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Feasibility of ecological compensation for offshore wind power in the Baltic Sea

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Abstract:

This thesis aims to study the feasibility of ecological compensation for offshore wind power projects in the Baltic Sea region from ecological, governance, financial, and social perspectives. Ecological compensation provides a potential method for mitigating the biodiversity impacts of offshore wind development on the Baltic Sea environment.

Data for the study was gathered through expert interviews, including insights from industry, government, research, and NGO representatives. The data was analysed using inductive content analysis with thematic coding. Findings indicate that ecological compensation for offshore wind development in the Baltic Sea is feasible under certain conditions. Social and governance factors support the feasibility of ecological compensation, whereas ecological and financial aspects face more challenges, often due to the limited knowledge and uncertainties considering marine ecosystems. Ecological compensation is the last step of the mitigation hierarchy and should be applied only after implementing all other mitigation measures.

For ecological compensation to be entirely feasible, more research is needed on marine underwater ecosystems, the biodiversity impacts of offshore wind development, the impact of introducing mandatory ecological compensation into legislation and the development of the Finnish compensation market. The possibility of establishing a dedicated authority to oversee ecological compensation projects could be explored. Implementing ecological compensation transparently and in close collaboration with stakeholders and research organisations could help gain practical experience and build essential knowledge of effective ecological compensation in the Baltic Sea region.

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Tiivistelmä:

Tämän tutkielman tavoitteena on tutkia ekologisen kompensaation toteutettavuutta Itämeren alueen merituulivoimaprojekteissa ekologisesta, hallinnollisesta, taloudellisesta, ja sosiaalisesta näkökulmasta. Ekologinen kompensaatio on keino lieventää merituulivoiman biodiversiteettivaikutuksia Itämeren ympäristössä.

Aineisto kerättiin haastattelemalla teollisuuden, hallinnon, tutkimuksen ja kansalaisjärjestöjen edustajia. Aineisto analysoitiin hyödyntämällä induktiivista sisältöanalyysiä ja temaattista koodausta. Tulosten mukaan ekologinen kompensaatio Itämeren merituulivoimatuotannon tapauksessa on toteutettavissa tietyin edellytyksin. Sosiaaliset ja hallinnolliset tekijät tukevat toteutettavuutta, kun taas haasteita on koskien erityisesti ekologista ja taloudellista toteutettavuutta, mikä johtuu suurimmilta osin meriekosysteemejä koskevan tiedon puutteesta ja sen epävarmuudesta. Ekologinen kompensaatio on lievennyshierarkian viimeinen vaihe, ja tulisi toteuttaa vasta muiden mahdollisten toimien jälkeen.

Jotta ekologinen kompensaatio olisi täysin toteutettavissa, tarvitaan lisää tutkimusta merenalaisista ekosysteemeistä, merituulivoiman ympäristövaikutuksista, pakollisen ekologisen kompensaation lainsäädäntöön sisällyttämisen vaikutuksista ja Suomen kompensaatiomarkkinan kehittymisestä. Mahdollisuutta perustaa viranomainen valvomaan kompensaatioprojekteja voitaisiin tutkia. Ekologisten kompensaatioiden toteuttaminen läpinäkyvästi yhteistyössä sidosryhmien ja tutkimusorganisaatioiden kanssa voisi auttaa lisäämään käytännön kokemusta ja sen myötä tietoa vaikuttavasta ekologisesta kompensaatiosta Itämeren alueella.

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1 Introduction

Climate change and biodiversity loss are two of the most pressing global challenges. Urgent action is required to mitigate and adapt to climate change as global temperatures continue to rise (IPCC, 2023). Biodiversity loss, driven by human activities such as land-use change, pollution, and resource overexploitation, is similarly alarming (IPBES, 2019). The combined pressures of climate change and biodiversity degradation demand a coordinated global response to mitigate their effects.

Finland, among other countries, is committed to addressing these challenges (European Commission, 2020b; Ilmastolaki 423/2022). It aims for carbon neutrality in 2035 and has set emission reduction targets for the coming decades (Ilmastolaki 423/2022). The energy sector, responsible for 72% of Finland's total emissions (Statistics Finland, 2024b), plays a role in achieving these targets. Currently, wind power represents the majority of new electricity capacity in Finland (Huttunen et al., 2024) and accounts for 18% of the total electricity production (Statistics Finland, 2024a). Offshore wind power is expected to grow after 2030 (Huttunen et al., 2024). It already faces strong interest, as offshore areas offer better wind conditions and space for larger wind farms than land areas (Renewables Finland, n.d.-a).

Offshore wind power can pose risks to biodiversity by potentially impacting the seabed, altering hydrodynamics, and degrading water quality, affecting marine mammals, birds, fish and benthic organisms (Nordic Energy Research & DNV, 2022). The Baltic Sea, already facing pressures such as eutrophication, pollution, and overfishing, is particularly vulnerable to increased human impact on marine ecosystems, such as offshore wind farm development (HELCOM, 2023; Korpinen et al., 2018). Impacts may also occur on land due to cable installation and grid network infrastructure (Nordic Energy Research & DNV, 2022).

Renewable energy production can sometimes conflict with biodiversity protection, leading to a green-green dilemma where sustainability efforts inadvertently cause biodiversity loss (Straka et al., 2020). One way to address this dilemma and mitigate biodiversity loss caused by project activities is ecological compensation. In Finland, voluntary ecological compensation was incorporated into the Nature Conservation Act in 2023 (Luonnonsuojelulaki 9/2023). The idea is that a party responsible for the environmental damage can offset it by restoring habitat or preventing future losses. Ecological compensation has been relatively rare in European offshore wind projects (Vaissière et al., 2014). Despite its potential benefits, significant barriers to its implementation are the lack of knowledge and the assumption that these projects' biodiversity impacts are non-significant (Vaissière et al., 2014).

This thesis aims to address this knowledge gap by exploring the feasibility of ecological compensation for offshore wind power projects in the Baltic Sea region from four perspectives: ecological, governance, financial, and social. Data was collected through 11 expert interviews with government, industry, research, and NGO representatives to gather various insights. The feasibility of ecological compensation of offshore wind energy in the Baltic Sea is examined under two research questions:

1) What are the current challenges and possibilities for implementing ecological compensation in offshore wind power projects in the Baltic Sea?

2) How feasible is the implementation of ecological compensation for offshore wind power projects in the Baltic Sea?

This thesis primarily focuses on the biodiversity impacts of offshore wind energy during the construction and operation phases in marine environments, briefly considering terrestrial impacts. Biodiversity impacts from the supply chain are not covered, as that would require a broader approach beyond the intended focus on local biodiversity. Focusing on the effects of construction and operation allows a more in-depth analysis of the impact relevant to the context of the Baltic Sea.

This thesis begins by providing background for the topic by presenting the current status of offshore wind power and ecological compensation in Chapter 2. Chapter 3 presents the feasibility framework used in this thesis, including ecological, governance, financial, and social dimensions. Chapter 4 describes the data collection process and the analysis method. The results of the interviews are presented in Chapter 5 by each feasibility dimension. The thesis finishes with the discussion, including policy recommendations, suggestions for future research and limitations in Chapter 6, and conclusions in Chapter 7.

2 Contextual background

This chapter covers the current state of offshore wind power production and its impact on biodiversity. It also defines ecological compensation (EC), outlines its economic background, and provides its current status in marine environments and the Baltic Sea. It provides an overview of key studies and reports related to the topic, focusing on the marine environment and laying the foundation for the following chapters.

2.1 Offshore wind power

2.1.1 The current state of offshore wind power

Interest towards offshore wind power is strong in Finland and globally (Global Wind Energy Council, 2023; Ministry of Economic Affairs and Employment et al., 2024) due to electrification, rising electricity consumption, and the need to reduce climate impacts of energy systems and increase energy self-sufficiency (Renewables Finland, n.d.-b). Offshore wind farms can produce more energy than onshore farms as the wind is typically stronger and more constant, and larger farms can be constructed at sea (Renewables Finland, n.d.-b).

Offshore wind power is growing strongly globally, with nearly half of the growth expected from Europe (Global Wind Energy Council, 2023). Offshore wind power plays a role in achieving the climate neutrality target of the European Union (EU) in 2050 (Regulation 2021/1119). The European Commission has developed a strategy for offshore renewable energy, setting a target of at least 60 GW of installed offshore wind power capacity by 2030 and 300 GW by 2050 (European Commission, 2020a). Currently, the offshore wind power capacity of the EU is about 20 GW (Wind Europe, 2024).

Finland, like the EU, is increasingly interested in developing offshore wind power, and the Finnish government aims to establish targets for offshore wind power capacity for the years 2035, 2040, and 2050 and advance offshore wind development processes in different ways (Ministry of Economic Affairs and Employment et al., 2024). Currently, Finland has one operating offshore wind farm, with turbine foundations built on the seabed (Renewables Finland, n.d.-a), and the offshore wind power capacity is about 70 MW (Wind Europe, 2024). Several offshore wind farm projects are under development, with a total output of several thousand megawatts (Renewables Finland, n.d.-a).

While renewable energy development generally enjoys broad support (Bergquist et al., 2020), offshore wind farms can face conflicts with other human activities and opposition related to project governance, natural landscapes, and recreational use, especially among local communities (Kermagoret et al., 2016). Stakeholder opinions vary depending on the project's impacts, their significance for people and the public’s attitudes towards the ocean (Bell et al., 2013; Bidwell, 2017).

According to Virtanen et al. (2022), in Finland, suitable areas for offshore wind power sites with favourable energy production conditions, moderate construction costs and limited disturbance to biodiversity, marine industries and people are primarily located in the Bothnian Sea and the Bothnian Bay. However, site suitability varies based on each area’s unique characteristics. For example, when only economic factors are considered, suitable areas are found closer to shore than when ecological and societal factors are prioritised.

