currently used in offshore wind (OWF) planning and design practice, with a focus on how they are embedded in decision-making processes, rather than only their analytical characteristics.

The review includes two categories of tools. First, it considers assessment and decision-support tools explicitly referenced in the SUSTAINOW proposal, namely Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), Life Cycle Assessment (LCA), Social Impact Assessment (SIA), and Cumulative Effects Assessment (CEA). These tools represent widely recognised approaches for assessing environmental and social effects of infrastructure development and are commonly embedded in regulatory or planning procedures.

Second, the review identifies additional analytical approaches and tools that are commonly used in practice, based on the professional experience of consortium partners. These include spatial screening tools, technical modelling tools, economic assessments, and other forms of analysis that support planning and project design decisions in offshore wind development.

Rather than aiming to provide an exhaustive inventory of all tools potentially relevant to OWF decisions, the purpose of this section is to capture the practical tool landscape as experienced and applied in practice and illustrate how different types of tools support decision-making across the phases of the OWF life cycle introduced in Section 2.

To support this analysis, information on tool use was compiled through a structured workshop among consortium partners covering Estonia, Portugal, Spain, and Denmark and hereby representing different institutional contexts and stages of offshore wind development.

For each country, tables 4-7 indicate the typical use of selected tools across OWF life-cycle phases, distinguishing between where tools are commonly applied, occasionally applied, or largely absent. These tables should be interpreted as indicative representations of current practice, reflecting dominant planning procedures rather than formal legal requirements in each case.

By relating tools to phases and associated decisions, the section provides a first overview of where existing tools support supports sustainability-relevant decisions in practice. This provides the empirical basis for the analysis in Section 4, which examines the sustainability scope and decision relevance of these tools in more detail.

The tools considered differ significantly in terms of their legal status, analytical scope, and role in decision-making, ranging from mandatory regulatory procedures to voluntary analytical approaches.

4.1. Overview of tools included in the analysis

The tools included in the analysis represent widely used approaches for generating information that informs planning and permitting decisions in offshore wind development. The following brief description clarifies the general purpose and typical application context of the tools considered in this section.

It should be noted that assessments required under the Habitats and Birds Directives, the Water Framework Directive (WFD), and the Marine Strategy Framework Directive (MSFD) were not explicitly addressed as separate tools in the partner workshop and country inputs. This reflects current practice, where these assessments are typically embedded within broader SEA and EIA processes rather than applied as stand-alone procedures.

Screening and Appropriate Assessment (AA) under the Habitats Directive and compliance assessments under the WFD and MSFD are often reflected in both SEA and EIA, including through cumulative impact assessment and ecosystem-based approaches. As a result, practitioners may not distinguish these as separate "tools", even though they introduce specific legal requirements and decision criteria that can be decisive for approval of the plan or the project.

For the purposes of this analysis, these directive-based assessments are therefore treated as integral components of the wider assessment framework, while being made explicit in the methodological overview to ensure that their regulatory significance and influence on decision-making are adequately captured.

4.1.1. Strategic Environmental Assessment (SEA)

Strategic Environmental Assessment (SEA) is a planning-level assessment used to evaluate the environmental implications of policies, plans, and programmes before they are adopted. Within the European Union, SEA is regulated through the SEA Directive (Directive 2001/42/EC), which requires environmental assessment of certain plans and programmes likely to have significant environmental effects. At the international level, SEA is also governed by the Protocol on Strategic Environmental Assessment (2003) to the Espoo Convention, which requires the consideration of environmental and health effects in plans and programmes and includes provisions for transboundary consultation where significant cross-border impacts may occur.

Responsibility for conducting SEA typically lies with public planning authorities, such as national ministries responsible for energy, maritime affairs, or spatial planning, or with designated planning agencies responsible for marine spatial planning. The assessment is usually prepared by consultants or research institutions on behalf of the responsible authority and conducted in parallel with plan preparation.

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In offshore wind development, SEA commonly informs strategic planning decisions, including the identification of suitable development zones in marine spatial plans or national plans for OWF. These early decisions establish spatial and environmental constraints that shape subsequent tendering and project development.

4.1.2. Environmental Impact Assessment (EIA)

Environmental Impact Assessment (EIA) is a project-level assessment procedure used to evaluate the likely environmental effects of specific development projects before development consent is granted. In the European Union, EIA is governed by the EIA Directive (Directive 2011/92/EU as amended by Directive 2014/52/EU), which requires environmental assessment of certain categories of projects prior to approval.

Transboundary environmental impacts are addressed under the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention, 1991), which requires that neighbouring countries be notified and consulted if a project is likely to cause significant environmental effects across national borders. Offshore wind farms, particularly those located near maritime borders or in shared sea basins such as the North Sea or Baltic Sea, may therefore require transboundary consultation procedures under the Espoo Convention.

Responsibility for preparing the EIA normally lies with the project developer (promoter), who commissions the environmental studies required for the environmental impact report. Public authorities are responsible for reviewing the assessment, conducting consultation procedures, and ultimately making the development consent decision.

In offshore wind planning practice, EIA informs decisions related to project design and alternatives, layout optimisation, environmental impacts, environmental mitigation measures, construction methods, and operational conditions, and forms a central element of project permitting procedures.

Holistic coverage of OWFs under the EIA Directive

OWFs are covered by the EIA Directive as complex, multi-component projects falling within several of the categories listed in Annex I and Annex II. Most notably, Annex I includes installations for the harnessing of wind power for energy production (wind farms) where they exceed specified thresholds, thereby requiring a mandatory environmental impact assessment. In addition, Annex I and II cover associated infrastructure such as overhead electrical power lines and installations for the transmission of electricity. Annex II further includes industrial installations to produce electricity, as well as infrastructure projects such as ports, coastal works, and grid connections, which may be required depending on the specific configuration of the offshore wind development.

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Importantly, the scope of application is not limited to the turbines themselves but extends to all integral parts of the project as defined under the directive. This includes offshore elements such as turbine arrays, foundations, inter-array cables and offshore substations, as well as export cables, landfall sites, onshore substations, and grid connection infrastructure. Through the combined application of Annex I and Annex II categories, the directive ensures that offshore wind developments are addressed as integrated projects rather than as isolated components. However, the practical implementation of this integrated approach, responsibility for export cables, grid connections, or onshore infrastructure may lie with different developers or transmission system operators rather than with the offshore wind developer itself. As a result, permitting and assessment processes may in practice be carried out through partially separate processes, despite the overarching integrated logic reflected in the directive.

This comprehensive coverage reflects a holistic understanding of OWFs as systems that span marine and terrestrial domains. It also aligns with the interpretation of project scope in practice, where functionally interdependent elements are considered part of a single project for the purposes of environmental assessment, even if they are geographically dispersed or subject to different permitting procedures.

