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

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ABSTRACT

The expansion of offshore wind power in the Baltic Sea raises concerns about biodiversity impacts. Ecological compensation (EC) is a potential strategy to mitigate these effects, but its feasibility remains uncertain. This study examines the viability of EC for offshore wind projects in the Finnish Baltic Sea region from ecological, governance, financial, and social perspectives. Through expert interviews with industry, government, NGOs, and researchers, we identify key challenges and opportunities of implementing EC measures, using Finland as a case study. While governance and social acceptance support EC, ecological and financial constraints pose significant barriers due to the limited knowledge and uncertainties considering marine ecosystems. Four suggestions are highlighted to improve the feasibility of EC, including 1) establishing a specialised authority for implementation and market management of EC, 2) initiate pilot projects in collaboration with stakeholders, industry and research institutes, 3) conduct further research on offshore wind impacts in the Baltic Sea and 4) adopt flexible and transparent policy frameworks supporting implementation of EC.

1. Introduction

Climate change and biodiversity loss are critical global issues demanding urgent action. Rising temperatures and human-driven biodiversity decline, through activities like land-use change, pollution, and resource overexploitation, threaten ecosystems worldwide [13,8]. Addressing these challenges requires coordinated global efforts. Further, we urgently need to decarbonise our energy systems to reduce emissions, limit the increasing impact from climate change and transition to clean and renewable energy.

Offshore wind is one promising alternative renewable energy source that can aid in decarbonisation but can have substantial environmental and social impacts, particularly during its construction. Offshore wind can threaten marine biodiversity by disrupting seabeds, hydrodynamics, affect water quality and marine life, particularly in vulnerable regions like the Baltic Sea [14,28]. Offshore wind has numerous advantages and opportunities for boosting economic development in a region, creation of jobs and skilled labour, and promoting energy independence and self-sufficiency [42]. This is a typical example of a green-green dilemma; the difficulty in choosing between producing green and renewable electricity that can decarbonise the energy system but may have substantial environmental and social impacts [36,43].

Finland, committed to carbon neutrality by 2035, is targeting significant emission reductions within the energy sector [10,24]. Currently, wind power accounts for approximately 14 % of electricity production [35], and this is almost all onshore wind. Wind power is expected to be a key component of the transition to carbon neutrality. Thus, the interest in developing offshore wind is also rapidly increasing. Currently, Finland has one offshore wind park in operation and several projects in different stages of development, including 6 GW of suitable marine areas releasing for auction in 2024/2025 [23]. Seven areas within the territorial waters have been identified as suitable for offshore wind ranging in size from 120 km^2 to 200 km^2 along the west coast of Finland. Offshore wind could be an important piece of the transition towards carbon neutrality but requires careful planning and mitigation of impacts before it can be rapidly upscaled.

To balance the development of renewable energy with biodiversity conservation, ecological compensation (EC) offers a potential solution. EC allows parties causing environmental harm to offset impacts through habitat restoration or protection (Ministry for the Environment, 9/2023). While it has seen limited use in offshore wind projects, its potential for mitigating biodiversity loss is growing. However, challenges such as knowledge gaps, the assumption of negligible impacts and legislative hurdles remain [27,39,5]. In Finland, EC is voluntary and guided

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by criteria in the 2023 Nature Conservation Act, allowing developers to offset damage prior to project implementation.

The terms biodiversity offsetting and ecological compensation are closely related and sometimes interchangeable. In Finland, the term ecological compensation is more commonly used than the internationally popular term biodiversity offsetting. Further, ecological compensation was the term used during the interview process with participants, so ecological compensation (EC) will be used throughout this article. EC should only be implemented after all efforts to avoid adverse biodiversity impacts, minimise unavoidable damage, and restore biodiversity on-site are exhausted [29]. Ecological compensation 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. EC efforts have been implemented mostly on terrestrial ecosystems, with fewer projects in marine and coastal environments [1,34] or offshore wind farm development [39]. Several compensatory measures have been outlined as suitable for offshore wind development, such as removing invasive species from seabird nesting grounds, improving habitat conditions for marine mammals or supporting the protection of critical species or habitats [3]. However, there is little information on how EC could effectively be implemented into offshore wind development projects in Finland, where the industry has great potential and may rapidly increase in the coming years.