2.1.2 Biodiversity impacts of offshore wind energy

This chapter describes the biodiversity impacts of offshore wind power, focusing on the construction and operation phases, as they have the most significant impacts (Bergström et al., 2014; Nordic Energy Research & DNV, 2022). Biodiversity impacts can be direct, indirect, and cumulative, influenced by the local environment and the installation type (Bergström et al., 2014; Nordic Energy Research & DNV, 2022), meaning either floating or bottom-fixed turbines (Jiang, 2021). Generally, construction has more frequent, intense, and short-term impacts, whereas operational impacts tend to be less severe but more permanent (Bergström et al., 2014; Vaissière et al., 2014).

During construction, pile driving impacts biodiversity significantly (Bas et al., 2016). It is commonly used in bottom-fixed installations, such as monopiles (Jiang, 2021), which is currently the most common type of foundation (Soares-Ramos et al., 2020). Floating turbines, by contrast, typically do not require pile driving (Jiang, 2021). Noise and vibration from pile driving can significantly impact marine mammals and some fish (Bas et al., 2016; Bergström et al., 2014; Vaissière et al., 2014). When installation does not involve pile-driving, acoustic impacts are less severe and arise mainly from other preparation activities such as drilling, dredging, and vessel traffic (Bergström et al., 2014).

Pile driving, cable laying, drilling, and dredging during construction physically alter the seabed and benthic habitats, potentially causing permanent changes and substratum loss (Hiscock et al., 2002; Nordic Energy Research & DNV, 2022). These activities also increase sediment dispersal, leading to turbidity, which can harm benthic organisms, seabed vegetation, and fish by reducing light penetration and disrupting photosynthesis and trophic chains (Vaissière et al., 2014).

In the operation phase, the primary biodiversity impacts include turbine blade movement, electromagnetic fields, and the reef effect (Bas et al., 2016). The impact of electromagnetic fields from cables depends on the cable type, burial depth, and current type (Nordic Energy Research & DNV, 2022). Noise from operating turbines, which varies by wind speed and construction type, may also disturb marine life (Nordic Energy Research & DNV, 2022). However, the acoustic disturbances and the effect of fisheries exclusion remain weakly understood (Bergström et al., 2014).

For fish, electromagnetic fields and noise can affect fish’s spawning, feeding, and migration (Bergström et al., 2014; Hiscock et al., 2002). Similarly, marine mammals’ communication, hunting, and breeding may be disturbed (Bergström et al., 2014; HELCOM, 2023; Hiscock et al., 2002). For birds, noise, electromagnetic fields, vibration, and changes in lighting may cause changes in migration routes (Nordic Energy Research & DNV, 2022; Vaissière et al., 2014). Additionally, the impacts may disturb some benthic communities (Bergström et al., 2014; Nordic Energy Research & DNV, 2022).

Operational wind farms can also alter local hydrodynamics around the turbines (Vaissière et al., 2014), meaning that wind turbine alters wind speeds, potentially affecting turbulence, wave energy, and water movement (Nordic Energy Research & DNV, 2022). However, the effect on animals remains uncertain (Nordic Energy Research & DNV, 2022).

Wind farms may act as barriers, disrupting species' regular movements, breeding grounds, and migration routes, but the effect is complex to quantify (Nordic Energy Research & DNV, 2022). Birds and bats, in particular, face collision risks, leading to mortality and changes in migration routes (Nordic Energy Research & DNV, 2022; Vaissière et al., 2014). Onshore cables can also pose collision hazards for certain species (Bennun et al., 2021).

Habitats can be disturbed in the development zone and along the cable route to shore (Hiscock et al., 2002). The impacts on animals vary by species and location (Nordic Energy Research & DNV, 2022). Habitat alteration in coastal areas with more migration routes and nesting sites threatens fish and seabirds (Bennun et al., 2021; HELCOM, 2023). While most fish, marine mammals, and birds temporarily avoid affected areas, they are expected to return after the disturbance ends (Bergström et al., 2014; Vaissière et al., 2014).

Moreover, offshore wind farms may act as artificial reefs (Knorrn et al., 2024). Fish and benthic organisms benefit from increased food, refuge, and recruitment opportunities (Nordic Energy Research & DNV, 2022; Wilhelmsson et al., 2006), which consequently benefits marine mammals and sea birds in increased food supply (Bergström et al., 2014; Nordic Energy Research & DNV, 2022; Vaissière et al., 2014). More knowledge is needed to understand the potential positive impacts of artificial reefs, especially in the Baltic Sea areas (Nordic Energy Research & DNV, 2022).

Research on offshore wind power's biodiversity effects primarily focuses on northern European marine waters, with fewer studies and limited knowledge specific to the Baltic Sea (Bergström et al., 2014; Rostin et al., 2013). Biodiversity impacts vary across the Baltic depending on local conditions (Rostin et al., 2013). For instance, some areas in Bothnian Bay experience potentially high environmental impacts (Virtanen et al., 2022). Although the biodiversity impacts are often considered minor and reversible, Baltic conditions may intensify them (Rostin et al., 2013).

2.2 Ecological compensation

2.2.1 Definition of ecological compensation

Ecological compensation, sometimes referred to as biodiversity offsetting, incorporates the value of ecological loss into project costs (OECD, 2016). Business and Biodiversity Offsets Programme (BBOP) is widely used in the literature to define and provide the basis for discussing compensations (see, e.g., OECD, 2016). It defines biodiversity offsetting as follows:

> Biodiversity offsets are measurable conservation outcomes resulting from actions designed to compensate for significant residual adverse biodiversity impacts arising from project development after appropriate prevention and mitigation measures have been taken. The goal of biodiversity offsets is to achieve no net loss and preferably a net gain of biodiversity on the ground with respect to species composition, habitat structure and ecosystem function and people's use and cultural values associated with biodiversity. (BBOP, 2018, p. 9)

The terms biodiversity offsetting and ecological compensation are closely related and sometimes interchangeable, depending on the language context, though they retain distinct meanings (BBOP, 2018; Koh et al., 2019). In Finland, the term ecological compensation is more commonly used than the internationally popular term biodiversity offsetting (Karlsson & Karhunmaa, 2024a). The principles behind the terms align in the Finnish context; for example, the Finnish Nature Conservation Act refers to biodiversity offsetting as "ekologinen kompensaatio" or ecological compensation (Karlsson & Karhunmaa, 2024b). Therefore, the term ecological compensation (EC) is used throughout this thesis.

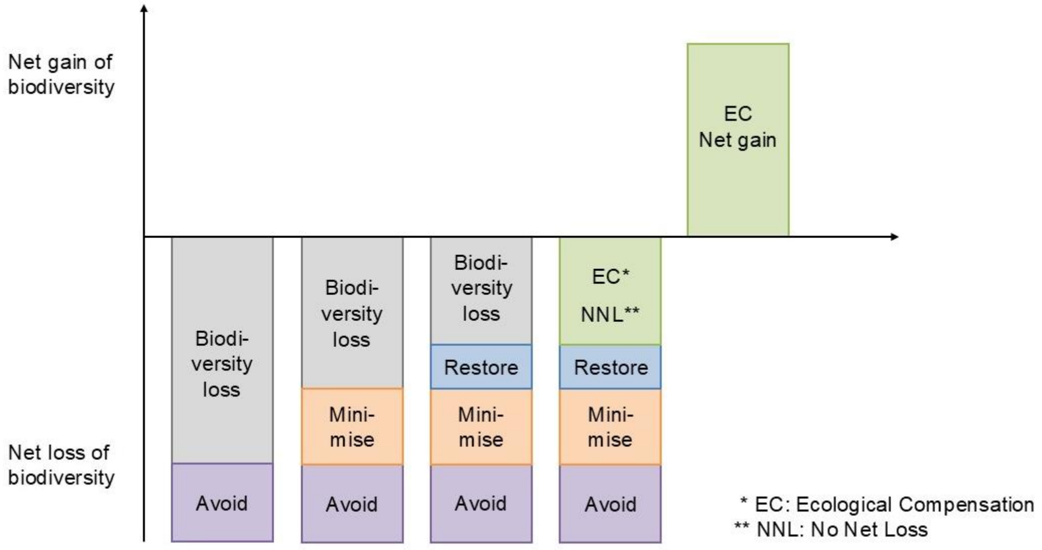

Figure 1. Mitigation hierarchy. Adapted from Bennet et al. (2017, p. 2).

EC represents the fourth and final step in the mitigation hierarchy, which involves avoiding, minimising, restoring, and compensating damage, as shown in Figure 1 (Bennett et al., 2017, p. 2). EC should only be implemented after all efforts to avoid adverse biodiversity impacts, minimise unavoidable damage, and restore biodiversity on-site are exhausted (BBOP, 2018; OECD, 2016). Avoidance involves measures to prevent impacts, such as careful spatial placement of infrastructure; minimisation reduces the duration, intensity or extent of unavoidable impacts; and restoration aims to rehabilitate or restore degraded ecosystems (BBOP, 2018).

According to Bennet et al. (2017), the primary goal of EC is to achieve “no net loss”, although a more ambitious “net gain” target is also possible. No net loss means balancing biodiversity losses with mitigation measures to prevent an overall decline in biodiversity. The net gain is achieved when the biodiversity gains exceed losses. Both are shown in Figure 1 (Bennet et al., 2017, p. 2). The compensation follows a “like-for-like” approach, where the compensation occurs in the same biodiversity type affected by the project, or a “like-for-like or better” approach, targeting habitats that are, for example, more vulnerable (BBOP, 2018).

Table 1. Key design and implementation features. Adapted from OECD (2016, p. 24) and BBOP (2018).