In this context, the “centre of gravity” principle provides a useful lens for understanding how such projects are framed within the directive. The principle highlights that, for complex activities involving multiple components and regulatory interfaces, the assessment is anchored in the dominant purpose of the project—typically energy generation—while still requiring that all associated and supporting infrastructure be included within the overall assessment framework (Duncan and Currie, 2020). This helps avoid fragmentation and ensures that interrelated components, such as offshore installations and onshore grid connections, are assessed in a coherent and coordinated manner.

This holistic approach is directly relevant to the objectives of SUSTAINOW, which emphasises the development of tools capable of capturing the full system of offshore wind developments. By reflecting the directive’s integrated treatment of turbines, cables, and land-based installations, such tools can better support comprehensive assessments that move beyond a narrow focus on individual components and instead address the OWF as a connected socio-technical and environmental system.

4.1.3. Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is an analytical method used to evaluate environmental impacts associated with the entire life cycle of a product, infrastructure system, or technology—from raw material extraction and manufacturing to operation and end-of-life management. The methodology is standardised through the ISO 14040 and ISO 14044 standards (ISO, 2006a, 2006b).

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Unlike SEA and EIA, LCA is not mandated through European environmental assessment directives, but it is widely used in sustainability assessment, product environmental footprint analysis, and circular economy studies (European Commission, 2021a). In the renewable energy sector, LCA is increasingly applied to evaluate lifecycle greenhouse gas emissions, material use, and environmental performance of energy technologies (IPCC, 2022; Das & Nandi, 2025).

Responsibility for conducting LCA typically lies with developers, manufacturers, consultants, or research organisations, depending on the purpose of the assessment. In offshore wind planning, LCA may inform technology selection, design optimisation, and evaluation of environmental performance across the life cycle of wind turbine components and associated infrastructure.

Recent EU policy developments, notably the EU Taxonomy Regulation (EU) 2020/852 (European Commission, 2021b), further reinforce the relevance of lifecycle-based approaches by requiring that economic activities such as offshore wind contribute to climate mitigation while complying with "Do No Significant Harm" criteria across multiple environmental objectives. Although the Taxonomy does not prescribe specific methodologies, its lifecycle-oriented logic creates an implicit demand for approaches such as LCA to support the assessment of environmental performance across the full life cycle of projects.

4.1.4. Cumulative Impact Assessment (CIA)

Cumulative Impact Assessment (CIA) refers to the assessment of the combined effects of multiple activities or projects on environmental receptors over space and time (European Commission, 2017a). Consideration of cumulative effects is required under both the SEA Directive (2001/42/EC) and the EIA Directive (2011/92/EU as amended), which require that environmental assessments address interactions between projects and other pressures on ecosystems. Assessment of 'in-combination' effects is furthermore required under the Habitats Directive, WRD, and MSFD. Cumulative impacts may also extend across national borders and therefore fall within the scope of transboundary assessment procedures under the Espoo Convention.

Responsibility for analysing cumulative effects typically lies with the authority responsible for SEA or the project developer responsible for EIA, depending on the decision level at which the assessment is conducted. In practice, CIA is often integrated within SEA or EIA rather than conducted as a stand-alone procedure.

In offshore wind planning, CIA is particularly relevant in marine environments where multiple wind farms and other maritime activities interact and where cumulative pressures may affect marine ecosystems.

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4.1.5. Social Impact Assessment (SIA)

Social Impact Assessment (SIA) focuses on the potential social consequences of development projects, including effects on communities, livelihoods, cultural values, and social acceptance (Vanclay, 2003, Vanclay et al., 2015). Within the European regulatory framework, social considerations are incorporated into environmental assessments under the EIA Directive (2011/92/EU as amended by 2014/52/EU), which explicitly requires the assessment of impacts on population and human health, as well as material assets, cultural heritage, and the interaction between these factors. Guidance on the preparation of EIA reports further clarifies how such socio-economic and human health aspects should be identified, assessed, and presented within the EIA process (European Commission, 2017c).

Responsibility for assessing social impacts usually lies with the project developer, who commissions studies as part of the EIA process, while public authorities review the adequacy of the assessment and consider social impacts in the consent decision (European Commission, 2017c).

In offshore wind planning practice, SIA is often integrated within EIA procedures and plays an important role in informing stakeholder engagement, addressing potential conflicts with fisheries and other maritime users, and identifying measures to manage local socio-economic effects, as also reflected in EU guidance on wind energy development (European Commission, 2020).

4.1.6. Assessments under nature and water-related EU Directives

In addition to the general environmental assessment procedures described above, offshore wind is also subject to a set of specific environmental assessments requirements under sectoral EU directives. These include assessments under the Habitats and Birds Directives, the Water Framework Directive (WFD), and the Marine Strategy Framework Directive (MSFD). While these are not always applied as stand-alone assessment processes, they introduce legally binding requirements that must be addressed within planning and permitting decisions. Whereas authorities are responsible for compliance with the directives, OWF developers are often required to prepare documentation for compliance.

Assessment under the Habitats and Birds Directives (Appropriate Assessments)

The Habitats Directive (92/43/EEC) and the Birds Directive (2009/147/EC) establish a framework for the protection of biodiversity through the Nature 2000 network of protected areas. Under Article 6 of the Habitats Directive, any plan or project likely to have a significant effect on a Natura 2000 site must undergo an Appropriate Assessment (AA).

The purpose of the assessment is to determine whether the plan or project will adversely affect the integrity of protected sites, taking into account conservation objectives. The assessment is typically carried out by the project developer as part of the permitting process, often in close connection with the EIA, but remains a distinct legal requirement with a strict decision criterion.

Competent authorities are responsible for evaluating the assessment and may only approve a project if it can be demonstrated that no adverse effects on site integrity will occur, unless specific derogation conditions are met.

In offshore wind planning, Appropriate Assessment is particularly relevant during site selection and project design, where potential impacts on marine habitats, birds, and protected species must be carefully evaluated.

Assessment under the Water Framework Directive (WFD)

The Water Framework Directive (2000/60/EC) establishes a framework for the protection of inland surface waters, transitional waters, coastal waters, and groundwater. A key requirement of the Directive is that projects must not lead to deterioration of the ecological or chemical status of water bodies or compromise the achievement of good ecological and chemical status. This obligation has been confirmed by the Court of Justice of the European Union, which clarified that member states (MS) must refuse authorisation for projects that may cause deterioration unless the conditions for derogation are fulfilled (CJEU, Case C-461/13 Weser).

Assessment under the WFD is typically integrated within project permitting processes and may be addressed as part of EIA documentation or as a separate compliance assessment. However, the organisation and procedural integration of WFD assessments vary between countries. In general, the responsibility for demonstrating compliance lies with the project developer, while competent water authorities assess whether the project is compatible with WFD objectives (European Commission, 2017b).

In the context of offshore wind development, WFD-related assessments are particularly relevant for decisions affecting seabed disturbance, sediment transport, and water quality, especially during construction and installation phases.