The Baltic Sea, already facing pressures from eutrophication and pollution, is particularly vulnerable to the impact from the construction of offshore wind on marine ecosystems [14]. Research on offshore wind impacts in the Baltic Sea is limited, and the unique environmental conditions there may exacerbate these effects [32]. Further, compensating for biodiversity loss in the Baltic Sea is challenging due to knowledge gaps and the unique conditions of the sea [31]. While EC has been applied more in terrestrial projects, lessons can be adapted for marine environments, despite challenges like high restoration costs and uncertain effectiveness [1,15]. For example, experiences from onshore projects can help developers and companies become familiar with the EC process, not necessarily in terms of ecological measures transferable offshore, but rather the administrative procedures and regulatory processes involved.

This study investigates the feasibility of EC in offshore wind power projects in the Finnish Baltic Sea area, considering ecological, governance, financial, and social perspectives with two main research questions:

1. Is it feasible to implement ecological compensation in offshore wind projects in the Finnish Baltic Sea area, and what are the challenges and opportunities for its implementation?
2. How do different stakeholder groups perceive the viability of ecological compensation for offshore wind projects in the Finnish Baltic Sea region?

To answer these research questions and explore the challenges and viability of implementing EC in offshore wind projects, data was collected from 11 expert stakeholder interviews. Offshore wind is a relatively new industry in Finland, and EC has only been part of the Nature Conservation Act since 2023 [26], so there were a limited number of experts knowledgeable in these intersecting topics. Thus, the smaller number of interviews was justified in this case while still providing a detailed overview of the viability dimensions of implementing EC.

2. Feasibility definition

Feasibility research assesses the viability and acceptability of projects, helping guide decision-making [12]. While there is no single definition of feasibility, it is commonly understood as the likelihood of a project achieving its goals. Solutions can be classified as feasible, efficient, or optimal, with feasible solutions meeting basic constraints and efficient solutions being a subset of those. Economic, technical and political feasibility are distinguished, incorporating factors such as social, institutional and administrative considerations. [19,20]

Building on this previous research, this study evaluates the feasibility of EC for offshore wind power projects in the Baltic Sea across four dimensions: ecological, governance, financial, and social. The three sustainability pillars—ecological, social, and financial—form the foundation of this framework, with governance added to align with national legislation. For EC to be viable, all four dimensions must be satisfied.

Ecological feasibility assesses the applicability and effectiveness of compensation measures in the Baltic Sea, considering habitat restoration potential and ecological equivalence to offshore wind power's biodiversity impacts.

Governance feasibility examines barriers and drivers within Finnish legislation, ensuring alignment with regulations and land tenure considerations.

Financial feasibility evaluates the costs of implementing different EC measures.

Social feasibility focuses on stakeholder acceptance, particularly in voluntary EC schemes, where local support is key for success and to avoid greenwashing risks.

While these dimensions may overlap, such as ecological equivalence and habitat availability affecting both ecological and governance feasibility, each contributes uniquely to the overall feasibility assessment. Greenwashing is defined as the process of deliberate corporate action to mislead consumers into thinking their business activities are more environmentally friendly than they are in reality [9].

The chosen feasibility dimensions 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 [30]. These dimensions were chosen based on preliminary readings and discussions, representing some of the most significant factors affecting EC feasibility.

2.1. Data and methods

Data was collected through semi-structured expert interviews. Experts were selected from four key groups: governmental (GOV1–2), industry (IND1–5), non-governmental organizations (NGO1–3), and research organizations (RES1–2), ensuring a broad range of ecological, governance, financial, and social insights. Interviews were conducted with 11 of 25 contacted experts, selected through academic networks and industry connections.

All interviews were conducted in Finnish, recorded with consent, and subsequently transcribed. The transcripts were reviewed to remove filler words, repetitions, and significant grammatical errors. Due to the added complexity of colloquial Finnish in the transcripts, they were translated into English. Quotations used in this article are translated from Finnish into English and edited for clarity and readability. All participants were anonymized, and data were handled in compliance with the University of Helsinki's data protection policies and GDPR requirements.

The interview data were analysed using inductive thematic content analysis, guided by the principles outlined by Braun and Clarke [6]. The process followed their six-phase model: (1) familiarisation with data, (2) generation of initial codes, (3) theme searching, (4) theme reviewing, (5) defining and naming themes, and (6) report production. This enabled an in-depth exploration of participants' perspectives surrounding ecological compensation in marine environments, free from pre-determined theoretical frameworks.