Design and implementation feature	Description
Threshold and coverage	EC will not always be able to deliver equivalent outcomes because biodiversity may be of exceptionally high value, irreplaceable, or vulnerable. Therefore, establishing thresholds for what can and cannot be compensated is critical. Coverage refers to the type of biodiversity intended to be addressed, and the sectors included in the programme.
Equivalence	As no two sites are ecologically identical, designing EC requires assessing how to achieve ecologically equivalent biodiversity benefits at the offset site compared to the impact site. Determining ecological equivalence necessitates comparing the biodiversity loss and offset sites in three dimensions: biodiversity type, location, and time.
Additionality	The biodiversity improvements at offset sites should contribute to biodiversity conservation above the existing levels. Therefore, a reference scenario is needed. EC should deliver new and additional outcomes that would not have resulted without the offset.
Permanence	EC should deliver conservation outcomes for at least as long as the biodiversity loss persists at the development site. Land tenure, financial sustainability, and appropriate incentives for land management are essential components of delivering permanence.
Monitoring, reporting, and verification (MRV)	Robust MRV methodologies that can assess progress toward EC objectives are critical. This includes adequate documentation of management plans, regular monitoring, including on-site checks, clear and transparent reporting, and verification by a third party.
Transaction costs	Transaction costs in EC programmes include the costs of identifying, creating, and securing an offset, applying for development permission, and undertaking MRV and enforcement. Reducing these administrative and time costs will increase the efficiency of an EC programme.
Compliance and enforcement	MRV frameworks must be supported by appropriate compliance and enforcement measures to create the incentives necessary for offset suppliers to deliver conservation outcomes over time.

Design and implementation features (Table 1) ensure that offset schemes are environmentally sustainable, cost-effective, and distributionally equitable (OECD, 2016). In addition to these features, there have been defined good practices for effective offset programmes: clear objectives, clear guidance on how the programme first into the mitigation hierarchy for a country, robust monitoring, reporting, and verification, the use of online databases, choosing the right approach, and regular programme evaluations (OECD, 2016). The critical question when implementing EC is how to ensure the equivalence between the loss at the development site and the gain at the target area (OECD, 2016). McKenney and Kiesecker (2010) identify the following key issues in EC implementation: location, timing and equivalence between project impacts and biodiversity gain, offset duration and management, additionality, and currency and mitigation replacement ratios.

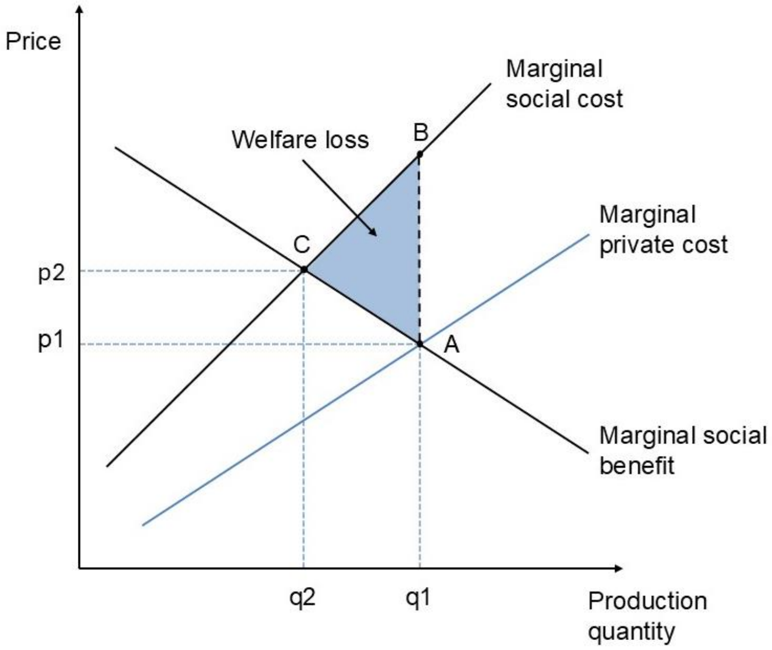

Figure 2. Private vs. socially optimal level of development. Adapted from OECD (2016, p. 55).

According to OECD (2016), biodiversity loss caused by human actions can be viewed as a market failure that requires correction through policy intervention. EC serves as one approach to address this issue. As a market-based instrument, it internalises negative externalities by incorporating the economic value of biodiversity loss into project costs. This cost increase can influence decision-making by encouraging developers to account for biodiversity impacts, incentivising them to choose socially optimal options, such as compensating for or avoiding environmental damage.

As OECD (2016) states, EC follows the polluter pays principle by making developers responsible for covering the environmental costs of their activities that harm biodiversity. Figure 2 illustrates the impact of accounting for production externalities on output levels and prices: A developer seeks to reach point A, where marginal private benefits equal marginal private costs, resulting in a welfare loss represented by the area ABC. The socially optimal solution at point C occurs where marginal social costs equal marginal social benefits. Price p_1 represents the cost without EC, while price p_2 reflects the cost after accounting for biodiversity loss.

In Finland, EC is currently voluntary. Compensation procedure and criteria are laid down in Chapter 11 of the Finnish Nature Conservation Act (Luonnonsuojelulaki 9/2023). The new Act, including the EC criteria, was enacted in 2023. It allows developers to offset environmental damage to habitats or species caused by their activities through compensatory or conservation measures. Both must be completed before any damaging activities occur.

According to the Nature Conservation Act (Luonnonsuojelulaki 9/2023), compensatory measures aim to restore a degraded area to its natural state or to a condition that supports biodiversity, increases the size or improves the ecological quality of the habitat. They must fully offset the damage caused. Required actions by other regulations are not accepted as compensatory measures. Conservation measures involve permanently protecting threatened ecosystems in their natural state, and it must prevent activities that would degrade the natural state. A requirement for conservation measures is that they must deliver a better ecological outcome than compensatory measures.

As the Nature Conservation Act (Luonnonsuojelulaki 9/2023) states, measures can only be applied to equally or more endangered natural values or habitat groups. They must occur in the same or adjacent region as the impact, upholding ecological equivalence. The marine regions included are Bothnian Bay, Kvarken, Bothnian Sea, Åland and Archipelago Sea, and Gulf of Finland (Ympäristöministeriön asetus vapaaehtoisesta kompensaatioista 933/2023).

2.2.2 Ecological compensation in marine environments

This section reviews the application of EC in offshore wind power development, focusing on challenges specific to the Baltic Sea and exploring its potential broader use in marine environments. EC efforts have been implemented mostly on terrestrial ecosystems, with fewer projects in marine and coastal environments (Bas et al., 2016; Shumway et al., 2018) or offshore wind farm development (Vaissière et al., 2014). Some lessons from terrestrial offsets can be applied in marine contexts as the fundamental principles remain despite differences in ecology, governance, and costs (Jacob et al., 2020; Shumway et al., 2018).

The Baltic Sea faces significant pressures from climate change and biodiversity loss, such as eutrophication, pollution, land use changes, and resource extraction (HELCOM, 2023). Many commercial fish stocks, some water bird and marine mammal species, and benthic habitats in open sea areas are in poor condition, which may affect the food web, decrease resilience against environmental changes, and disturb ecosystem services (HELCOM, 2023; Korpinen et al., 2018). The unique characteristics of the Baltic Sea, such as low species diversity, ice formation, and limited water transparency, may intensify the effects of human activities (Rostin et al., 2013), making the ecosystem especially vulnerable to disturbances like offshore wind construction. Therefore, while eutrophication remains a key concern in the region, EC can mitigate further pressures on this delicate ecosystem.

According to Raunio et al. (2019), compensating for biodiversity loss in the Baltic Sea is challenging. Due to underwater habitats’ strong dependency on water quality, only 12% of them are suitable for offsetting by improving the same or more endangered habitats. Compensation opportunities are more promising in coastal areas, as 33% of habitats offer offset potential in the same or a rarer habitat type.

Currently, compensating for the biodiversity loss from construction in Baltic underwater areas lacks effective restoration measures, though potential methods exist (Raunio et al., 2019). EC could mitigate habitat loss and seabed disruption caused by construction activities (Kostamo et al., 2018). Possible EC measures include creating new artificial habitats, dredging, relocating species, financial compensations, the creation of artificial habitats, and restoring or establishing habitats, such as pike and bird wetlands, benthic communities, seabed vegetation, and spawning grounds (Kostamo et al., 2018; Raunio et al., 2019). The potential measures vary depending on the habitat (Kostamo et al., 2018; Raunio et al., 2019).

Nevertheless, in the Baltic Sea context, habitat protection and restoration are insufficient without ensuring water quality (Raunio et al., 2019). Addressing the nutrient load by land-use changes, chemical binding of nutrients, improved livestock manure processing, buffer zones, and wetland establishment, together with measures in the target area, can enhance the effectiveness of marine EC (Kostamo et al., 2018).

In the general context of offshore wind, compensatory measures could include, for instance, protecting and restoring prey species stocks, removing invasive species from seabird nesting grounds, or improving conditions in marine mammals' foraging or breeding areas (Bennun et al., 2021). Loss avoidance measures could include protecting migratory bird nesting grounds, supporting locally managed marine areas to protect critical species or habitats, and supporting the prevention of fisheries bycatch for priority species (Bennun et al., 2021). Although some developers have proposed using artificial reefs for EC, they are typically not accepted since they result from construction activities and are not considered additional measures (Vaissière et al., 2014).

Implementing EC in marine environments poses several challenges compared to terrestrial offsets due to hydrological connectivity, dynamic environment, data gaps and limited knowledge, legislative gaps, and limited evidence of restoration success (Bos et al., 2014; Jacob et al., 2020; Niner et al., 2017; Shumway et al., 2018). High and uncertain costs of marine restoration and the limited availability of suitable measures offering ecological equivalence add further barriers (Bas et al., 2016; Bayraktarov et al., 2016). Additionally, offshore wind's impact assessment faces some uncertainties (Bas et al., 2016; Niner et al., 2017), and occasionally, developers may view biodiversity impacts as insignificant, assuming the marine environment is resilient and positive impacts will outweigh the negative ones (Vaissière et al., 2014).

Careful planning, comprehensive environmental impact assessments and integrating biodiversity considerations into site selection and project design are essential steps before implementing EC (Bas et al., 2016; Jacob et al., 2018). Even in ideal scenarios, compensation rarely fully offsets the damage caused (Raunio et al., 2019), highlighting the importance of other mitigation measures.

3 Conceptual background

This chapter introduces the framework used in this thesis to evaluate the feasibility of EC based on relevant research. It defines the term feasibility and describes how ecological, governance, financial, and social dimensions were chosen based on previous research. Although no universally accepted definition of feasibility or its dimensions exists, various approaches have been applied in academic papers.