Assessment under the Marine Strategy Framework Directive (MSFD)

The Marine Strategy Framework Directive (2008/56/EC) aims to achieve or maintain Good Environmental Status (GES) of marine waters. It provides a framework for assessing cumulative pressures on marine ecosystems and requires Member States to develop marine strategies based on ecosystem-based management.

While the MSFD does not establish a project-level assessment procedure comparable to EIA, it provides an important policy and assessment framework that informs planning decisions, particularly at strategic levels. MSFD descriptors (e.g. biodiversity, seafloor integrity, underwater noise) are often used as reference points in environmental assessments and monitoring programmes.

Responsibility for implementing the MSFD lies with national authorities, but its requirements are reflected in both SEA and EIA processes. In offshore wind planning, the MSFD is particularly relevant for addressing cumulative impacts and ecosystem-level considerations across multiple projects and pressures.

4.1.7. Additional analytical and technical tools

In addition to formal regulatory assessment instruments, offshore wind planning and design rely on a range of technical modelling tools, spatial decision-support systems, and economic analyses. These tools are generally not mandated through EU environmental legislation but are widely used by developers, consultants, and authorities to support technical and spatial decision-making.

Examples identified by the consortium partners in the country mapping include spatial modelling tools such as WindPRO and Youwind, which support wind resource assessment, layout optimisation, and environmental modelling, as well as technical frameworks such as GTS used in Denmark to guide the design and construction of renewable energy infrastructure. WindPRO is a widely used software platform for wind energy planning that supports wind resource assessment, turbine siting, energy yield calculations, noise and shadow flicker analysis, visualisation, and environmental impact modelling. Youwind is applied in offshore wind development to support spatial analysis, layout optimisation, and scenario development by integrating geospatial, technical, and environmental data relevant to marine planning and project design.

Responsibility for applying these tools usually lies with project developers, engineering consultancies, and technical advisors, although authorities may also apply spatial decision-support tools during planning processes.

Where projects involve hazardous substances or storage facilities (e.g. battery systems), risk assessments may also be required under the Seveso III Directive (Directive 2012/18/EU) concerning the control of major accident hazards.

The tools considered in this review differ in terms of their regulatory basis, governance structure, and role in decision-making processes. Table 3 summarises the main characteristics of the tools included in the analysis, including their regulatory status, initiating triggers, responsible actors, and relevance for transboundary assessments.

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Tool	Regulatory status	Main regulatory framework	Initiating trigger	Level of decision-making	Main responsible actor(s)	Role of authorities	Transboundary dimension
SEA	Mandatory for certain plans and programmes	EU SEA Directive (2001) Protocol on SEA to the Espoo Convention	Preparation or revision of plans and programmes (e.g. marine spatial plans)	Strategic planning level	Public planning authorities (e.g. ministries, marine spatial planning authorities)	Authorities initiate or commission the SEA and integrate its findings into planning decisions	Transboundary consultation required where plans may cause cross-border environmental impacts
EIA	Mandatory for projects likely to have significant environmental effects	EU EIA Directive (2011, 2014) Espoo Convention	Submission of a project requiring environmental consent	Project permitting level	Project developer commissions the EIA; consultants typically prepare the studies	Authorities review the EIA documentation, conduct consultations, and grant/refuse consent	Transboundary consultation required where projects may affect neighbouring states
LCA	Not mandatory	ISO 14040 / ISO 14044 standards Sometimes linked to EU sustainability or taxonomy frameworks	Potentially required by legislation or lending schemes. Undertaken by developers or manufacturers	Technical / analytical support	Developers, manufacturers, consultants, researchers	Authorities may consider LCA results indirectly in policy development or sustainability evaluation	Typically, not part of formal transboundary assessment procedures
SIA	Usually integrated within EIA and SEA rather than required as a separate procedure	Conducted as part of EIA and SEA	Part of project SEA and EIA process	Project-level decision support	Developers commission studies; social scientists or consultants conduct analyses	Authorities review social impacts as part of EIA and SEA process and through public consultation procedures	Social impacts may be considered in Espoo consultation where relevant
CIA	Required within SEA and EIA procedures	SEA Directive EIA Directive Various EU guidance documents on cumulative effects	Required where multiple activities or projects may interact and produce cumulative impacts	Strategic and project-level	Depending on level: authorities (SEA) or developers (EIA)	Authorities ensure cumulative impacts are considered in planning and permitting decisions	May include cumulative impacts across national borders
TIA	Mandatory where significant cross-border impacts are expected	Espoo Convention (1991), SEA Protocol (2003)	Identification of potential cross-border environmental impacts	Strategic and project-level	Initiated by country of origin. Developers provide supporting documentation	Authorities notify affected states and coordinate the consultation process	Core purpose is to address cross-border environmental impacts
AA	Mandatory where Nature 2000 sites may be affected	Habitats and Birds Directive (2009)	Potential significant effect on Natura 2000 sites	Project and planning level	Authorities oversees compliance. Developer provides documentation	Authorities must ensure no adverse effect on site integrity before approval	May be relevant in transboundary contexts
WFD	Mandatory compliance requirement	Water Framework Directive (2000)	Risk of deterioration of water body status	Project level compliance	Authorities oversees compliance. Developer provides documentation	Authorities assess compliance with water status objectives	May involve shared water bodies
MSFD	Framework directive (not project-level mandatory tool)	Marine Strategy Framework Directive (2008)	Marine planning and environmental status assessments	Strategic and cumulative level	Authorities oversees compliance. Developer provides documentation	Authorities define GES and integrate into planning and assessment	Strong relevance for transboundary marine regions

Table 3 Comparative characteristics of assessment tools used in offshore wind planning and project design.

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4.2. Mapping of tool use across national contexts

The regulatory framework and actor responsibilities described above help explain the observed patterns in how assessment tools are applied across national offshore wind planning systems. The following country-based mapping illustrates how these tools are typically used across different phases of the OWF life cycle in current planning practice. The mapping reflects dominant practices, rather than formal legal requirements, and scope of tools is presented in table 1 in section 1.3. The identification of tool use is based on a combination of documented sources and the team's expert/practical knowledge.

4.2.1. Cross-country observations

Across the four countries analysed (Estonia, Portugal, Spain, and Denmark), several common patterns can be observed in the use of assessment tools across offshore wind life-cycle phases.

First, Strategic Environmental Assessment (SEA) plays a central role in the early planning and siting phases, particularly where marine spatial planning processes are used to identify suitable areas for offshore wind development. In several cases, SEA provides the initial environmental and spatial assessment framework that guides later project-level decisions and informs tendering processes.

Second, Environmental Impact Assessment (EIA) is the most consistently applied tool across the later life-cycle phases, particularly during project design, construction, and operation. EIA typically functions as the main regulatory mechanisms through which environmental considerations are integrated into project permitting and approval processes.