The transcribed and translated interview data were imported into Atlas.ti for the analysis. Transcripts were read multiple times during the familiarisation phase, and notes were systematically written to capture emerging patterns and insights. The next phase involved inductive coding, where codes were derived directly from the data without imposing pre-existing frameworks. For example, phrases such as “the seabed is modelled rather than fully mapped, which is a challenge” and “ecological compensation can enhance public acceptability” were coded as “lack of knowledge” and “positive social acceptance”.

Then, the codes were refined to align with the research problem, and redundant or overlapping codes were combined. For example, codes “fishers”, “local people” and “public opinion” were grouped under broader codes such as “positive social acceptance” and “negative social acceptance”. The refined codes were organised into broader thematic categories that reflected patterns across stakeholder responses. For example, the theme “governance feasibility” included codes such as “compensation market”, “legislation: challenges”, and “legislation: possibilities”.

Finally, themes and codes were further analysed across the four stakeholder groups, allowing comparison of shared and divergent perspectives. Patterns that recurred across multiple interviews were identified, and particular attention was paid to the frequency and divisiveness of specific codes among the groups. This comparative analysis provided deeper insight into the feasibility of ecological compensation for offshore wind power in the Baltic Sea.

3. Results

The integration of biodiversity considerations into offshore wind projects is widely acknowledged as important by most interviewees, who stress that addressing biodiversity loss should be part of business decisions. Tools such as environmental impact assessments and compliance with frameworks like the EU Taxonomy are essential. The pressure to address biodiversity loss is increasing, especially with deteriorating biodiversity in Finland and the poor state of the Baltic Sea. Experts argue that the green energy transition should be sustainable and respect key marine ecosystems.

> “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, some experts downplay the significance of offshore wind power’s biodiversity impacts, suggesting that all activities affect biodiversity, and offshore wind power is not necessarily the worst offender. They advocate 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)

Despite widespread support for biodiversity protection, the implementation of ecological compensation (EC) remains controversial. Many interviewees stress that EC should be a last resort, to be used only after all other mitigation measures, such as harm avoidance, have been applied. Others view EC as crucial for mitigating unavoidable biodiversity harm, particularly in areas where sensitive habitats cannot be avoided.

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

Optimism exists regarding the future of EC, with some experts advocating for practical steps to begin implementation, despite uncertainties. They emphasize learning through trial and error, rather than waiting for perfect conditions. 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. Conversely, 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 flexible, supportive legislation. Fig. 1 below shows key themes that arose from the responses.

3.1. Ecological feasibility

Experts view compensating for offshore wind’s biodiversity impacts as challenging, primarily due to the uncertainty surrounding these impacts. Seabed damage is considered easier to address, while compensating for impacts on animal migration and electromagnetic fields is seen as difficult. Social impacts on fishers’ livelihoods are also important, though not compensable under the Finnish Nature Conservation Act. The Baltic Sea’s unique and degraded ecological conditions further complicate EC efforts. The lack of mapped data and ecological knowledge is another significant barrier.

> “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)

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)

Shallow coastal and seabed habitats are considered the most suitable targets for EC, with drainage areas seen as potential opportunities for EC due to eutrophication concerns. However, the Finnish Nature Conservation Act limits the applicability of EC to offshore wind projects, as these projects do not directly involve nutrient emissions. A combination of conservation and restoration measures is recognized as essential to achieving effective compensation.

> “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)

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.

Fig. 1. A word cloud highlighting the common themes that arose from the response.

3.2. Governance feasibility

Government representatives see the Nature Conservation Act as enabling EC, as it includes clear compensation criteria and aligns with broader regulations like the RED Directive. For businesses, this regulatory clarity reduces the risk of greenwashing.

> "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)

However, industry representatives argue that the Act's inflexibility and voluntary nature may limit EC adoption. The acts overreliance on the natural value hectare concept may be too restrictive.

> "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)

Legal challenges also arise from the need for ecological equivalence and issues related to land tenure in marine areas. 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.

