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Financing marine restoration through offshore wind investments

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Abstract

Offshore wind farms (OWFs) are proliferating globally across marine ecosystems. We argue that alongside traditional avoidance, mitigation, compensation, and offsetting measures to reduce project-level OWF impacts, allocating a small percentage of OWF investments to marine restoration as a licensing fee for using marine space would catalyze large-scale marine restoration. This involves establishing large marine-protected areas and implementing active ecosystem restoration to help recover key habitats and species. Allocating just 1%–5% of the projected US$6 trillion global offshore wind farm investments by 2050 to marine conservation and restoration could have a powerful impact, creating a historic opportunity to achieve biodiversity goals on time.

Keywords: ecology, sustainability, policy/ethics, aquatic ecosystems, conservation

Global consortia are investing billions to rapidly scale up offshore wind farms (OWFs), accelerating the shift from fossil fuels to renewable energy to meet Paris Agreement targets. Predictions forecast OWFs to expand sevenfold from 56 gigawatts (GW) worldwide in 2021 to a massive 371 GW in 2031 (figure 1, supplemental table S1.1; Duarte et al. 2020, GWEC 2021, 2022). This growth represents an estimated US$945 billion investment to build around 25,000 turbines of over 200 meters height (supplemental table S1.2). Moreover, to meet climate targets, an additional investment of US$4.9 trillion will likely be required to reach 2000 GW by 2050 (table S1.1). This massive upscaling across multiple continents causes conflicts with other economic uses, including shipping, fishing, oil and gas, aquaculture, military, conservation, and recreation (OFL 2020). With an estimated semiexclusive footprint of about 100 square kilometers (km^2) per GW, OWFs will claim 200,000 km^2 of marine space in 2050. This is 100 times the current global seaweed culture (supplemental table S1.3) and will therefore redefine the use of sea space.

Overexploitation, pollution, and climate change have driven a greater human-induced biodiversity loss since 1955—and more than any other time in human history (Centre for Sustainable Systems 2023). In contrast to more traditional industries such as fishing, dredging, and oil and gas, OWFs may offer positive biodiversity effects by providing enormous semiexclusive protection zones, along with alleviating future climate change and associated biodiversity loss (OFL 2020, Xu et al. 2021, UN Global Compact 2024). However, this expansion could further damage marine habitats already in poor ecological condition, which urgently need restoration after 150 years of intensified human impact (Duarte et al. 2020).

Current legislation aims to limit the direct, indirect, and cumulative negative impacts of OWFs on marine environments at the project level as much as possible through, for example, environmental impact assessments and strategic environmental assessments based on national and international laws and guidelines (OFL 2020, Galparsoro et al. 2022, RSPB 2022, UN Global Compact 2024). For this purpose, potential negative effects are extensively studied in remote and *in situ* research, often funded by governments and wind operators (OFL 2020, RSPB 2022, Eneco 2023, Ørsted 2024, SSE 2024). We argue that, rather than just avoiding and mitigating impacts at the project level (Backes et al. 2018), OWF development should also contribute to actively restoring marine ecosystems, helping to revive lost seabed habitats and support the return of large, long-lived species.

Initiatives such as the United Nations (UN) Sustainable Development Goals, the Kunming-Montreal Global Biodiversity Framework (GBF), and the Rio Conventions aim to tackle biodiversity loss but often lack clear guidance on financial mechanisms to achieve their targets. Also, the EU Green Deal does not take a holistic approach to preserve and restore marine ecosystems but refers to existing nature conservation legislation without adding new or