Third, several sustainability-related assessment components are often integrated within broader assessment frameworks rather than conducted as stand-alone tools. For example, Cumulative Impact Assessment (CIA) and Social Impact Assessment (SIA) are frequently addressed within the EIA or SEA procedures rather than as separate assessments. Similarly, Life-Cycle Assessment (LCA) appears to be used less systematically and is sometimes replaced by alternative approaches such as Carbon Footprint Analysis.

The following country descriptions provide context for interpreting the tables, highlighting how regulatory frameworks, planning practices, and institutional arrangements shape the application of assessment tools.

4.2.2. Estonia

The site selection phase is primarily addressed through the SEA process carried out for MSP, within which CIA, SIA, and transboundary consultation and assessment procedures are also undertaken. These processes establish the main spatial and environmental conditions for subsequent offshore wind development.

The tender phase typically follows the designation of suitable areas through marine spatial planning and primarily takes the form of an auction-based allocation process through which a developer obtains the right to pursue development within a designated area. The selected developer subsequently proceeds with the permitting and licensing process and is required to carry out an EIA in accordance with the conditions established through the MSP and SEA processes.

Once a project progresses to the permitting, design, construction, and operation phases, environmental assessment is primarily addressed through an integrated EIA procedure, which forms the main regulatory instrument in Estonia. The EIA typically covers both construction and operational impacts and is carried out within the superficies permit procedure, while also providing the basis for subsequent water permit and building permit applications. Within this framework, project-specific baseline studies are conducted and additional analyses such as CIA, SIA, transboundary consultation and assessment, and risk assessments may be incorporated depending on project characteristics. Risk-related assessments may include, for example, impacts on vessel navigation and aviation activities.

Repowering and decommissioning are areas where regulatory practices are still evolving. Repowering has not yet been widely addressed in the Estonian context, while decommissioning issues are currently under discussion, particularly regarding responsibilities, waste management, and the handling of turbine components at the end of the project life cycle. At present, these issues are generally addressed only to a limited extent within the EIA process. As a result, assessment requirements for these later life-cycle phases are expected to develop further as offshore wind deployment progresses.

PHASES	EIA	SEA	LCA	CIA	SIA
Siting		Always	Seldom	Included in SEA	Included in SEA
Tender	The state organizes a specific MSP area and there is no additional assessment (Auction to find a developer for the area)				
Design	Always		Seldom	Included in EIA	Included in EIA
Construction	Always		Seldom	Included in EIA	Included in EIA
Operation	Always		Seldom	Included in EIA	Included in EIA
Repowering	A topic that has not yet been covered and is not currently being covered (probably EIA)				
Decommissioning	Often/ included in earlier EIA		Seldom		

Table 4 Indicative use of assessment tools across OWF life-cycle phases in Estonia.

4.2.3. Portugal

In Portugal, offshore wind planning and development relies strongly on the regulatory framework for environmental assessment, with EIA serving as the primary instrument for evaluating project-level impacts across most life-cycle phases.

SEA is applied primarily during the siting phase, particularly where spatial planning processes are used to identify potential offshore wind areas.

Additional analyses, such as cumulative and social impact assessments, are typically addressed within the EIA process. In specific cases, risk assessments may also be required, for example, where projects fall under the Seveso Directive (European Commission, 2012), due to the presence of hazardous materials such as energy storage systems.

PHASES	EIA	SEA	LCA	CIA	SIA
Siting	Often	Always		Included in SEA	Included in SEA
Tender	Potentially				
Design	Always			Included in EIA	Included in EIA
Construction	Always			Included in EIA	Included in EIA
Operation	Always			Included in EIA	Included in EIA
Repowering	Always			Included in EIA	Included in EIA
Decommissioning	Always				

Table 5 Indicative use of assessment tools across OWF life-cycle phases in Portugal.

4.2.4. Spain

In Spain, offshore wind planning combines strategic spatial planning processes with project-level environmental assessment procedures. SEA is commonly applied during early planning stages, while EIA constitutes the main regulatory instrument for assessing the environmental impacts of individual projects.

As illustrated in Table 6, cumulative and social impact considerations are generally incorporated within the EIA process rather than conducted as stand-alone assessments. LCA is rarely applied directly, although related analyses such as carbon footprint assessments may be used in project studies.

A specific feature of the Spanish assessment process is the Documento de Inicio (DIP). The DIP is the preliminary document submitted by the project developer at the beginning of the administrative procedure. The purpose of the DIP is to initiate consultation with the competent authority and determine the scope and level of detail required for a subsequent EIA.

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	EIA	SEA	LCA	CIA	SIA
Siting	Always/often	Always/often		Included in SEA	Always/often
Tender		Seldom			
Design	Always/often		Always/often	Included in EIA	Included in EIA
Construction	Always/often		Seldom	Included in EIA	Included in EIA
Operation	Always/often		Seldom	Included in EIA	Included in EIA
Repowering	Seldom				
Decommissioning	Always/often		Seldom	Seldom	Included in EIA

Table 6 Indicative use of assessment tools across OWF life-cycle phases in Spain.

4.2.5. Denmark

SEA is systematically applied during the siting phase, where national planning processes identify suitable development zones and assess environmental constraints. The results of these assessments are typically carried forward into the tender phase.

EIA plays a central role during project design, construction, and operation, where environmental and social considerations are assessed within the permitting process.

PHASES	EIA	SEA	LCA	CIA	SIA
Siting		Always	Seldom	Included in SEA	Included in SEA
Tender		Indirect	Seldom		
Design	Always		Seldom	Included in EIA	Included in EIA
Construction	Always		Seldom	Included in EIA	Included in EIA
Operation	Always		Seldom	Included in EIA	Included in EIA
Repowering	A topic that has not yet been covered and is not currently being covered (probably EIA)				
Decommissioning	Often				

Table 7 Indicative use of assessment tools across OWF life-cycle phases in Denmark.

To synthesise the relationship between decisions and assessment tools across the OWF life cycle, Table 8 links key sustainability-relevant decisions to the primary regulatory tools and supporting analytical approaches, as well as the actors responsible for initiating and approving these decisions.

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OWF phase	Key sustainability-relevant decisions	Holistic assessment tools[2]	Other assessment tools	Initiating actor	Decision authority
Site selection	Identification of suitable development areas Balancing energy production with environmental protection and other sea uses	SEA	CIA, SIA	Planning authorities	National or regional planning authorities
Tender	Definition of environmental and technical Requirements Allocation of development rights	SEA (indirect input)	Technical feasibility studies, economic assessments	Public authorities responsible for tendering	Government or designated (energy)authority
Project design	Turbine selection Layout optimisation Mitigation measures	EIA	CIA, SIA, LCA, modelling tools	Developer	Competent permitting authority
Construction	Construction methods Environmental mitigation Monitoring	EIA	CIA, SIA, LCA, MSFD descriptors, technical modelling	Developer	Competent permitting authority
Operation	Maintenance strategies Environmental monitoring Operational mitigation measures	EIA follow-up	CIA, SIA, (ecosystem monitoring framework), environmental management	Operator	Regulatory authority overseeing permits
Repowering	Upgrade or redesign of infrastructure Assessment of environmental implications	EIA (case-by-case),	LCA, CIA, feasibility studies	Developer	Competent permitting authority
Decommissioning	Infrastructure removal Material recycling Site restoration	EIA (where required)	LCA, waste management analysis, (ecosystem recovery context)	Developer	Competent permitting authority

Table 8 Assessment tools supporting decisions across offshore wind life-cycle phases.