> "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)

3.3. Financial feasibility

Interviewees have limited insight into EC project costs, given the lack of data and experience in the Baltic Sea's marine environment. High costs, especially for restoration measures, are seen as a significant barrier to EC implementation. EC may increase the overall cost of offshore wind projects, threatening their profitability. However, conservation measures are generally perceived as less expensive than restoration efforts, though their effectiveness is questioned if eutrophication issues are not addressed. Uncertainty about costs further decreases the appeal of EC projects.

> "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)

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, at least, be noticeable to avoid unnecessary harm.

3.4. Social feasibility

The social acceptability of EC in offshore wind projects is mixed. Positive effects are seen when local stakeholders are involved in the process, and clear, official compensation criteria are established to avoid greenwashing.

Negative social impacts stem from prior negative experiences, opposition to the projects, and concerns about the effectiveness of compensation measures. When EC is implemented transparently, it can enhance social acceptance, particularly if it is seen as a genuine effort to minimize environmental harm.

> "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)

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)

4. Discussion

The first objective within this research was to identify the challenges, opportunities and viability in the implementation of ecological compensation (EC) in offshore wind projects in Finland. Ecological compensation has potential to aid in biodiversity protection and could be feasible in offshore wind development, but several challenges remain that need to be addressed. While implementing EC appears feasible in governance and social respects, ecological and financial factors face challenges.

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 and uncertainties considering the biodiversity impacts of offshore wind. 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 [1,15,27,39].

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 [38]. Involving local stakeholders is crucial both in the damaged area and the target area, although it requires additional time, financial resources, and education [38,4].

Another challenge highlighted in this study is the voluntariness of the Finnish Nature Conservation Act. The Act’s rigid, but voluntary requirements may reduce its attractiveness for developers and hinder the widespread adoption of EC. 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 [37]. Mandatory EC could increase the availability of suitable target areas by providing greater certainty for landowners. Target areas are specific locations or ecosystems that have been identified as suitable for ecological compensation efforts that are equivalent to the area that has, or will be, damaged during the project development. 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 [16]. For the system to function effectively, the market needs to be strong enough [44].

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 research is required on the market’s development and the impacts of gradually integrating mandatory EC into legislation. It is essential to ensure that developers can adapt to regulations without facing an overwhelming burden. Too strict requirements could exacerbate the green-green dilemma, where biodiversity conservation conflicts with low-carbon energy targets, complicating renewable energy development.

This study indicates that shallow coastal areas and 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. Further, shallow coastal regions often have higher biodiversity, the presence of breeding and nesting areas, and lower cost of restoration in coastal areas compared to deeper marine areas [14,18,31,40,3]. Onshore impacts from offshore wind development usually stem from cable installation and grid connection, and should be restored upon finalising construction [28]. To clarify further, in addition to offshore cables, the connection points between the offshore wind turbines and the grid network are also built onshore, and impacts to the coastline occur from these connection points. Therefore, cables to connect the offshore wind parks to grid connections are installed underwater and on the coastline.

There is much knowledge regarding the restoration of Finnish mire and forest habitats compared to marine habitats [22]. These areas also have degraded habitats suitable for restoration and the general potential for EC [16]. Lessons from terrestrial EC experiences could prove a foundation for developing marine compensation practices, as the core principles remain similar. Experiences from onshore projects can help developers and companies become familiar with the EC process, not necessarily in terms of ecological measures transferable offshore, but rather the administrative procedures and regulatory processes involved.

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 [18,31].

Uncertain and potentially high costs challenge the financial feasibility of EC in the Baltic Sea [2,40]. 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 [2]. 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, indicating a relatively minor economic impact [37]. Nevertheless, costs will likely increase in marine environments, leaving the impact on the profitability of offshore wind power projects uncertain.

Escalating costs could again exacerbate the 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 and minimising unnecessary harm to biodiversity without undermining the viability of renewable energy projects.

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 [29,11]. The observation that assumptions about minimal impacts often justify not implementing EC [39], alongside the range of experts’ opinions, emphasises the need for continued knowledge-building and stronger collaboration among the industry, stakeholders, and research organisations.

5. Limitations and considerations

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 [7]. Distortion was minimised by systematically coding the data and reflecting on the analysis throughout the research process.

While this study 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. Suggestions for improving the viability of ecological compensation

Four suggestions to enhance the viability of ecological compensation stem from the results. Firstly, consider 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 [21]. 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 [37]. Long-term monitoring is significant for the success of EC projects [1,2].