Feasibility research aims to determine whether and how a project or idea can be evaluated and implemented, exploring its acceptability and viability to help decision-making (Gadke et al., 2021). Piccolo et al. (2024) describe feasibility as the likelihood that a project will achieve its objectives. Majone (1975b, p. 51) states that “alternative solutions are classified as feasible, efficient, or optimal. A feasible solution satisfies the constraints. Efficient solutions form a subset of the feasible ones.” Similarly, an optimal solution is a subset of efficient ones (Majone, 1975b).

Majone (1975a) divides feasibility into economic, technical, and political feasibility, further defining it in various constraints, including social, political, administrative, institutional, technical, and economic factors (1975b). Gadke et al. (2021) propose a feasibility framework that includes ten dimensions, including social validity, practicality, adaptability, implementation, and effectiveness, among others.

Some feasibility studies considering biodiversity issues have been applied. Piccolo et al. (2024) studied mangrove habitat restoration using five factors: biophysical, social, governance, logistical, and resources. Pilgrim et al. (2013) assessed the compensability of biodiversity impacts through four issues: biodiversity conservation concern, residual impacts magnitude, availability of areas or actions, and practical offset feasibility, including confidence in offset techniques, technical capacity, financing, and timelines of offsets. Additionally, Levrel et al. (2012) emphasise that political, social, and legal consensus is needed to implement EC, regardless of the state of technological innovation, highlighting the role of governance factors.

Based on the previous research and the current status of EC, this study evaluates the feasibility of EC for offshore wind power projects in the Baltic Sea across four dimensions: ecological, governance, financial, and social, as illustrated in Figure 3. While developing the feasibility dimensions for this study, the three pillars of sustainability – ecological, social and financial – were considered as a foundation. Additionally, the governance dimension was incorporated into the framework to ensure alignment with national legislation. In line with Majone's (1975b) idea that certain constraints must be met for a solution to be feasible, these four dimensions must all be satisfied for EC to become fully viable.

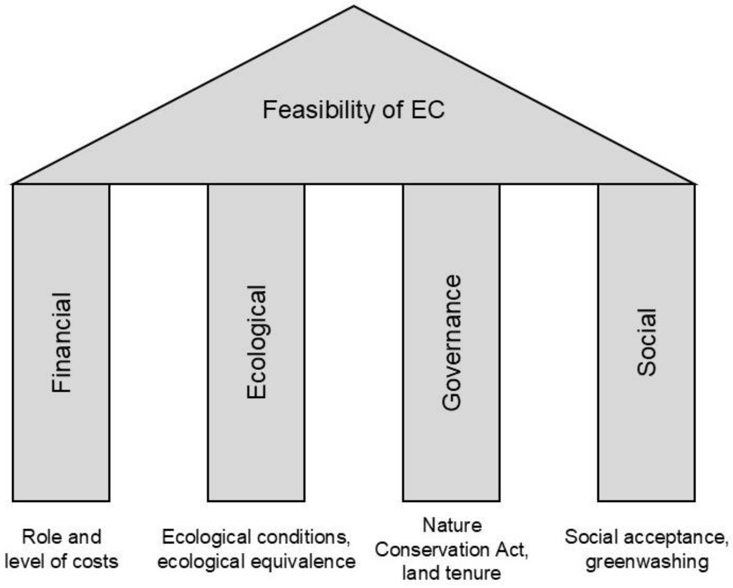

Figure 3. The feasibility dimensions and examples of factors affecting them.

Ecological feasibility evaluates how well compensation measures can be applied in the Baltic Sea areas and their equivalence with the negative biodiversity impacts of offshore wind power development. It considers the ecological conditions, potential for habitat restoration, and availability of suitable habitats. This dimension is crucial for assessing whether compensation measures are ecologically viable and effective.

Governance feasibility examines the barriers and drivers of current Finnish legislation concerning EC in Finnish sea areas. It also includes aspects related to land tenure. For EC to be implemented, it must align with existing regulations, as legal consensus is a crucial factor affecting feasibility (Levrel et al., 2012).

Financial feasibility assesses the costs of implementing EC. Specific numerical data on costs are unavailable, so this dimension assesses the role and level of costs. Given that EC is currently voluntary under Finnish regulations, costs may be critical in deciding whether to include compensation in offshore wind power projects.

Social feasibility refers to the acceptance and support of EC measures for Baltic offshore wind power projects by local communities, electricity consumers, and other stakeholders. It considers factors such as stakeholder acceptance and the risk of greenwashing. Local social acceptance is vital for enhancing the project's effectiveness, particularly in the case of voluntary EC, where social support is crucial (Varumo et al., 2023), as well as the company’s reputation.

There may be some overlapping between feasibility dimensions. For example, ecological equivalence and the availability of target areas connect to both ecological and governance feasibility.

4 Data and methods

This chapter outlines the study's research approach, methodology and data collection. First, the reasons behind selecting the qualitative method are clarified, followed by a description of the data collection process. Lastly, the analysis method is explained.

4.1 Research approach

This study explores the feasibility of EC in the Baltic Sea region in the case of offshore wind power. A qualitative research approach is suitable for exploring this complex and multidisciplinary topic from various perspectives. It helps to understand how the feasibility of EC and its challenges and possibilities are perceived. Additionally, the qualitative approach can reveal new and unexpected insights, especially since EC is a relatively new concept incorporated into Finland's Nature Conservation Act in 2023.

The primary data collection method in this study was interviews. The study followed four common steps of an interview study: preparation, interviewing, analysis, and reporting (Brinkmann, 2013). These phases were not discrete but instead overlapped with a back-and-forth process throughout. Preparation included refining the research problem and familiarising oneself with the topic. After that, the interviews were conducted. The analysis and reporting were carried out after the data was collected through interviews.

4.2 Data

Data collection was carried out through semi-structured expert interviews. Interviews are especially valuable for this topic due to the limited experience and literature on EC in Finnish marine areas and the lack of comprehensive data on biodiversity offset schemes in general (OECD, 2016).

Four groups of experts were identified as relevant when considering EC of offshore wind power production in the Baltic Sea. Selecting experts with diverse backgrounds from these different organisations allowed the research problem to be examined from various perspectives, addressing ecological, governance, financial, and social insights. Given the limited research and experience on EC in Finnish marine areas, this ensures a comprehensive overview of the topic. Selected expert groups are representatives from

- governmental organisations (GOV1, GOV2),
- industry sector (IND1, IND2, IND3, IND4, IND5),
- non-governmental organisations (NGO1, NGO2, NGO3), and
- research organisations (RES1, RES2).

Government representatives shared insights into legislation and land tenure issues, which are critical aspects of the practical implementation of EC. Industry representatives discussed the feasibility of EC from their perspective. NGO representatives highlighted environmental concerns regarding Finnish sea areas, emphasising the importance of considering natural values in offshore projects. Researchers provided extensive expertise on ecological and governance aspects, helping to understand the potential and impacts of EC.

Potential participants were identified through academic networks and connections with possible experience in offshore wind or EC. They were contacted via email and provided with an overview of the study, its objectives, and the purpose of data collection. In total, 25 potential interviewees were contacted, and 11 responded positively. Given the novelty of both EC and the offshore wind industry in Finland, there is a limited number of individuals with relevant expertise. The number of interviews was determined by this limitation while ensuring a sufficient amount of data to generate meaningful results.

After the interviews were scheduled, an information sheet (Appendix 1) and an interview guide (Appendix 2) were sent to each participant. The information sheet included an overview of the study, a description of data protection, and a summary of the current state of offshore wind power and EC in Finland. The interviews were conducted in Finnish via Teams. Phone calls were used as an alternative in cases of connection issues. Each interview lasted between 30 and 60 minutes and was recorded after obtaining the interviewee’s consent. Most of the interviews were conducted individually, except for interviewees IND1 and IND2, who were interviewed together.

The recordings were transcribed using Microsoft Office’s automatic transcription tool and reviewed to remove filler words, repetitions, and significant grammatical errors.

To save time and effort as the spoken language in transcripts offered additional challenges, the transcriptions were translated from Finnish into English with the assistance of the AI tool ChatGPT-4, being careful that no personal information was shared. Quotations used in this thesis are translated from Finnish into English and edited for clarity and readability. AI tools ChatGPT-4 and Grammarly were utilised as a writing assistant to ensure the grammatical quality and clarity of the text of this thesis.

To ensure the confidentiality and transparency of the study, all interviewees were anonymised in the reporting, and sensitive information was handled carefully. The interviewees were informed about the purpose of the study and the use of data. It was made clear that the participation is voluntary. Oral consent was obtained from all participants before recording the interview. Information is stored and handled in accordance with the data protection principles of the University of Helsinki (University of Helsinki, n.d.).

4.3 Methods

Thematic content analysis, specifically inductive content analysis, was used to analyse the interview data. One of the main reasons for choosing this method is its flexibility. Braun and Clarke (2006, p. 78) state that thematic analysis “provides a flexible and useful research tool, which can potentially provide a rich and detailed, yet complex, account of data”. This method is beneficial for identifying patterns in the data (Braun & Clarke, 2006), making it well-suited for under-researched topics like EC of offshore wind power.

This study is based on an inductive approach, meaning that the analysis was guided by the data rather than pre-existing theories (Braun & Clarke, 2006). Brinkmann (2013, p. 54) notes that “inductive designs are particularly well suited to study new and emergent phenomena, where it is premature to formulate specific hypotheses.” A thematic and inductive approach allows for a deep exploration of insights and perceptions surrounding EC at sea.

Data-driven coding was used to analyse systemically the transcribed interview data. Thematic coding is a key component in thematic analysis (Braun & Clarke, 2006) and analytic induction (Brinkmann, 2013). The codes were identified at a semantic level, meaning that the analysis happened within the explicit meaning of the data and did not identify underlying ideas, assumptions, or ideologies beyond what an interviewee said (Braun & Clarke, 2006). The aim was to systemically examine similarities and differences between interviews to analyse the feasibility of EC of offshore wind power. The thematic content analysis followed the structure presented in Table 2 (Braun & Clarke, 2006, p. 87). However, the process was not linear, involving back-and-forth movement between the stages.

Table 2. The phases of thematic analysis. Adapted from Braun and Clarke (2006, p. 87).