4.3. Cross-country observations on the use of assessment tools in OWF planning

The country mapping illustrates both common patterns and important differences in how assessment tools are applied across offshore wind planning systems in Estonia, Portugal, Spain, and Denmark. While institutional arrangements, planning traditions, and levels of

[2] In this overview, assessments under the HD, BD, WFD, MSFD and Espoo convention are included where relevant in the SEA and EIA tools.

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offshore wind development vary, several consistent features can be identified regarding the role of different tools across the OWF life cycle.

A first observation concerns the central role of Environmental Impact Assessment (EIA). Across all four countries, EIA is the most consistently applied tool and forms the primary mechanism through which environmental considerations are integrated into project-level decision-making. It is systematically used in the design, construction, and operation phases and is closely linked to permitting procedures. This reflects its strong regulatory basis in and its function as a key interface between environmental analysis and formal decision-making.

A second observation relates to the role of Strategic Environmental Assessment (SEA) in early planning stages. SEA is primarily associated with the site selection phase, where it supports decisions on the identification of suitable development areas, often in connection with marine spatial planning. In this role, SEA contributes to defining environmental and spatial boundary conditions for subsequent project development. However, the extent to which these decisions influence later phases varies and depends on how SEA outcomes are translated into planning frameworks and tender conditions. In some countries, SEA outcomes in the process of marine spatial planning are translated into frameworks and conditions for subsequent licensing/permitting procedures and the related EIA process, which also relates to OWF.

The analysis also shows that several important assessment components are typically not applied as stand-alone tools but are instead integrated within broader assessment frameworks. This is particularly the case for cumulative impact assessment (CIA) and social impact assessment (SIA), which are most often addressed within SEA and EIA procedures.

A similar pattern applies to assessments required under the Habitats and Birds Directives and the Water Framework Directive (WFD), which are generally embedded within plan and project level environmental assessments. While this integration reflects both regulatory structures and practical planning approaches, it may influence how explicitly these aspects are addressed and communicated in decision-making processes.

A further observation concerns the role of Life Cycle Assessment (LCA), which appears less systematically integrated in current practice. While LCA is increasingly recognised as a relevant tool for assessing lifecycle environmental performance (European Commission, 2013a, 2013b; European Commission, 2021a), its application remains largely voluntary and project specific. This partly reflects the nature of the EU regulatory framework, where the SEA and EIA Directives are primarily procedural and do not prescribe methods, models, or data requirements, leaving flexibility in how assessments are carried out. As a result, approaches such as LCA are not mandated, even though they could strengthen the assessment of broader sustainability impacts.

At the same time, EU guidance has sought to strengthen the integration of key sustainability aspects into these procedures. In particular, guidance on integrating biodiversity and climate change into SEA and EIA (European Commission, 2013a; 2013b) explicitly promotes the use of life-cycle thinking, and where relevant, LCA-based approaches to better capture indirect, global and long-term impacts. Despite this, the uptake of LCA in practice remains uneven, and it tends to play a supplementary role.

In addition to formal assessment tools, the mapping highlights the importance of technical modelling and analytical tools used by developers and consultants. These tools support decisions related to wind resource assessments, layout, and engineering design, and are particularly prominent in the project design phase. While they are not part of regulatory assessment frameworks, they interact closely with EIA and other assessments by providing technical and economic basis for evaluating alternatives and mitigation measures.

Finally, the mapping indicates that later life-cycle phases – particularly repowering and decommissioning – are less consistently addressed in current assessment practice, reflecting both the relatively recent expansion of offshore wind development and limited practical experience with end-of-life management. As offshore wind portfolios mature, these phases are likely to become increasingly important for sustainability, particularly in relation to circularity, long-term environmental impacts, and future use of marine space.

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5. Sustainability scope of tools

This section synthesises the findings from the review of existing tools by examining their scope in relation to sustainability. Rather than analysing each tool in isolation, the section compares how different tools address environmental, social, and economic dimensions of sustainability and how they frame the management of impacts.

Two aspects of scope are particularly relevant. First, tools differ in the sustainability dimensions they address, including environmental, social, and socio-economic considerations. Second, tools vary in their orientation toward managing impacts, particularly in terms of whether they focus primarily on mitigating negative effects or also aim to identify opportunities for positive contributions through enhancement.

Examining tools through these two lenses provides a basis for understanding how comprehensively current assessment approaches address sustainability concerns. It also reveals differences in emphasis across tools and highlights areas where important sustainability perspectives may be underrepresented.

5.1. Basis for analysing sustainability scope of tools

This section establishes the analytical basis used to assess how different tools address sustainability in offshore wind planning and development. Building on the identification of tools in Section 3 and the conceptual framing of sustainability in Section 4, the analysis applies two complementary perspectives:

1. The unfolding of sustainability factors, based on the environmental concept embedded in SEA and EIA.
2. The distinction between mitigation and enhancement, reflecting different ways in which tools contribute to sustainability outcomes.

These perspectives enable a structured comparison of tools in terms of both what they assess and how they contribute to sustainability.

5.1.1. Unfolding sustainability factors

To analyse the sustainability scope of the assessment tools identified in Section 3 in a systematic and comparable way, this report adopts the environmental concept embedded in European SEA and EIA regulation as its primary analytical framework.

This choice reflects four interrelated considerations concerning regulatory relevance, conceptual robustness, practical applicability, and alignment with the overarching project framework.

First, the SEA Directive (2001/42/EC) and the EIA Directive (2011/92/EU, as amended by 2014/52/EU) provide a legally established and widely operationalised definition of the environment in European planning and project development. This definition encompasses biodiversity, population and human health, soil, land, water, air, climate, material assets, cultural heritage, and the interactions between these factors. As such, it reflects an integrated understanding of sustainability, spanning environmental, social, and socio-economic dimensions. Using this definition as a basis ensures that the analysis is anchored in existing regulatory practice and directly relevant to how offshore wind development is planned, assessed, and permitted across Europe.

At the same time, it is important to recognise that the SEA and EIA Directives are fundamentally procedural in nature. They define what should be considered, but do not prescribe how assessments should be conducted in terms of methods, indicators, or data requirements. This procedural character introduces flexibility but also leads to variation in how sustainability factors are interpreted, operationalised, and prioritised in practice. To support more consistent consideration of key sustainability issues, the European Commission has developed guidance on the integration of biodiversity and climate change mitigation and adaptation in SEA and EIA, including the use of life-cycle thinking and, where relevant, LCA-inspired approaches. These developments highlight both the evolving scope of assessment practice and the need for complementary tools to address aspects not fully covered by traditional procedures.