Secondly, initiate pilot projects in close collaboration with stakeholders, industry, government authorities and researchers. Transparency and active stakeholder involvement are 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 [17,33,41].

Thirdly, conduct further research to fill data and knowledge gaps on the impact of offshore wind on marine ecosystems and habitats, the compensation market, the potential impacts of mandatory EC legislation, and the underwater ecosystems of the Baltic Sea. 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 [39], as effective EC must rely on the best available knowledge [18,2]. It has been proposed that research should be initiated 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 [25,10]. These efforts could enhance EC's feasibility for future offshore wind projects.

Fourthly, develop clear and flexible legal frameworks that support EC adoption while addressing ecological equivalence and land tenure issues. Flexibility in legislation will encourage industry participation and ensure effective compensation measures.

7. Conclusions

This article 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 on marine biodiversity is a significant ecological challenge, as effective compensation is difficult without a clear understanding of what is being damaged. The Finnish 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. In addition to the marine environment, offshore wind power projects can impact the terrestrial environment due to grid connections. According to the Finnish Nature Conservation Act, the damage to the marine environment must be compensated in a similar ecosystem. Thus, the terrestrial areas cannot be used to compensate for the damage in the marine environment, and vice versa, but only for the damage associated with equivalent areas.

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. 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.

Author statement

Firstly, thanks for the smooth and easy review process. The comments received on the manuscript were useful and we believe strengthened the manuscript.

We have updated the manuscript based on all (except perhaps one) comment provided by the reviewer and the attached document describes how and where these changes were implemented.

All authors contributed to and are happy with the changes and comments received, and we now submit the strengthened, updated manuscript for your review.

CRediT authorship contribution statement

Vilma Herronen: Methodology, Conceptualization, Writing – original draft, Writing – review & editing, Formal analysis. **Jamie Jenkins:**

Supervision, Conceptualization, Writing – review & editing, Formal analysis.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT-4 in order to translate interview data from Finnish to English, and proofread select paragraphs. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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Data availability

Data will be made available on request.