Phase	Description of the process
1. Familiarisation with the data	Transcribing data, reading and re-reading the data, and noting down initial ideas.
2. Generating initial codes	Coding interesting features of the data systematically across the entire data set, collating data relevant to each code.
3. Searching for themes	Collating codes into potential themes, gathering all data relevant to each theme.
4. Reviewing themes	Checking if the themes work with the coded extracts and the entire data set, generating a thematic ‘map’ of the analysis.
5. Defining and naming themes	An analysis is conducted to refine the specifics of each theme and the overall story the analysis tells, generating clear definitions and names for each theme.
6. Producing the report	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating of the analysis to the research question and literature, producing a scholarly report of the analysis.

The transcribed and translated interview data was imported into the Atlas.ti for qualitative data analysis. The coding process was conducted in three rounds: First, initial codes were identified based on emerging themes from the interviews, and then, the codes were refined to align with the research problem of the study. Finally, the codes and themes were reviewed to ensure the codes were relevant, sufficiently prevalent, and worked cohesively. The themes and codes are listed in Table 3 (Appendix 3).

5 Results

This chapter presents the results of the data analysis focusing on the challenges and opportunities of EC for offshore wind power in the Baltic Sea region from ecological, financial, governance, and social perspectives based on the interview data. The chapter begins with exploring the experts' perspectives on EC in offshore wind power projects. It continues by providing a more detailed analysis of the ecological, governance, financial, and social factors.

Most interviewees acknowledge the importance of integrating biodiversity considerations into offshore wind power projects. They emphasise that addressing biodiversity loss must be part of business and investment decisions, highlighting tools like environmental impact assessment and compliance with current frameworks such as the EU Taxonomy. Several experts say the green energy transition should account for biodiversity values.

> Something needs to be done, and all indicators also show worsening biodiversity in Finland. There is certainly increasing pressure on the business community to address biodiversity issues. (IND2)
>
> The transition to green energy should happen sustainably, considering our most important nature value areas at sea. (GOV1)

However, a few critical perspectives emerge regarding the significance of offshore wind power's biodiversity impacts. These responses argue that all activities impact biodiversity and that offshore wind power is not one of the worst. Rather than entirely dismissing the importance of considering biodiversity issues, they suggest focusing on broader systemic issues rather than individual projects.

> Compared to other energy production methods, I would not necessarily see that offshore wind power specifically requires special attention in ecological compensation. (IND1)
>
> Discussions about how responsible wind power is might not be a central issue at the moment; the priority is often to get the broader system in order. While addressing these issues well is important, I think we should focus on the larger picture first. (IND3)

While broad support exists for biodiversity protection, implementing EC is more controversial. It is seen as viable after certain conditions. Some interviewees question its necessity or effectiveness, particularly in the marine environment, while others see it as a vital measure in mitigating biodiversity harm. The interviewees highlight that EC should be implemented only after all other mitigation measures, such as harm avoidance, have been implemented. Some argue that EC might be unnecessary from the developer's perspective if projects can meet regulatory requirements without it.

> Harm can be prevented by planning things well. Compensation mindset is a bit like throwing up our hands and saying, "Let's build it now, acknowledge that there will be harm, and then compensate with money." I fear market forces will win, and real nature will be the loser. (NGO3)

Despite concerns, some interviewees see EC as an essential tool for mitigating the inevitable harm caused by offshore wind power projects, especially when avoiding sensitive areas is not possible. The Baltic Sea's already degraded state is cited as a strong motive for using EC to improve marine conditions.

> I think it [ecological compensation] is important. The Baltic Sea as a marine area is in such poor condition, and offshore wind power is massive infrastructure construction, so harmful impacts are inevitable. Even though efforts are made to minimise harmful impacts, they will still occur. (IND5)

Some experts are optimistic about the future of EC, advocating for practical steps to begin implementation despite uncertainties. Researchers especially emphasise the importance of starting EC efforts without waiting for complete certainty, as this would allow for learning and refining the process over time. Table 4 (Appendix 3) presents the frequency of the quotations considering the significance of EC.

> I hope they will start doing them. I would like to believe that the pieces exist and that we should be able to get started. There are undoubtedly a million practical questions that we do not know yet. I do not believe we can solve them without actually starting. ... I am not saying we know everything so perfectly that we can manage this effectively, but by learning together and communicating openly about these matters. I think we could very well start doing and experimenting. (RES1)

Overall, the interviews reveal that EC in sea areas faces more challenges than opportunities (Table 5, Appendix 3). The main obstacles identified include the lack of knowledge, the uncertainty of impacts of offshore wind, difficulties in finding suitable target areas, challenges with the Baltic Sea's marine conditions, legislative challenges, social unacceptability and challenges related to the ecological equivalence (Table 6, Appendix 3). On the other hand, some pathways for success have been identified, and the potential opportunities focus on EC in drainage and coastal areas, improving social acceptability, avoiding greenwashing, and enabling legislation (Table 7, Appendix 3). These drivers could help overcome the barriers and make EC a viable option for offshore wind power projects. A detailed breakdown of the challenges and opportunities identified will be explored further in chapters 5.1–5.4.

Interviewees also discuss alternatives or supplements to EC to mitigate biodiversity impacts. These include artificial reefs, comprehensive environmental impact assessments, funds and panels, harm avoidance by careful site selection, local stakeholder involvement, various technical solutions, and building pilot sites.

In conclusion, while experts widely recognise the importance of integrating biodiversity considerations into offshore wind power projects, the feasibility of EC in marine environments remains divisive. Many highlight challenges and concerns, but also encouragement and positive attitudes emerge. Although implementing EC in offshore energy poses difficulties, addressing the challenges through careful planning and open communication could enhance the perspectives towards EC.

5.1 Ecological feasibility

Experts primarily view compensating for the biodiversity impacts of offshore wind projects as challenging, mainly due to the significant uncertainty surrounding the impacts. This concern is highlighted in nearly every interview. Among the biodiversity impacts, seabed damage with immediate effects is identified as the most straightforward to address. In contrast, impacts on electromagnetic fields and animal migration, for instance, are seen as challenging to offset. Social impacts, such as impacts on fishers' livelihood, are also considered important, although they are not compensable under the Nature Conservation Act.

> Offshore wind power, in particular, seems to present additional challenges. For example, how would one compensate for impacts on birds? I struggle to imagine how to compensate specifically for impacts on birds' migration routes, fish or benthic organisms. (IND2)

The interviewees perceive the Baltic Sea's aquatic environment as challenging due to the diffusion of indirect effects and lack of EC experience. The region's northern, unique, and ecologically poor conditions raise concerns about the sufficiency of EC. Additionally, characteristics of the Baltic Sea, such as the low number of species, pose potential problems.

> Regarding aquatic environments, at least for streams, we know that the natural value hectare concept is very poorly suited or not applicable at all. I cannot say directly about marine environments, but issues might be similar to streams with broader impacts. (IND2)

A key barrier is the lack of ecological knowledge, especially in the Baltic Sea, where much of the environment has been modelled rather than fully mapped. Without a clear understanding of what is being harmed, compensating for the damage is difficult. These concerns are particularly considered in deep-sea areas, where compensation efforts are seen as unfeasible due to logistical and technical challenges and lower biodiversity values.

> Realistically, there is little that can be done in deep-sea areas. … [T]here are no significant actions that could realistically improve conditions of deep seabed areas. (RES1)

> Generally, shallow areas have higher biodiversity, whereas deep-sea areas have less. We have a lot of deep-sea areas, but the coastline, where nature is concentrated, is much more limited. (RES1)

Shallow coastal areas and seabed habitats are considered the most functional for EC, especially for the underwater impacts. Terrestrial areas are seen as straightforward target areas when compensating for the cable-related impacts on land. Interviewees state that if an offshore wind developer is willing to compensate, terrestrial habitats may be the clearest one to start.

Drainage areas are considered to have the most potential for EC, as eutrophication is the key challenge in the Baltic Sea. However, EC in these areas does not apply to offshore wind projects due to the Nature Conservation Act’s requirement for ecological equivalence since the impacts of offshore wind do not involve nutrient emissions. Nonetheless, restoration in drainage areas could help to improve the condition of hard substrates and support the effect of other measures.

> There are drainage area restoration measures for hard substrates that could potentially be used. It depends on whether a corresponding drainage restoration opportunity exists for that specific habitat type group. These areas are usually quite restricted, so you cannot do it anywhere. (RES2)

Conservation is seen as more feasible than restoration, though the need for both is recognised. However, both face more challenges than possibilities. Challenges include concerns about the high and uncertain costs and the ineffectiveness of measures if eutrophication is not addressed. Interviewees highlight that conservation and restoration are insufficient alone and should ideally be used together to supplement each other for efficient results.

> Probably a combination [of restoration and conservation measures is necessary]. Under the Nature Conservation Act, protection is always part of the process. For marine environments, it is likely a mix. (RES1)

> Even if we protect certain areas, if they continue to eutrophicate, there is not much we can do. It undermines the benefits of both protection and restoration. Our main challenge with underwater habitats in Finland is still solving the eutrophication issue. It is not an easy task, and compensation alone will not suffice. (RES2)

The need for conservation measures is recognised due to the EU biodiversity strategy and the poor condition of Baltic habitats. Challenges include monitoring difficulties at sea and a requirement to conserve large areas to compensate for the damage.

> Definitely protection [is needed more]. Currently, 11% of marine areas are protected, and the EU biodiversity strategy aims for 30% protection at sea as well. (GOV1)

> To compensate for the total loss of one hectare, we would need to protect areas about a hundred times larger. This is quite a fatal blow to the mechanism's use. (RES2)

Challenges related to restoration measures include the uncertain availability of suitable marine areas, slow benefits, and potential failures. However, restoration can be effective if appropriately planned and monitored afterwards. The need for restoration measures in the Baltic Sea was recognised.