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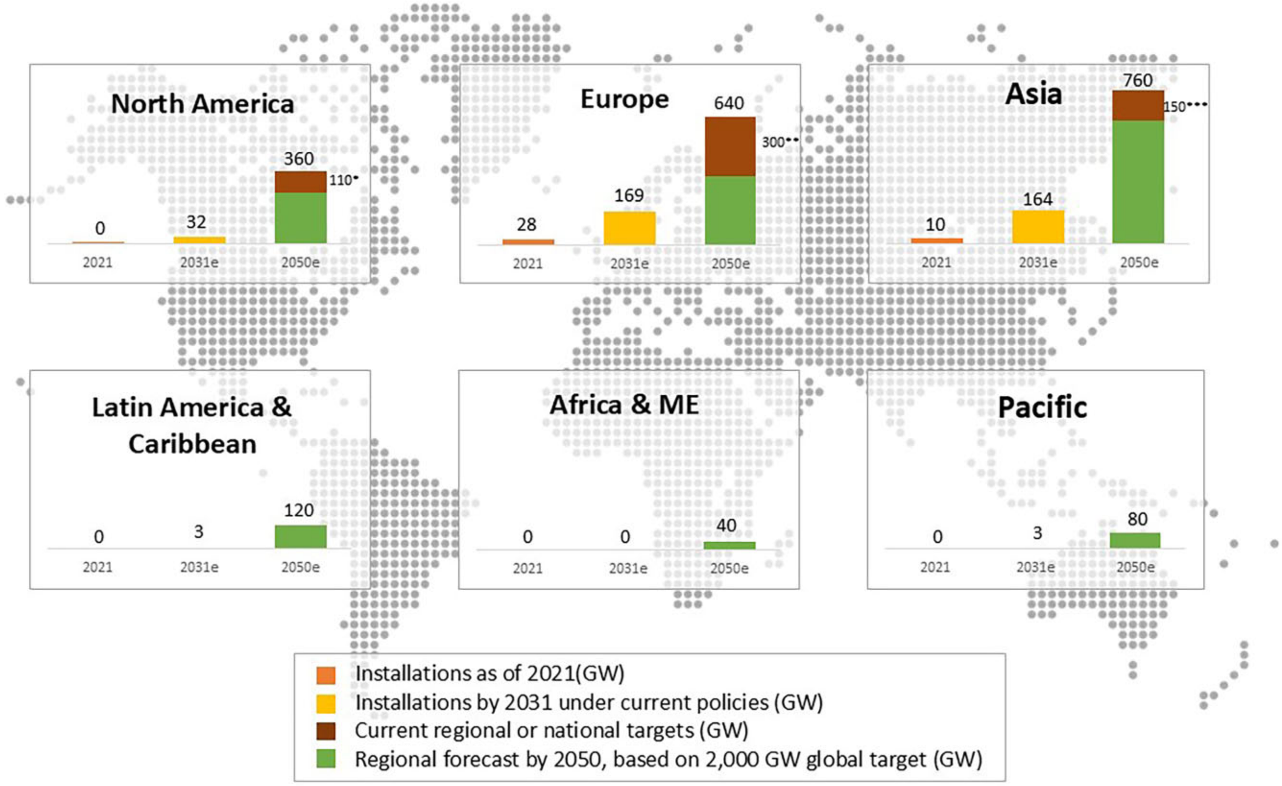

Figure 1. Expected global OWF development. Global operational OWFs and expected development of OWFs for 2021 (56 GW), 2031 (371 GW) and 2050 (2000 GW), in GWs based on the Global Wind Energy Council report of 2021 and 2022 (supplemental table S1.1). Abbreviation: e, estimate. *US 2050 target. **EU "Green Deal" 2050 target. ***Total announced 2030/2035/2040 targets by China, Japan, South Korea, Taiwan.

innovative approaches or stimulus. The GBF, which seeks to restore 30% of damaged ecosystems by 2030, urges governments to involve the private sector in reaching these goals. Integrating OWF investments with broader marine restoration efforts through licensing conditions presents a historic but untapped opportunity to advance global biodiversity objectives. This approach could help halt marine degradation and accelerate large-scale restoration efforts, aligning with key UN, EU, and GBF policies (Abelson et al. 2020, Airoldi et al. 2021, Xu et al. 2021).

Coupling new OWFs to overarching marine conservation goals

Global OWF projections predict a tremendous growth from 0 to 32 GW in the United States, from 28 to 164 GW in Asia, and from 28 to 169 GW in the European Union by 2031 (figure 1, table S1.1; GWEC 2021, 2022). Meanwhile, programs focused on actively restoring or strengthening ecosystems have remained small in scale, whereas governments struggle to meet biodiversity targets because of delays, a lack of ambition, and regulatory issues (Vrooman et al. 2022, UNEP 2023, IPBES 2024). In fact, by 2020, only 6 of the 20 Aichi global biodiversity targets were met—and even then, only partially (Xu et al. 2021). At the same time, nature-negative investments in marine economies, such as fisheries and oil and gas subsidies still exceed funding allocated for nature-positive initiatives such as protection and active restoration (UNEP 2023, IPBES 2024), which presents an increasing need for nature-positive investments. Unfortunately, funding for marine biodiversity goals remains inadequate, a mere fraction of the investments in OWFs and other industries (RSPB 2022, WWF 2022, UNEP 2023, IPBES 2024).