References

[1] A. Bas, C. Jacob, J. Hay, S. Pioch, S. Thorin, Improving marine biodiversity offsetting: a proposed methodology for better assessing losses and gains, J. Environ. Manag. 175 (2016) 46–59, https://doi.org/10.1016/j.jenvman.2016.03.027.
[2] E. Bayraktarov, M.I. Saunders, S. Abdullah, M. Mills, J. Beher, H.P. Possingham, P. J. Mumby, C.E. Lovelock, The cost and feasibility of marine coastal restoration, Ecol. Appl. 26 (4) (2016) 1055–1074, https://doi.org/10.1890/15-1077.
[3] L. Bennun, J. Van Bochove, C. Ng, C. Fletcher, D. Wilson, N. Phair, G. Carbone, 2021, Mitigating biodiversity impacts associated with solar and wind energy development: Guidelines for project developers. (No Title).
[4] C. Bidaud, K. Schreckenberg, J.P.G. Jones, The local costs of biodiversity offsets: comparing standards, policy and practice, Land Use Policy 77 (2018) 43–50, https://doi.org/10.1016/j.landusepol.2018.05.003.
[5] M. Bos, R.L. Pressey, N. Stoeckl, Effective marine offsets for the Great Barrier Reef World Heritage Area, Environ. Sci. Policy 42 (2014) 1–15, https://doi.org/10.1016/j.envsci.2014.05.002.
[6] V. Braun, V. Clarke, Using thematic analysis in psychology, Qual. Res. Psychol. 3 (2) (2006) 77–101, https://doi.org/10.1191/1478088706qp063oa.
[7] S. Brinkmann. *Qualitative Interviewing*, Oxford University Press, 2013, https://doi.org/10.1093/acprof:osobl/9780199861392.001.0001.
[8] E.S. Brondízio, J. Settele, S. Diaz, Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Ngo (2019).
[9] S.V. de Freitas Netto, M.F.F. Sobral, A.R.B. Ribeiro, G.R. d L. Soares, Concepts and forms of greenwashing: a systematic review, Environ. Sci. Eur. 32 (1) (2020) 19, https://doi.org/10.1186/s12302-020-0300-3.
[10] Finnish Government, A Strong and Committed Finland, 2023. Retrieved from, ⟨http://urn.fi/URN:ISBN:978-952-383-818-5⟩.
[11] G. Bennett, M. Gallant (2017). State of Biodiversity Mitigation.
[12] D.L. Gadke, T.R. Kratochwill, M. Gettinger, Incorporating feasibility protocols in intervention research, J. Sch. Psychol. 84 (2021) 1–18, https://doi.org/10.1016/j.jsp.2020.11.004.
[13] H. Lee, K. Calvin, D. Dasgupta, G. Krinner, A. Mukherji, P. Thorne, C. Trisos, J. Romero, P. Aldunce, K. Barret (2023). IPCC, 2023: Climate Change 2023: Synthesis Report, Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.
[14] HELCOM, 2023, State of the Baltic Sea 2023: Third HELCOM holistic assessment 2016-2021. ⟨https://helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2023/⟩.
[15] C. Jacob, J.-W. van Bochove, S. Livingstone, T. White, J. Pilgrim, L. Bennun, Marine biodiversity offsets: pragmatic approaches toward better conservation outcomes, Conserv. Lett. 13 (3) (2020) e12711, https://doi.org/10.1111/conl.12711.
[16] J. Kangas, M. Ollikainen, Economic insights in ecological compensations: market analysis with an empirical application to the Finnish economy, Ecol. Econ. 159 (2019) 54–67, https://doi.org/10.1016/j.ecolecon.2019.01.003.
[17] N.S. Koh, T. Hahn, C. Ituarte-Lima, Safeguards for enhancing ecological compensation in Sweden, Land Use Policy 64 (2017) 186–199, https://doi.org/10.1016/j.landusepol.2017.02.035.
[18] K. Kostamo, M. Pekkonen, P. Ahlroth, R. Heikkinen, M. Kallasvuo, S. Kuningas, L. Laamanen, A. Lappalainen, L. Veneranta, Ekologiset kompensaatiot Suomen rannikolla ja merialueilla, Suomen Ympäristökeskuksen raportteja 24 (2018) 68.
[19] G. Majone, The feasibility of social policies, Policy Sci. 6 (1) (1975) 49–69, https://doi.org/10.1007/BF00186755.
[20] G. Majone, On the notion of political feasibility, Eur. J. Political Res. 3 (3) (1975) 259–274, https://doi.org/10.1111/j.1475-6765.1975.tb00780.x.
[21] B.A. McKenney, J.M. Kiesecker, Policy development for biodiversity offsets: a review of offset frameworks, Environ. Manag. 45 (1) (2010) 165–176, https://doi.org/10.1007/s00267-009-9396-3.
[22] Metsähallitus, 2013, Ojitettujen soiden ennallistamisopas [Handbook for the restoration of drained peatlands]. ⟨https://julkaisut.metsa.fi/julkaisu/ojitettujen-soiden-ennallistamisopas/⟩.
[23] Metsähallitus, 2023, Finland to tender 6,000 MW of offshore wind power in 2023-2024. ⟨https://www.metsa.fi/en/tiedotteet/finland-to-tender-6000-mw-of-offshore-wind-power-in-2023-2024/⟩.