> Restoration is ... a good solution in the long run, but as we have seen with the Helmi project in the Yyteri mudflats, that restoration really should continue and be maintained; it is never a one-time solution. (NGO2)

> There is a significant need for restoration. I would imagine it is more in the inner archipelago and coastal areas, where eutrophication is a major problem. (RES2)

In conclusion, compensating for the biodiversity impacts of offshore wind projects in the Baltic Sea faces challenges due to the region's ecological complexity and uncertainties of biodiversity impacts. While some feasible EC opportunities exist, particularly in terrestrial and coastal areas and on the seabed, effective solutions will require a combination of conservation and restoration efforts alongside broader strategies to tackle eutrophication.

5.2 Governance feasibility

Government representatives especially find the Nature Conservation Act an enabling regulation for EC. They cite the increased public interest due to the restoration regulation, the RED Directive, and the decreased risk for greenwashing due to the Act’s clear compensation criteria.

> With the restoration regulation passed and the RED Directive that allows exceptions for renewable energy, it actually significantly accelerates and enables more than previous legislation because they are considered projects of overriding public interest. (GOV2)
>
> For businesses, having a clear system where things are verified removes the fear of greenwashing accusations. Since it [ecological compensation] is voluntary, companies want to show their responsibility to financiers that they operate with no significant harm or aim for no net loss. ... In that sense, it enables. (GOV2)

On the other hand, some industry representatives find the Nature Conservation Act’s inflexibility and reliance on the natural value hectare concept too restrictive. Additionally, the EC's voluntary nature may limit its adoption, as development projects can proceed without the implementation of EC. Voluntariness is also a barrier for landowners, as restoration areas have no guaranteed demand.

> Another major challenge is that the criteria for conservation offsets in Finnish legislation are very strict. It is limited to endangered habitats that are representative of natural value or state of preservation, meaning the site must be an endangered habitat and already in very good condition. (RES2)

Another major legal challenge highlighted by interviewees is achieving ecological equivalence, a requirement under the Finnish Nature Conservation Act, emphasising the difficulty of ensuring it in marine areas.

> Effective Baltic Sea protection and improvement would involve reducing nutrient emissions from drainage areas. This could be done, but in the context of ecological compensation, which involves a promise of ecological equivalence – ensuring that compensation benefits target the same type of nature as was destroyed – challenges arise. (RES1)

Land tenure in marine areas lacks clarity. The interviewees suspect that coastal and archipelago regions are likely privately owned and as a result, gathering large enough areas may be challenging. Outer open sea areas are often government-owned, and areas may face competing uses. In both cases, negotiations can be resource intensive.

Additionally, offshore wind sites, harmed habitats, or possible target areas may be located in international waters. Implementing the EC outside Finland's jurisdiction may present some additional challenges.

> If it [compensation area] is in international waters, Finnish authorities will not issue papers. It is clear that they only operate within their jurisdiction. Regarding Åland, they have their own legislation, so I cannot comment on that. ... It needs to be seen which legislation's area is in operation and our legislation's scope of application. That brings some challenges. (GOV2)

In conclusion, government representatives had a more positive approach to the legislative perspectives of EC than other groups. In contrast, industry representatives saw the Nature Conservation Act as too strict and not appealing enough. Based on the interview data, there are no actual legal barriers to implementing EC in sea areas, and marine habitats can be used for EC. However, the Nature Conservation Act's requirements and practical implementation may bring challenges.

5.3 Financial feasibility

The interviewees have limited insights into the costs of compensation projects, which is expected given the lack of mapped habitat data, experience, and knowledge regarding EC in the Baltic Sea's marine environment.

Currently, as EC is voluntary, the interviewees emphasise the role of the costs and the uncertainty related to them. Industry representatives, in particular, note that offshore wind power projects are already on the edge of economic viability and adding compensation costs could further threaten profitability.

> Costs certainly play a role. Companies often consider the cost-benefit aspect of compensation – what do you get out of it? (IND2)

> However, if comprehensive compensation measures were implemented, they could become so expensive that they undermine the project's profitability. (IND3)

Measures like moving the seabed, planting eelgrass, and other restoration actions require site visits and diving. They are seen as expensive and resource-intensive activities. Similarly, activities further away, including construction and transportation, are more costly than areas closer to land. Due to that, EC in deep-sea areas was perceived as particularly expensive.

Conservation measures are estimated to be less expensive than restoration efforts, which involve additional action-related expenses. The need for large areas increases conservation costs. There is much uncertainty about this topic.

> I would say this applies quite globally to all habitat types and environments: Conservation is generally cheaper than restoration because conservation usually involves just the purchase price of the area and possible negotiation costs. In restoration, we need to do that, plus the restoration actions themselves. Essentially, restoration is always more expensive. Of course, restoration costs can vary widely. (RES2)

> If I think about underwater habitats, I cannot immediately think of a type that could be used for protection offsets under these current rules, especially without requiring that every hectare be compensated by a hundred hectares of protection. This becomes so expensive that no one will want to do it. (RES2)

Furthermore, it was mentioned that purchasing areas for conservation in marine environments may be cheaper than in land environments, as there is no assigned value for the land in marine areas.

> It is certainly more expensive on land because land areas have an assigned value, unlike marine areas. … Because of the low compensation, nobody wants to sell, considering they lose ownership of the area. … [I]t is much more lucrative [on land] because the value of the timber and other factors are included. Based on this, I would say conserving water areas is currently a cheap method because no financial compensation is needed. … It is easier to specify what is being paid for on land, while it is much more ambiguous in water areas. (NGO1)

The final factor regarding financial feasibility is that high costs may deter landowners from implementing measures, as there is uncertainty about demand. Landowners are unwilling to invest in expensive restoration measures without guaranteed demand for the areas. This issue is linked to the voluntary nature of EC, as discussed in the previous section.

In conclusion, there is a common view that the high costs of EC could increase the overall project costs, and uncertainty about costs decreases the attractiveness of EC projects, especially in the case of offshore wind development, which is already expensive. However, research representatives emphasise that the primary goal of a compensation system is to increase project costs high enough to incentivise minimising environmental harm, intending that the costs should be noticeable.

5.4 Social feasibility

The experts highlighted both positive and negative effects on the project's social acceptance. Involving local stakeholders in the process and aligning efforts with the Nature Conservation Act are emphasised as crucial factors to avoid greenwashing.

The main reasons behind the negative impact on social acceptance include prior negative experiences, the ineffectiveness of compensation measures, the significance of the damaged areas to individuals who do not benefit from EC elsewhere, pre-existing opposition to the projects, conflicts between stakeholders, and possible restrictions imposed on those living near the target areas.

> This is a double-edged sword. When people oppose a project, they see compensation as greenwashing. When they understand what it is about, it certainly supports local communities' welfare, ensuring that their marine environment remains healthy. (IND5)

On the other hand, having clear criteria and official approval through legislation plays a crucial role in reducing the risk of greenwashing. EC may significantly enhance social acceptance of projects, particularly among stakeholders who already have a positive view of EC and offshore wind power projects.

> For others who may not have such a close connection to the area, knowing that “at least the environmental damage was compensated, and nature did not suffer overall” might be sufficient for acceptance. Especially when talking about something like wind power, it is probably the electricity customer who might think, “Oh, they compensate for their environmental impacts, that is great,” thus, acceptance might come through the attraction of gaining customers. (RES2)

In conclusion, the perception of social aspects of EC in offshore wind projects is nuanced, reflecting both positive and negative impacts on social acceptance. Involving local stakeholders is crucial, as past negative experiences can lead to scepticism and accusations of greenwashing, particularly among those who already oppose the projects. However, when implemented transparently in cooperation with research organisations and according to the Nature Conservation Act, EC can enhance positive social perspectives and demonstrate corporate responsibility.

6 Discussion

This thesis aims to contribute to addressing the research gap in implementing EC in offshore wind energy projects in the Baltic Sea, examining feasibility across four dimensions: ecological, governance, financial, and social. While implementing EC in the Baltic Sea's offshore wind projects appears feasible in governance and social respects, ecological and financial factors face challenges (Figure 4). Ensuring EC's entire viability in the Baltic Sea requires more knowledge about the underwater habitats of the Baltic Sea and the impacts of offshore wind development on marine ecosystems.

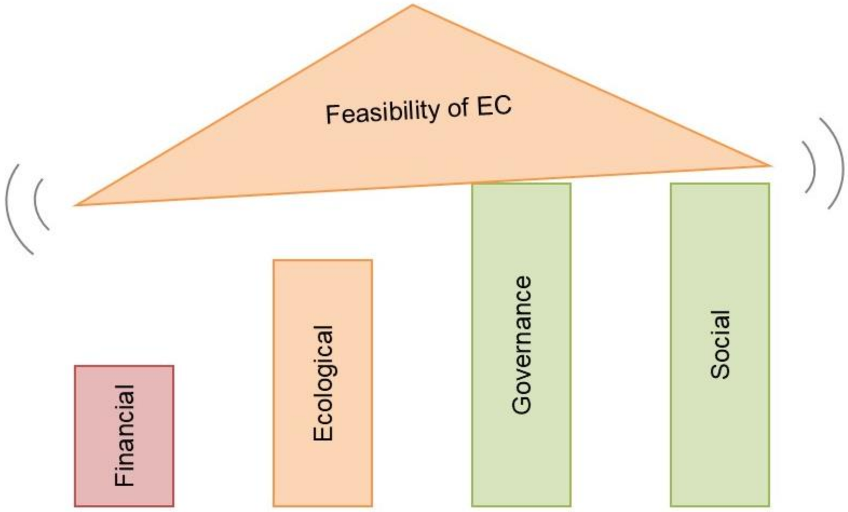

Figure 4. Feasibility dimensions. Green indicates the highest feasibility, orange moderate, and red the lowest.

One major challenge considering EC's feasibility is fulfilling the Finnish Nature Conservation Act's requirement for ecological equivalence in marine environments. Although marine areas can legally be used for EC, finding ecologically equivalent sites remains difficult, depending on the habitat type. This challenge is compounded by limited data on the underwater ecosystems of the Baltic Sea and uncertainties considering the biodiversity impacts of offshore wind. Previous research supports this, as the complexity of marine environments and restricted knowledge and uncertainty in offshore wind power projects' impact assessments are mentioned as barriers to implementing EC in marine environments (Bas et al., 2016; Jacob et al., 2020; Niner et al., 2017; Vaissière et al., 2014).