The funding gap for marine biodiversity goals could be partially resolved by integrating large-scale marine restoration into OWF licensing fees, interlocking the two. Despite the common application of OWF licensing fees and nonfinancial bidding criteria (Staatscourant 2022, WWF 2022), governments rarely mandate investments in achieving broader marine biodiversity goals. An exception is the Dutch nature-inclusive tender Hollandse Kust West site VI, which required OWF consortia to contribute, although only within the OWF area (Staatscourant 2022). Embedding licensing conditions that link OWFs to a timely, ambitious, and balanced mix of passive and active restoration measures in and outside OWFs could boost marine life restoration through large, square-kilometer-scale projects. This approach would tackle the climate and biodiversity crises simultaneously, ensuring marine restoration keeps pace with renewable energy expansion (RSPB 2022).

Recent actions by offshore wind industry stakeholders demonstrate a growing commitment to achieving net positive outcomes for nature—not only on a project level and within new OWFs but on a broader ecosystem scale. Examples include joint industry projects in the United Kingdom, such as a recent project to explore and redefine a nature-inclusive approach to wind farms (Wood Thilsted 2024), as well as industry–nongovernmental organization collaborations such as the WWF–Ørsted biodiversity projects, which support restoration and research efforts (Ørsted 2024). The English Crown Estate through the Offshore Wind Evidence and Change program also invests in nature restoration projects (Memija 2023, The Crown Estate 2025a). However, these examples remain rare, primarily project based and often limited in funding. Most importantly, the lack of consistent integration into national or international policies makes the

Table 1. The potential footprint of active marine restoration if fueled by a 1%–5% OWF licensing fee.

Heading	Stony reefs	Oyster reefs	Coral reefs	Kelp	Seagrass	Mangroves	Saltmarsh
Restorable surface considering 315 GW in 2022–2031 using a 1% licensing fee, RB = $9,450,463,500 (km^2)	3 –	24,434 186,827	1,143 141,760	2 703,055	21,256 1,420,482	61,597 25,891,681	6,029 28,465,252
Restorable surface considering 315 GW in 2022–2031 using a 5% licensing fee, RB = $47,252,317,500 (km^2)	17 –	122,168 934,136	5,716 708,802	9 3,515,274	106,280 7,102,408	307,986 129,458,404	30,143 142,326,258
Restorable surface considering 1944 GW in 2022–2050 using a 1% licensing fee, RB = $58,323,450,000 (km^2)	21 –	150,791 1,153,002	7,055 874,874	11 4,338,897	131,181 8,766,489	380,146 159,790,274	37,205 175,673,042
Restorable surface considering 1944 GW in 2022–2050 using a 5% licensing fee, RB = $291,617,250,000 (km^2)	105 –	753,956 5,765,010	35,277 4,374,368	55 21,694,484	655,903 43,832,444	1,900,732 798,951,370	186,026 878,365,211
Restorable surface relative to OWF footprint—considering the 1% licensing fee (1 GW = 100 km^2; percentage)	0.0 –	5.2 39.5	0.2 30.0	0.0 148.8	4.5 300.6	13.0 5479.5	1.3 6024.1
Restorable surface relative to OWF footprint, considering the 5% licensing fee (1 GW = 100 km^2; percentage)	0.0	25.9	1.2	0.0	22.5	65.2	6.4
Total	–	197.7	150.0	743.9	1503.1	27,397.3	30,120.5

Note: The restorable surfaces of a 1% or 5% flat levy on OWF investments (restoration budget) to fuel active marine restoration for different habitat types (see supplements S3.2). The restoration budget has been calculated for 315 GW over 2022–2031 and for 1944 GW over 2022–2050. The numbers in the upper half per row (worst case) are based on Bayraktarov et al. 2016, restoration costs in purchasing power parity-adjusted 2010 international dollars per km^2, the numbers in the lower half per row (best case) are based on Saunders and colleagues (2020), wherein presented cost data are also converted to US$ base year 2010 per km^2. Unconverted data for stony reefs and kelp are based on Svendsen et al. 2022 and Eger et al. 2022.

long-term viability of such initiatives uncertain, whereas a sustained and well-funded program is necessary for significant nature recovery.