[24] Ministry for Economic Affairs and Employment, National Energy and Climate Strategy for 2030. Publications of the Ministry of Economic Affairs and Employment: Työ- ja elinkeinoministeriö, 2017.
[25] Ministry of Economic Affairs and Employment, Merituulivoiman edistämisen toimenpidesuunnitelma, 2024. ⟨http://urn.fi/URN:ISBN:978-952-327-543-0⟩.
[26] Nature Conservation Act, (9/2023). ⟨https://www.finlex.fi/en/laki/kaannokset/2023/en20230009?search%5Btype%5D=pika&search%5Bkieli%5D%5B0%5D=en&search%5Bpika%5D=nature%20conservation⟩.
[27] H.J. Niner, B. Milligan, P.J.S. Jones, C.A. Styan, A global snapshot of marine biodiversity offsetting policy, Mar. Policy 81 (2017) 368–374, https://doi.org/10.1016/j.marpol.2017.04.005.
[28] Nordic Energy Research, Accommodating Biodiversity in Nordic Offshore Wind Projects, 2022. ⟨https://www.norden.org/en/publication/accommodating-biodiversity-nordic-offshore-wind-projects⟩.
[29] OECD. (2016). Biodiversity Offsets: Effective Design and Implementation. https://doi.org/10.1787/9789264222519-en.
[30] R.L. Piccolo, C.J. Brown, D.A. Friess, C.E. Lovelock, B.M. Brown, C. Buelow, M. I. Saunders, Feasibility of habitat restoration under multidisciplinary constraints, Ocean Coast. Manag. 249 (2024) 106977, https://doi.org/10.1016/j.ocecoaman.2023.106977.
[31] A. Raunio, S. Anttila, M. Pekkonen, O. Ojala, Suitabil. Habitat Types Biodivers. Offset Finl. (2019).
[32] L. Rostin, G. Martin, K. Herkül, Environmental concerns related to the construction of offshore wind parks: Baltic Sea case, WIT Trans. Ecol. Environ. 169 (2013) 131–140.
[33] M. Sheaves, N.J. Waltham, C. Benham, M. Bradley, C. Mattone, A. Diedrich, J. Sheaves, A. Sheaves, S. Hernandez, P. Dale, Z. Banhalmi-Zakar, M. Newlands, Restoration of marine ecosystems: understanding possible futures for optimal outcomes, Sci. Total Environ. 796 (2021) 148845, https://doi.org/10.1016/j.scitotenv.2021.148845.
[34] N. Shumway, J.E.M. Watson, M.I. Saunders, M. Maron, The Risks and Opportunities of Translating Terrestrial Biodiversity Offsets to the Marine Realm, BioScience 68 (2) (2018) 125–133, https://doi.org/10.1093/biosci/bix150.
[35] Statistics Finland, 2022, Energy Supply and Consumption, 2022. ⟨https://pxdata.stat.fi/PxWeb/pxweb/en/StatFin/StatFin_ehk/statfin_ehk_pxt_12vq.px/table/tableViewLayout1/⟩.
[36] T.M. Straka, M. Fritze, C.C. Voigt, The human dimensions of a green–green-dilemma: lessons learned from the wind energy — wildlife conflict in Germany, Energy Rep. 6 (2020) 1768–1777, https://doi.org/10.1016/j.egyr.2020.06.028.
[37] G. Tucker, Biodiversity offsetting in Germany, Institute for European Environmental Policy, 2016.
[38] A.-K. Tupala, S. Huttunen, P. Halme, Social impacts of biodiversity offsetting: a review, Biol. Conserv. 267 (2022) 109431, https://doi.org/10.1016/j.biocon.2021.109431.
[39] A.-C. Vaissière, H. Levrel, S. Pioch, A. Carlier, Biodiversity offsets for offshore wind farm projects: the current situation in Europe, Mar. Policy 48 (2014) 172–183, https://doi.org/10.1016/j.marpol.2014.03.023.
[40] C.L. Van Dover, J. Aronson, L. Pendleton, S. Smith, S. Arnaud-Haond, D. Moreno-Mateos, E. Barbier, D. Billett, K. Bowers, R. Danovaro, A. Edwards, S. Kellert, T. Morato, E. Pollard, A. Rogers, R. Warner, Ecological restoration in the deep sea: Desiderata, Mar. Policy 44 (2014) 98–106, https://doi.org/10.1016/j.marpol.2013.07.006.
[41] L. Varumo, J.M. Kotilainen, E. Primmer, Social acceptance of biodiversity offsetting: motivations and practices in the designing of an emerging mechanism, Environ. Policy Gov. 33 (3) (2023) 301–312, https://doi.org/10.1002/eet.2031.
[42] E.A. Virtanen, J. Lappalainen, M. Nurmi, M. Viitasalo, M. Tikanmäki, J. Heinonen, E. Atlaskin, M. Kallasvuo, H. Tikkanen, A. Moilanen, Balancing profitability of energy production, societal impacts and biodiversity in offshore wind farm design, Renew. Sustain. Energy Rev. 158 (2022), https://doi.org/10.1016/j.rser.2022.112087.
[43] C. Voigt, T. Straka, M. Fritze, Producing wind energy at the cost of biodiversity: a stakeholder view on a green-green dilemma, 063303-063303, J. Renew. Sustain. Energy 11 (2019), https://doi.org/10.1063/1.5118784.
[44] S. Wissel, F. Wätzold, A conceptual analysis of the application of tradable permits to biodiversity conservation, Conserv. Biol. 24 (2) (2010) 404–411, https://doi.org/10.1111/j.1523-1739.2009.01444.x.