Second, this environmental concept has been further conceptualised and operationalised in environmental assessment research and practice, notably by Kørnøv et al. (2023) and further elaborated in Ravn-Boess et al. (2026). In this work, the broad regulatory definition is translated into a structured and operational framework that supports systematic identification and analysis of sustainability factors across environmental, social, and socio-economic domains.

Third, this conceptualisation has been implemented in practice through the Danish EA Tool, which provides a shared data space and structured set of GIS-based layers for environmental assessment, covering both onshore and offshore contexts. The EA Tool demonstrates how the environmental concept can be translated into operational categories and datasets, enabling more consistent screening, scoping, and analysis across projects and planning processes.

Fourth, the adoption of this framework is closely aligned with the scope and expectations defined in the project's call and grant agreement. The call emphasises the development of modelling and design tools supported by holistic, life-cycle-oriented assessment of environmental, social, and economic impacts of offshore wind, including cumulative effects and interactions with ecosystems and communities.

The environmental concept embedded in the SEA and EIA Directives directly reflects this integrated understanding, encompassing multiple sustainability dimensions and their interactions. Using this concept as the analytical foundation therefore ensures that the framework captures the breadth of issues required by the call, while remaining anchored in established regulatory practice and decision-making contexts.

These four elements—the regulatory definition, its conceptual development in research, its operationalisation in tools and practice, and its alignment with the project framework —provide a robust and practice-oriented foundation for analysing the sustainability scope of assessment tools.

Based on this foundation, Table 9 presents a structured overview of sustainability factors used to analyse the scope of the reviewed tools. The table retains the environmental factors as defined in the SEA and EIA Directives, while illustrating how these factors are operationalised in practice through examples of impacts and impact pathways. The distinction between impacts (i.e. effects on environmental and societal receptors) and impact pathways (i.e. causal chains linking project-related pressures to these effects) reflects standard environmental assessment logic and supports a more precise analysis of how different tools address sustainability.

It should be emphasised that the table does not represent an exhaustive or prescriptive list of impacts, but rather an analytical operationalisation of the sustainability concept. The level of detail and specific issues considered in practice will vary depending on project characteristics, data availability, methodological choices, and regulatory interpretation at national level.

Finally, while the environmental concept provides a comprehensive and widely accepted basis for sustainability assessment, it does not fully capture all dimensions relevant to offshore wind development. In particular, lifecycle impacts, global supply chain effects, and broader system-level interactions are only partially addressed within SEA and EIA practice. These aspects are therefore considered explicitly in the subsequent analysis, including through tools such as Life Cycle Assessment (LCA), and are reflected in the identification of gaps and complementarities between assessment approaches.

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Sustainability dimension	Factor	Examples of impact	Examples of impact pathways (pressure → receptor → impact)
Environmental	Biodiversity, flora and fauna	Habitat loss, disturbance, displacement, mortality, reduced ecological connectivity, changes in species composition	Construction noise/seabed disturbance/turbines' presence → marine mammals, birds, fish, benthic habitats → disturbance, displacement, mortality
	Soil and seabed	Physical disturbance, sediment resuspension, contamination, erosion, alternation of seabed structure	Foundation installation/cable laying → seabed and sediment systems → disturbance, erosion, contamination, creation of artificial substrate and invasive/non-native species
	Land	Land take, land-use change, spatial fragmentation, loss of habitats	Onshore infrastructure development → habitats → land take, fragmentation
	Water	Reduced water quality, turbidity, eutrophication, changes in ecological status	Sediment plumes/discharges → coastal and marine waters → turbidity, water quality, deterioration
	Air	Air pollution, reduced air quality, emissions of pollutants	Emissions from vessels and construction → air environment → reduced air quality
	Climatic (including climate mitigation and adaptation)	Greenhouse gas emissions (direct and indirect), contribution to climate change, climate vulnerability, reduced resilience	Lifecycle emissions / exposure to extreme weather → global climate system / infrastructure → emissions / climate risks
	Landscape and seascape	Visual intrusion, altered landscape and seascape, cumulative visual effects	Presence of turbines / lighting → visual receptors (coastal users, landscapes) → visual impacts
	Cultural heritage	Damage to archaeological sites, loss of cultural value, disturbance of heritage landscapes	Seabed disturbance / construction → underwater heritage, cultural sites → damage or loss
Social	Population	Restricted access, displacement of activities, distributional impacts, changes in livelihood	Spatial exclusion / safety zones → local communities, fisheries, users → displacement, access restrictions, reduced livelihood
	Human health	Noise disturbance, stress, reduced well-being, potential physical health effects	Noise / emissions / visual exposure → nearby populations → health and well-being impacts
Socio-economic	Material assets	Reduced access to resources, pressure on existing assets, infrastructure interactions	Project infrastructure → fisheries, shipping, tourism → access limitations, socio-economic impacts, conflicts, benefits
Cross-cutting	Risks of accidents and disasters[3]	Cable damage, vessel collision, unexploded ordnance, or sabotage of subsea cables. Introducing new risks in e.g. PtX infrastructures.	PtX infrastructure with storage of large number of gasses → nearby population → increased risks of fatalities.
	Resource efficiency[1]	High use of resources, e.g. scarce minerals, non-renewable resources.	Use of neodymium for magnets → global stock of neodymium → resource scarcity
	Interaction between factors (including cumulative effects)	Cumulative impacts, system-level changes, interaction across sectors and ecosystems	Multiple OWFs / combined pressures → ecosystems and communities → cumulative and interacting impacts over time and space

Table 9 Sustainability factors, impacts impact pathways, and examples. Cumulative impacts can occur in all examples.

[3] Risks of accidents and disasters and resource efficiency are not explicitly mentioned in among the factors to be assessed upon in the EIA and SEA Directives, but they are highlighted in the preamble to the EIA Directive as aspects that should "constitute important elements in assessment and decision-making processes" (preamble 7). They are therefore included in the list of sustainability factors.

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5.1.2. Mitigation versus enhancement

In addition to identifying which sustainability factors are addressed, it is essential to analyse how assessment tools contribute to sustainability outcomes. A key distinction in this regard is between mitigation-oriented and enhancement-oriented approaches.

Environmental assessment practice in Europe has historically been dominated by a mitigation logic, rooted in regulatory requirements under the SEA and EIA Directives. In this context, assessment primarily serves to:

- Identify potential adverse impacts.
- Avoid impacts where possible (e.g. through site selection).
- Minimise impacts through design and operational measures.
- Correct impacts through mitigation and restoration of affected areas.
- Compensate for residual impacts where avoidance is not feasible[4].