Propelling marine conservation and restoration through OWF development

We advocate for a regenerative OWF licensing approach that actively accelerates large-scale marine restoration (figure 1). This approach should protect and restore long lost key habitats and species (Duarte et al. 2020). Clearly, passive restoration, such as establishing marine protected areas and no-take zones, is essential for enabling active restoration efforts such as marine habitat restoration and nature-inclusive designs. Although the number and global area of marine protected areas increased over the past decades (Vrooman et al. 2022), the achieved area and actual level of protection fell short of meeting the Aichi target 11 of 10% by 2020. With current financial gaps, achieving the 30% target by 2030 under the GBF seems unlikely (Xu et al. 2021, Vrooman et al. 2022, UNEP 2023). Governments must strengthen protection measures within marine protected areas to enhance their effectiveness. Like marine protected areas, OWFs restrict certain activities such as dredging and shipping, but the growing trend of allowing multiuse activities such as fishing and aquaculture threatens their protective potential (OFL 2020, Xu et al. 2021). We argue that, contrary to the current plans that favor synergies and coexistence of multiple uses, OWFs can be designed to restrict extractive uses and complement marine protected areas. Furthermore, OWF investments can fuel protection beyond the boundaries of OWFs, particularly in those areas where the protective function is most effective. Protection would be an effective measure in, for example, industrialized coastal seas with moderately exploited and degraded ecosystems (Jones and De Santo 2016) and areas with vulnerable but highly biodiverse reefs (Saunders et al. 2020). We also emphasize that OWF-supported actions should extend beyond protection, because passive recovery alone can take decades or longer (Duarte et al. 2020, Saunders et al. 2020). Active restoration of degraded areas within and outside the OWF areas targeting critical habitats, such as (biogenic) reefs, kelp forests, saltmarshes, mangroves, and seagrass can catalyze natural recovery at global significant scales (table 1 and supplemental table S3.2; Bayraktarov et al. 2016, Saunders et al. 2020, Eger et al. 2022, Svendsen et al. 2022).

Although passive restoration relies mainly on policy and governance changes, active restoration requires significant financial investments to reach impactful, large-scale outcomes. Innovative technology often supports active restoration (Duarte et al. 2020, Saunders et al. 2020, Airoldi et al. 2021). Therefore, governments should adopt a bolder, fundamentally transformative management strategy on active restoration, rather than applying the precautionary approach resulting in small-scale actions and small investments (IPBES 2024). A science-based, learning-by-doing approach is crucial for restoration. Despite uncertainties related to the small-scale innovative projects in Saunders and colleagues (2020), this approach can scale active marine restoration to large, square kilometer-scale projects (Saunders et al. 2020). Such an approach will boost the unprecedented restoration at tens to millions of square kilometers to yield healthy and functional marine ecosystems, while enabling a learning curve supporting cost-effective restoration at spatial scales comparable to OWFs by 2031 (table 1). Active restoration could also benefit from greening designs of OWF infrastructure (nature-inclusive designs; Airoldi et al. 2021) or, as a last option, from other active compensation actions to maximize biodiversity offsetting (RSPB 2022). This approach can deliver unparalleled ecological, social, and economic benefits from ecosystem services (Saunders et al. 2020, Airoldi et al. 2021).

Funding marine biodiversity action through OWFs

The OWF industry stands at a crossroad regarding marine restoration investments. Governmental biodiversity ambitions in licensing procedures will become pivotal. Globally, offshore wind auctions are increasingly including nonprice criteria