The results indicate that identifying suitable target areas for EC is difficult without detailed information on the specific biodiversity impacts and damaged habitats from offshore wind development. More research on compensation measures' long-term and cumulative impacts is needed (Vaissière et al., 2014), as effective EC must rely on the best available knowledge (Bayraktarov et al., 2016; Kostamo et al., 2018). The Finnish government aims to initiate research on the impacts of offshore wind power on migratory fish, marine mammals, migratory birds, and bats, as well as increase the quality and quantity of data from the deeper sea areas of the Baltic Sea (Ministry of Economic Affairs and Employment et al., 2024). These efforts could enhance EC's feasibility for future offshore wind projects.

Despite uncertainties in finding suitable compensation sites in the Baltic Sea, some construction impacts offer possibilities for future restoration (Raunio et al., 2019). This study’s findings indicate that seabed damage in shallow coastal areas, often due to cable installation, may be functional for EC in offshore wind power projects. This aligns with prior literature, attributing it to higher biodiversity, the presence of breeding and nesting areas, and lower costs in coastal areas compared to deeper marine areas (Bennun et al., 2021; HELCOM, 2023; Kostamo et al., 2018; Raunio et al., 2019; Van Dover et al., 2014). Impacts from the operational phase, such as noise, turbidity, and electromagnetic fields, are less discussed (e.g., Nordic Energy Research & DNV, 2022), and according to the results of this study, they may be unfeasible to compensate. Nonetheless, impactful marine restoration is possible despite challenges (Sheaves et al., 2021), echoing the opinions of research representatives who see potential in marine EC despite existing challenges.

Additionally, drainage area restoration emerged as an important complementary measure to marine EC efforts. Although reducing nutrient loads alone may not be sufficient as a compensation method for offshore wind, it can support other EC measures. Combining drainage management with marine restoration could enhance the Baltic Sea’s water quality, which is heavily impacted by eutrophication (Kostamo et al., 2018; Raunio et al., 2019).

The study indicates that terrestrial habitats could offer more apparent opportunities to start implementing EC due to existing restoration experiences, availability of suitable measures, simpler monitoring methods, and more straightforward land value evaluation than in marine areas. Onshore impacts from offshore wind development usually stem from cable installation and grid connection and should always be restored upon finalising construction (Nordic Energy Research & DNV, 2022). There is much knowledge regarding the restoration of Finnish mire and forest habitats (Aapala et al., 2013; Junninen & Similä, 2011). These areas also have degraded habitats suitable for restoration and the general potential for EC (Kangas & Ollikainen, 2019). Lessons from terrestrial EC experiences could prove a foundation for developing marine compensation practices, as the core principles remain similar.

The voluntary framework of the Nature Conservation Act may hinder the widespread adoption of EC, as the Act’s requirements may reduce its attractiveness for developers. For example, in Germany, some developers have stated that the EC regulation and criteria may reduce implementation efficiency, especially in sectors operating in many countries, such as the energy sector (Tucker, 2016). The results of this study indicate that mandatory EC could increase the availability of suitable target areas by providing greater certainty for landowners. With a more stable demand for EC, landowners would find it more appealing to engage in restoration, knowing there will likely be a buyer for their efforts. Voluntary EC limits demand and thus shrinks the market (Kangas & Ollikainen, 2019). For the system to function effectively, the market needs to be strong enough (Wissel & Wätzold, 2010).

However, the voluntary EC has only recently been introduced into Finnish legislation, and the compensation market is still developing, meaning that more time is needed to assess its effects. Therefore, more and research is required on the market's development and the impacts of gradually integrating the mandatory EC into legislation. It is essential to ensure that developers can adapt regulations without facing an overwhelming burden. Too strict requirements could lead to a green-green dilemma, where biodiversity conservation conflicts with low-carbon energy targets, complicating renewable energy development.

According to this study, uncertain and potentially high costs, also noted by Bayraktarov et al. (2016) and Van Dover et al. (2014), challenge the financial feasibility of EC in the Baltic Sea. Estimating the costs is further complicated by limited local experience from the Baltic Sea region, as the expenses depend heavily on the local ecosystem, regional economy, and restoration techniques (Bayraktarov et al., 2016). The high costs of EC may discourage offshore wind industry investments. However, in German terrestrial EC projects, costs have been about 2–5% of total construction costs (Technische Universität Berlin, n.d. & Tucker et al., 2016 in Tucker, 2016), indicating a relatively minor economic impact (Tucker, 2016). Nevertheless, costs will likely increase in marine environments, leaving the impact on the profitability of offshore wind power projects uncertain.

Escalating costs could again lead to a green-green dilemma, potentially deterring developers due to the already high expenses of offshore wind power projects. Conversely, low expenses might reduce the effectiveness of EC in preventing biodiversity loss. Establishing a balanced cost level is crucial for incentivising responsible ecological practices among developers without undermining the viability of renewable energy projects. Despite the high costs, implementing EC is important due to its broader ecological and social benefits (Van Dover et al., 2014). To create feasible compensation strategies in the context of the Baltic Sea, further research should explore the costs in the Baltic Sea region and its implications for renewable energy development, including a qualitative cost-benefit analysis to enhance the attractiveness of EC for developers.

Experts' opinions on the seriousness of offshore wind's biodiversity impacts and the significance of EC varied. Researchers tended to support for EC, while NGO representatives favoured harm avoidance by setting up projects in low-impact areas rather than relying on EC. Industry representatives were divided: some perceived the biodiversity impacts and their mitigation as less significant, while others emphasised the need for EC within the mitigation hierarchy, particularly in the sensitive Baltic Sea. In general, it was highlighted that EC should not justify biodiversity damage. Rather, it should be the last resort after all measures to mitigate harm have been fully exhausted (Bennett et al., 2017; BBOP, 2018; OECD, 2016). The observation that assumptions about minimal impacts often justify not implementing EC (Vaissière et al., 2014), alongside the range of experts' opinions, emphasises the need for continued knowledge-building and stronger collaboration among the industry, stakeholders, and research organisations.

Some interviews raised concerns about the impacts of offshore wind energy farms on local stakeholders, such as fishers' livelihoods. It has been considered whether it is possible to compensate for biodiversity and local community values simultaneously (Tupala et al., 2022). Involving local stakeholders is crucial both in the damaged area and the target area, although it requires additional time, financial resources, and education (Bidaud et al., 2018; Tupala et al., 2022).

The study also highlights transparency and active stakeholder involvement as essential in the implementation of EC. Developers should foster collaboration with stakeholders and researchers in EC projects to build trust and avoid perceptions of greenwashing. Challenges with transparency emerged, with interviewees advocating for open information-sharing to enhance future EC implementation. Transparency and public engagement, alongside ecological and economic values, ensure positive social and ecological outcomes (Koh et al., 2017; Sheaves et al., 2021; Varumo et al., 2023).

One potential approach to improve EC's feasibility would be establishing a specialised authority for EC market management and implementation. Such an authority could address some existing challenges by serving as an intermediary, managing, coordinating and monitoring EC efforts, and ensuring consistent standards across projects. This would provide developers with policy guidance, facilitate the identification of suitable compensation sites, and oversee the long-term monitoring of EC measures to secure their effectiveness considering time and costs (McKenney & Kiesecker, 2010). German experience shows that common reasons for EC failures are difficulties in finding suitable sites and a lack of clear requirements for authorities for long-term monitoring (Tucker, 2016). Long-term monitoring is significant for the success of EC projects (Bas et al., 2016; Bayraktarov et al., 2016).

While this thesis primarily addresses compensating for marine impacts, it is also essential to recognise that offshore wind development influences terrestrial environments and has biodiversity impacts throughout the supply chain of offshore wind. Future research could focus on offshore wind development's terrestrial and supply chain impacts to provide a more holistic understanding of its effects and the feasibility of compensating for them. In addition, it would be worthwhile to examine how evolving national and EU legislation might impact the feasibility of EC across its various dimensions.

6.1 Limitations

The findings of this thesis are limited by the following factors.

First, the chosen feasibility dimensions do not offer a comprehensive picture of the topic, as they do not include all factors affecting the decision-making and success of EC projects. Some elements may have been excluded, such as the influence of biological, physical, and chemical conditions on EC success (Piccolo et al., 2024). These dimensions were chosen based on preliminary readings and discussions, representing some of the most significant factors affecting EC feasibility.

Second, the number of interviewees may limit the generalisability of the results, and the selected experts may not be knowledgeable about all relevant factors. For instance, technical and logistical aspects were underexplored, and the perspectives on social acceptance were based solely on the experts' assumptions about stakeholder views. However, considering the relative novelty of EC in marine environments, the limited pool of experts with sufficient knowledge justifies the sample size used. In addition, qualitative research presents challenges to objectivity, as interviews are shaped by experts' opinions and the researcher’s interpretive decisions (Brinkmann, 2013). Distortion was minimised by systematically coding the data and reflecting on the analysis throughout the research process.

Lastly, the interview responses generally revealed more negative tones, highlighting challenges and barriers more frequently than opportunities. This may be partly due to the interview setting, where experts may find it easier to recognise obstacles than opportunities. Research on negativity bias suggests that people are more likely to emphasise and remember challenges as they often appear more urgent in decision-making contexts (Baumeister et al., 2001).

7 Conclusions

This thesis investigated the feasibility of ecological compensation in the context of offshore wind power development in the Baltic Sea. It examined the challenges and opportunities associated with ecological compensation, considering ecological, financial, governance, and social factors.

The study analysed diverse perspectives on implementing ecological compensation in Baltic offshore wind power projects through expert interviews with representatives from industry, government, research, and NGOs. While experts expressed varying opinions on the implementation of ecological compensation, a commonly shared perspective was that ecological compensation should only be considered after all other mitigation measures have been exhausted, in accordance with the mitigation hierarchy. Although ecological compensation can mitigate biodiversity loss, its implementation in the Baltic Sea faces challenges, mainly due to existing knowledge gaps.