This mitigation hierarchy remains fundamental and continues to play a critical role in preventing environmental harm and ensuring regulatory compliance.

However, as increasingly recognised in impact assessment research and recent developments in policy and practice, this approach is necessary but not sufficient for achieving broader sustainability objectives. Emerging literature emphasises that impact assessment should also support proactive and positive contributions to sustainability, rather than focusing primarily on impact avoidance and reduction. This shift is reflected in recent discussions on the evolution of impact assessment towards more transformative and sustainability-oriented approaches, where the role of assessment expands from controlling negative effects to actively shaping desirable outcomes (see e.g. recent contributions in impact assessment literature such as Kørnøv et al., 2025; Bond et al., 2013; Morrison-Saunders and Sánchez, 2024; Sinclair et al., 2022).

In this report, enhancement is understood as the identification and realisation of opportunities to:

- Improve environmental conditions (e.g. ecosystem restoration, biodiversity net gain, artificial reef effects associated with turbine foundations).
- Generate positive social outcomes (e.g. community benefits, co-use of space with fisheries or aquaculture).
- Contribute to broader socio-economic value creation (e.g. local supply chains, innovation, regional employment opportunities).

[4] The term "compensation" can be somewhat sensitive in environmental assessment terminology, particularly in relation to AA under the Habitats Directive, where compensatory measures are generally associated with situations where adverse effects on Natura 2000 site integrity cannot be avoided, and the use of such terminology may therefore imply a specific legal interpretation and potentially increase the risk of legal challenge or litigation.

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- Support long-term system-level sustainability transitions, including circularity and resource-efficient infrastructure development.

Enhancement thus implies a proactive and opportunity-oriented perspective, in contrast to the reactive and impact-focused logic of mitigation. A distinction can also be made between enhancement measures that are necessary to achieve sustainability objectives or compensate for impacts within the assessment framework, and broader positive societal or economic benefits that may arise from offshore wind development more generally.

Many tools contain elements of both mitigation and enhancement, but with different degrees of emphasis and levels of systematic integration. For example, while SEA has the potential to support enhancement through early strategic choices, and EIA may include enhancement measures in project design, both are still predominantly structured around mitigation requirements. Conversely, tools such as Life Cycle Assessment (LCA) and certain planning or design tools may more explicitly support optimisation and improvement but are often not embedded in regulatory decision-making.

The distinction between mitigation and enhancement therefore provides a critical analytical lens for this report. It enables a more nuanced assessment of how tools contribute to sustainability by examining:

- whether they primarily support impact avoidance and reduction,
- whether they also enable proactive sustainability improvements, and
- how systematically these functions are integrated into decision-making processes.

In the context of offshore wind development, this distinction is particularly important, as decisions across the life cycle—from site selection to decommissioning—shape not only the extent of environmental impacts but also the potential for positive contributions to sustainability outcomes.

5.2. Tool scope

Building on the overview of assessment tools in Section 3 and the conceptual framing of sustainability factors in Section 4, this section analyses the extent to which different tools address the various dimensions and factors of sustainability in OWF planning and design.

5.2.1. Sustainability factors

Tool	Biodiversity, flora and fauna	Soil and seabed	Land	Water	Air	Climate (mitigation and adaptation)	Landscape and seascape	Material assets	Cultural heritage	Population	Human health	Risk of accidents and disasters	Resource efficiency
SEA	+	+	+	+	+	+	+	+	+	+	+	(+)	(+)
EIA	+	+	+	+	+	+	+	+	+	+	+	(+)	(+)
LCA	(+)		(+)	(+)	(+)	+		(+)			(+)		+
SIA								(+)	(+)	+	+	(+)	
CIA	+	+	+	+	+	+	+	+	+	+	+	(+)	
TIA	+	+	+	+	+	+	+	+	+	+	+	(+)	
AA	+											(+)	
WFD Assessment				+								(+)	
MSFD	+	+		+								(+)	

Table 10 Tools' sustainability coverage. [5]

[5] Risks of accidents and disasters and resource efficiency are not explicitly mentioned in among the factors to be assessed upon in the EIA and SEA Directives, but they are highlighted in the preamble to the EIA Directive as aspects that should "constitute important elements in assessment and decision-making processes" (preamble 7). They are therefore included in the list of sustainability factors.

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5.2.2. Mitigation vs enhancement

Building on the distinction between mitigation and enhancement introduced in Section 5.1.2, this section analyses how the reviewed tools support different types of sustainability contributions in offshore wind development.

Across the assessed tools, a pattern emerges: mitigation is systematically embedded and often mandatory, whereas enhancement is unevenly addressed and rarely required, see Table 11.

Dominance of mitigation-oriented approaches

The analysis shows that the core regulatory tools governing offshore wind planning and development—particularly SEA, EIA, Appropriate Assessment (AA), and Water Framework Directive (WFD) assessments—are strongly oriented towards mitigation.

Mitigation is not only a central objective but typically a legal requirement, embedded in:

- The identification of likely significant effects (SEA).
- The prediction and mitigation of project-level impacts (EIA).
- Strict protection requirements (AA).
- Threshold-based environmental objectives (WFD and MSFD).

These tools therefore provide a robust framework for avoiding and reducing negative impacts, particularly in relation to biodiversity protection and regulatory compliance.

Limited and uneven integration of enhancement

In contrast, enhancement is not systematically required in any of the core regulatory tools.

Where enhancement is addressed, it is typically:

- Implicit rather than explicit.
- Optional rather than mandatory.
- Dependent on implementation practice rather than regulatory structure.

For example:

- SEA provides opportunities for enhancement through the consideration of alternatives and strategic choices, but this depends heavily on how objectives are framed.
- EIA may include enhancement measures (e.g. biodiversity improvements), but these are not required and are often secondary to mitigation. In some cases, biodiversity improvements may also result from compensatory measures required to offset residual significant adverse impacts. However, such measures are intended to counterbalance identified harm and therefore do not constitute voluntary or proactive enhancement, even if they lead to positive environmental outcomes.

- MSFD introduces a broader ambition of achieving Good Environmental Status, but this operates at a system level and is not directly translated into project-level enhancement requirements.

Some tools and approaches demonstrate a stronger orientation towards enhancement, although they are typically not mandatory:

- LCA supports identification of lifecycle impacts and enables optimisation of materials, design, and resource use, thereby contributing to system-level improvements and circularity.
- SIA, where applied proactively, can support community benefits, co-use of space, and local value creation, although this is rarely systematic in practice.

These tools therefore contribute to enhancement primarily through design and optimisation, rather than through regulatory requirements.

Tool / approach	Is mitigation mandatory?	Is enhancement mandatory?	Comments on role in practice
SEA	Yes Identification and mitigation of likely significant effects required	No Possible through alternatives and orientation towards objectives	Strong potential for enhancement, but depends on how plans and alternatives are framed
EIA	Yes Mitigation measures required as part of assessment and permitting	No May be included voluntarily	Central regulatory tool. Strong on mitigation, limited systematic focus on enhancement
LCA	No But identifies impact hotspots	No But enables optimisation and improvement	Strong on identifying improvement potential; weak regulatory integration
SIA	Mitigation of social impacts expected where SIA is applied	Enhancement depends on context and ambition	High potential for enhancement (e.g. community benefits), but rarely systematic
CIA	Mitigation of cumulative impacts expected where CIA is applied	Enhancement depends on context and ambition	Strong analytical role; limited influence on proactive design.
TIA	Yes Cross-border impacts must be identified and addressed	No	Ensures consideration of trans-boundary impacts; mitigation-focused
AA	Yes Strict requirement to avoid adverse effects on Natura 2000 sites	No	Functions as a hard constraint; may indirectly drive better solutions. In some cases, authorities require compensatory measures involving restoration of areas larger than those affected.
WFD assessment	Yes No deterioration and protection of water status required	Partly Improvement required to achieve “good status,” but framed as compliance rather than enhancement	Improvement obligations exist but are framed as threshold compliance rather than proactive enhancement
MSFD	Yes Reduction of pressures required	Partly Achieving Good Environmental Status implies improvement, but not project-specific enhancement	Ecosystem-based; enhancement indirect and policy-driven

Table 11 Assessment tools' coverage of mitigation and enhancement.

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6. Tools under development in European research and innovation projects

In addition to tools currently used in OWF planning practice, a growing number of European research and innovation projects are developing analytical methods, databases, and decision-support tools aimed at improving sustainability outcomes in offshore wind development. This section provides an overview of such tools based on a targeted mapping of recent and ongoing projects relevant to offshore wind planning and marine spatial decision-making.

The purpose of this section is not to provide an exhaustive review of individual projects, but to identify common approaches, thematic emphases, and emerging trends in research-based tool development. The review complements the practice-based mapping presented in Section 4 by highlighting how sustainability challenges are currently being addressed in the research and innovation landscape, and where gaps and overlaps with existing practice can be observed.

6.1. Basis for the project mapping

The mapping is based on a structured screening of EU-funded research and innovation projects that are started or finalised after 2021. The mapping is focusing on projects that develop decision-support tools, evaluation methods, or develop dataspaces relevant to offshore wind energy planning. The overview of EU-funded projects is supplemented by selected other relevant research projects.

Projects were identified through a search in https://cordis.europa.eu/ and supplemented by consortium partners' knowledge of relevant European and national projects, including projects focusing on environmental mapping, cumulative impact assessment, social acceptance, techno-economic analysis, and integrated spatial decision support. For each identified project, information was collected on the main purpose of the tool or framework, the year of expected finalisation, and the sustainability dimensions covered.

The mapping is not intended to be exhaustive but to provide a representative overview of current research and innovation efforts that are relevant for sustainability-oriented decision support in offshore wind planning. This approach ensures coverage of both well-established thematic areas and emerging approaches, while maintaining a clear focus on decision relevance across OWF planning phases.

Related SUSTAINOW topic	Project abbreviation (and link)	Year of completion	Purpose	Scope sustainability
Marine data	ILIAD	2025	To develop a data-intensive, cost-effective Digital Twin of the Ocean	Environment, social
Marine data	SEADITO	2027	Restore ocean health by social-ecological analysis and models for digital twin ocean.	Social, environment
Marine data	AquaInfra	2026	Restore ocean health by developing a virtual environment with multidisciplinary data and services	Environment
Marine data, siting	DTWO	2027	Digital twin of offshore wind, siting conditions	Socio-economy
Siting	Spowind	2026	Overcoming challenges with a marine spatial planning WebGIS tool. Focus on Mediterranean Sea	Social, socio-economy, Environment
Siting, Impacts	WIMBY	2025	Addressing restrictive regulations and negative public perception, providing a Web-GIS interactive platform	Environment, social
Tenders, impacts	WindScore	2028	To develop a decision-making tool in the form of a 360-degree KPI toolbox. Design of tender criteria and holistic evaluation	Environment, social, socio-economy
Impacts	GES4SEAS	2026	Achieving good environmental status for maintaining ecosystem services, methods for assessing integrated impacts of cumulative pressures.	Environment
Impacts	ActNOW	2027	Advancing understanding of cumulative impacts on European marine biodiversity, ecosystem functions and services for human wellbeing. Method developed.	Environment
Impacts	Off-coustics	2028	Reducing offshore wind and tidal turbine damage with focus on acoustic repercussions. Model developed.	Environment
Impacts, Floating	FloatFARM	2027	Offshore wind, reducing negative impacts on marine life and enhancing acceptability. Method developed.	Environment, social
Impacts, Floating	FLOATANT	2022	Deep water floating wind, exploring environmental and social impact of floating platform. Method developed.	Environment, social
Impacts, Floating	ATLANTIC	2029	Technological advancement of floating offshore wind turbines. Method development.	Environment
Impacts, Floating	CoreWind	2023	Research on concrete-based floating substructure concepts. LCA work.	(LCA)
Impacts	ROMEO	2022	Solutions for reducing Operation & Maintenance (O&M) costs, LCoE reductions method	Socio-economy
Impacts	UNITED	2023	Multi-use platforms or co-location of different activities in a marine and ocean space. Method developed.	Environment, socio-economy

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Impacts	MARINEWind	2025	Provide an interactive tool to assess the Levelised Cost of Energy for offshore wind technologies.	Socio-economy
Mitigation, Impacts	EcoCorp	2025	Integration of biodiversity in offshore wind planning by combining ecosystem and corporate approaches.	Environment
Mitigation, Floating	INF4INiTY	2027	Nature inclusive designs for subsea components of floating offshore wind installations.	Environment
Mitigation	OCEaN	-	Achieving a nature-friendly energy transition, catalogue of mitigation measures	Environment
Acceptance	WENDY	2025	Unravelling the factors triggering social acceptance of wind farms – technical, environmental and social	Environment social

Table 12 Mapping of ongoing research and innovation projects of relevance for SUSTAINOW.

Across the mapped projects, tool development is most concentrated on methods for evaluating technological innovation, however, there are also tools related to marine data, siting and project evaluation. The majority seems to recognise the importance of early decisions for sustainability outcomes. Many projects aim to improve specific types of impacts, either on nature-specific, social, economic, or cumulative impacts. Most of the mapped projects are focusing on impacts on nature.

The projects focused on project design, have focus on environmental mitigation, layout optimisation, and cost modelling. By contrast, relatively few research-based tools explicitly target the tender phase, despite its strategic importance for embedding sustainability requirements through contractual and governance mechanisms.

Tool development related to construction and operation phases is more limited and often focused on technical or economic optimisation rather than on broader sustainability considerations. Tools addressing repowering and decommissioning remain scarce, even though these phases are increasingly important for circularity, long-term environmental impacts, and future sea use.

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