Uncertainty regarding the impacts of offshore wind farms impacts on marine biodiversity is a significant ecological challenge, as effective compensation is difficult without a clear understanding of what is being damaged. The Nature Conservation Act’s requirement for ecological equivalence may further complicate compensation efforts in marine environments. The effects on the seabed in coastal areas and terrestrial ecosystems associated with offshore wind development were seen as possibilities for compensation. Integrating drainage area restoration with underwater restoration efforts can promote overall ecosystem health.

The financial factors present a second significant challenge, as marine restoration can be resource-intensive, increasing offshore wind projects' costs and decreasing the attractiveness of EC for project developers. Furthermore, uncertainties in cost estimations pose risks for project developers, mainly due to the limited experience of ecological compensation in the Baltic Sea region. Establishing an appropriate level of costs is essential to make the mitigation of biodiversity impacts feasible for project developers without impeding the development of renewable energy.

From a governance perspective, marine areas can be utilised for ecological compensation. However, the inflexibility of legislation could limit its attractiveness to the industry. Additionally, the voluntary nature of ecological compensation presents challenges for landowners offering compensation areas, as there is no guaranteed demand for areas designated for restoration. Socially, ecological compensation could enhance social acceptance when implemented transparently and following the Nature Conservation Act.

In conclusion, while experts recognise the role of ecological compensation as a final measure within the mitigation hierarchy, its practical implementation remains challenging. This study recommends several key actions to promote ecological compensation in the Baltic Sea region. It is important to strike a balance in making ecological compensation a feasible mitigation measure for project developers without hindering renewable energy development or neglecting biodiversity loss.

First, establishing a dedicated authority responsible for supporting and monitoring the implementations could help to ensure consistency, compliance, and public trust. Further study of the implications of such an authority is recommended. Second, more research is needed on the development of the compensation market, the potential impacts of mandatory ecological compensation legislation, the underwater ecosystems of the Baltic Sea, and the biodiversity impacts of offshore wind farms. One way to address these knowledge gaps is to initiate pilot compensation projects transparently and in close collaboration between industry, government, researchers, and local stakeholders.

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Appendices

Appendix 1. Information sheet

Note: This information sheet has been translated from Finnish, with minor citation corrections from the original document.

About the study

The goal of this thesis is to develop an understanding of the use of ecological compensation in Finland's marine areas, using offshore wind power projects in the Bothnian Sea as a case example. The study examines the economic, ecological, and social drivers and barriers of ecological compensation, as well as related risks and uncertainties, to improve the state of biodiversity in the Baltic Sea.

Interest in offshore wind power production is increasing in Finland and the Baltic Sea. The demand for clean energy is growing due to emission reduction targets and electrification, and offshore wind power is part of the solution. Marine areas offer better wind conditions and more space for larger power plants. In Finland, suitable production areas are found in the Bothnian Sea, the Bay of Bothnia, and the Gulf of Bothnia (Virtanen et al., 2022).

However, according to Renewables Finland (n.d.-a) and Vaissière et al. (2014), offshore wind power has negative impacts on the surrounding biodiversity, although many of these are local or temporary. The construction of structures required for power plants and transmission and the operation of an active power plant cause impacts. The construction phase can affect, among other things, movement and fishing, water quality, seabed, hydrodynamics, and local species. An operational power plant can impact marine traffic, fishing, currents, and local species and cause noise and flicker. The state of biodiversity in the Baltic Sea is deteriorating due to human activities, and its poor condition affects essential ecosystem functions such as fishing, tourism, and nutrient cycling and can also cause economic harm (HELCOM, 2023; Korpinen et al., 2018).

Ecological compensation is a way to incorporate the cost of environmental damage into production costs (OECD, 2016). The Nature Conservation Act defines ecological compensation as measures by which the entity causing the damage can compensate for the harm caused to a habitat through compensatory or conservation measures.

Eolus, a renewable energy developer, commissioned the thesis, which will be published in the University of Helsinki's open repository Helda.

Interview

Participation in the interview is voluntary. The estimated duration is 30–60 minutes. Interviews will be recorded if the interviewee agrees. The results will be used solely for research purposes and will be treated anonymously. Information will be stored in accordance with the data protection principles of the University of Helsinki and the EU's General Data Protection Regulation (GDPR).

The semi-structured interview includes questions and discussions about the environmental impacts of offshore wind power and their possible ecological compensations in marine areas.

Appendix 2. Interview guide

1. Introduction
    - Interviewee’s background
    - Familiarity with offshore wind power, ecological compensation and biodiversity of the Baltic Sea
2. Offshore wind power and its biodiversity impacts
    - The future of offshore wind power
    - Biodiversity impacts of offshore wind power
    - Mitigating the biodiversity impacts of offshore wind power
3. Ecological compensation in marine areas
    - Selection of habitats, target areas and measures
    - Legislation and land tenure
    - Social acceptability
    - Compensation market: supply and demand of target areas
    - Estimated costs of compensation measures
    - The role of the project developer
4. Summary

Appendix 3. Tables

Table 3. Themes and codes used in the analysis.

Theme	Codes
Alternatives for EC	Artificial reefs, environmental impact assessment, funding, harm avoidance, collaboration between organisations and stakeholders, piloting, placement, technical solutions
Ecological feasibility	Baltic Sea / marine conditions (challenges, possibilities), coastal areas, deep sea areas, drainage areas, terrestrial areas (challenges, possibilities, need), conservation measures, restoration measures (challenges, possibilities, need), lack of knowledge, ecological equivalence
Economic feasibility	Costs, other resources
Governance feasibility	Compensation market, legislation (challenges, possibilities)
Offshore wind	Impacts: Bothnian Sea National Park, flora and fauna, other, seabed, social, terrestrial areas, uncertainty.
Other	Other, eutrophication
Practical implementation	Lack of experience, logistical and technical feasibility, monitoring, the supply of target area (challenges, possibilities)
Significance of EC	Considering biodiversity (important, not important), criticism of EC, encouraging EC, positive attitude towards EC
Social feasibility	Greenwashing (helps to avoid, increases risk), social acceptance (negative, positive, should be considered)
Challenges	Baltic Sea / marine conditions (challenges), coastal areas (challenges), deep sea areas (challenges), drainage areas (challenges), ecological equivalence greenwashing (increases risk), impacts (uncertainty), lack of experience, lack of knowledge, legislation (challenges), logistical and technical feasibility (challenges), monitoring, ecological equivalence, social acceptance (negative), the supply of target area (challenges)
Possibilities	Baltic Sea / marine conditions (possibilities), coastal areas (possibilities), deep sea areas (possibilities), drainage area (possibilities), ecological equivalency (possibilities), encouraging EC, greenwashing (helps to avoid), legislation (possibilities), logistical and technical feasibility (possibilities), monitoring (possibilities), social acceptance (positive), the supply of target area (possibilities)

Table 4. The frequency of codes for the theme "significance of EC" presented by the groups. The number of interviews is indicated in parentheses.

Codes	GOV (2)	IND (4)	NGO (3)	RES (2)	Total
Considering biodiversity: important	1	9	6	2	18
Considering biodiversity: not important	-	4	-	-	4
Criticism of EC	2	12	9	2	25
Encouraging EC	-	-	-	4	4
Positive attitude towards EC	-	6	4	5	15

Governmental (GOV), industry (IND), non-governmental organisation (NGO) and research (RES) representatives.

Table 5. Challenges and possibilities presented by the groups. The number of interviews is indicated in parentheses.

Themes	GOV (2)	IND (4)	NGO (3)	RES (2)	Total
Challenges	32	34	22	52	149
Possibilities	11	7	4	18	40

Governmental (GOV), industry (IND), non-governmental organisation (NGO) and research (RES) representatives.

Table 6. Challenges from the most frequent to the least frequent, including the codes, their descriptions, and the number of quotations related to them.

Code	Description of the code	Total
Lack of knowledge	Lack of research or data considering EC and marine habitats	26
Impacts: uncertainty	Difficulty in predicting biodiversity impacts of offshore wind projects	20
The supply of target area: challenges	Finding suitable areas for EC is problematic	17
Baltic Sea / marine conditions: challenges	Baltic Sea's ecological characteristics and eutrophication issues complicate EC	16
Legislation: challenges	Perceived obstacles in current legislation	13
Ecological equivalence	Finding habitats that match those affected by wind development	13
Social acceptance: negative	Risk of negative reactions among stakeholders	13
Deep sea areas: challenges	Difficulties in implementing EC measures in deep sea areas	5
Drainage area: challenges	Difficulties implementing EC in drainage areas	5
Lack of experience	Lack of EC experience in the Baltic Sea areas; connects with the code "lack of knowledge"	5
Monitoring	Challenges in monitoring EC effectiveness in marine environments with existing tools and methodologies	5
Greenwashing: increases risk	Increased risk of greenwashing when using EC	5
Coastal areas: challenges	Difficulties in implementing EC in coastal areas	4
Logistical and technical feasibility: challenges	Logistical challenges and lack of technical measures	2
Total		149

Table 7. Possibilities from the most frequent to the least frequent, including the codes, their descriptions, and the number of quotations related to them.

Code	Description of the code	Total
Drainage area: possibilities	EC measures can be applied in drainage areas	10
Social acceptance: positive	Support for EC among key stakeholders	8
Coastal areas: possibilities	EC measures can be applied to coastal areas	5
Legislation: possibilities	Current legislation supports and enables the implementation of EC in marine areas	5
Encouraging EC	Expressions of support and encouragement for EC	4
The supply of target area: possibilities	Suitable target areas exist within the Baltic Sea	4
Greenwashing: helps to avoid	Properly implemented EC can help avoid greenwashing accusations	3
Baltic Sea / marine conditions: possibilities	Marine areas and the Baltic Sea offer opportunities for EC	1
Deep sea areas: possibilities	EC measures can be applied to deep-sea areas	-
Logistical and technical feasibility: possibilities	Marine logistical and technical challenges can be managed, and the necessary technologies are available	-
Monitoring: possibilities	Monitoring EC in marine environments is feasible with existing tools and methodologies	-
Ecological equivalence: possibilities	Potential to find areas that are equivalent to the ecological values lost	-
Total		40