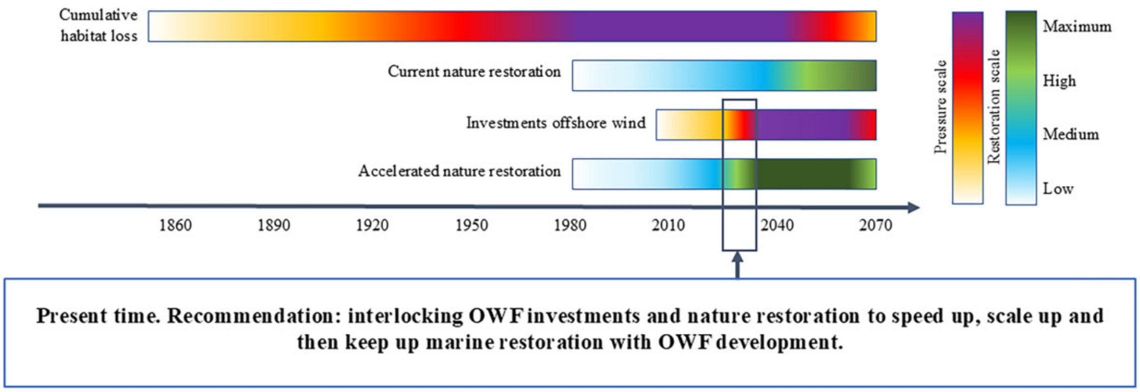

Figure 2. Visualization of the recommendation of interlocking OWF investments to nature restoration. Above: schematic representation of the speed of cumulative habitat loss and the slower speed of nature restoration. This schematic overview is adapted from Duarte and colleagues (2020). Below: schematic representation of investments in offshore wind and accelerated nature restoration with the recommendation to interlock them to simultaneously address the climate and nature crisis'.

alongside financial bids, paving the way for nature-inclusive tendering. To win tenders, bidding consortia typically focus on sustainability-related metrics including system integration, circularity, and the use of local suppliers and biodiversity (ERM 2024). However, biodiversity ambitions are at risk of dropping out in licensing procedures, given the declining profitability driven by lower oil and gas prices and shifting environmental priorities, as are reflected by some parties withdrawing from the Paris climate agreement (McGrath 2020, Kerber 2025). Another pressure hampering the ambition to make OWFs contribute to wide scale restoration is the perception that the OWF industry faces a disproportional environmental scrutiny relative to traditional industries (Willsteed et al. 2018), which may result in delays in OWF development (Galparsoro et al. 2022).

We argue that failing to link large-scale OWF development to funding large-scale marine restoration would be a classic case of penny wise, pound foolish thinking: sacrificing long-term ecological gains for short-term cost savings. First, without sufficient efforts, strict environmental legislation may eventually stall future OWF developments in already degraded marine ecosystems. Second, allocating even a minor percentage of OWF investments presents a significant opportunity to bend the biodiversity-loss curve. To jointly solve the crises on climate, biodiversity, and energy, we must invest in nature and green energy, even during periods with lower energy prices. Within this playing field, the pivotal questions remain as to whether government biodiversity ambitions in OWF licensing will reduce OWFs into just another industry that limits its impacts while contributing to climate change mitigation or will embrace nature-inclusive licensing, positioning OWFs as drivers of both green energy production and large-scale marine ecosystem restoration, securing future development and leading traditional industries by example (figure 2).

Dutch, Danish, and British tendering, licensing, and leasing procedures illustrate that reserving 1%–5% of OWF investments for nature restoration is feasible (supplemental table S2). This can be achieved by redistributing funds from financial bids, incorporating tendering criteria, or channeling contributions via OWF leasing fees in centralized licensing processes. Nature-inclusive designs can also be funded by operators by integrating these requirements into site decisions. A higher percentage could compete with other nonprice criteria, potentially conflicting with other sustainability goals (UN Global Compact 2024). Therefore, marine restoration investments can stem from a balanced mix of governmental funds, blue and green bonds, private operator funds, and cost reductions related to a centralized approach.

Globally, OWF restoration funds have the potential to significantly support the required large-scale marine ecosystem restoration initiatives. Governments and the European Investment Bank have already shown that licensing fees and impact investing can link hard contractual obligations to environmental protection and restoration (Airoldi et al. 2021). Reserving 1%–5% of OWF investments yields US$58–US$292 billion up to 2050 which can cover 10%–49% of costs for passive marine restoration (supplement S3.1). Such a budget can also actively restore marine habitats such as stony reefs, oyster reefs, coral reefs, kelps, seagrass beds, saltmarshes, and mangroves over vast areas (table 1, supplement S3.2). According to the UNEP *State of Finance for Nature* report, such a budget can also cover 5%–26% of the total financial resources needed to actively restore seagrass beds, mangroves, and salt marshes globally towards 2050—an estimated total of US$1.1 trillion (UNEP 2023). This brings us significantly closer to achieving the GBF target for these habitats. Moreover, such investments can return US$2–US$12 for each dollar invested, delivering benefits such as food security, recreation of blue carbon habitats, and shoreline protection (Duarte et al. 2020, Saunders et al. 2020).

Alternatively, failing to meet broader marine restoration objectives could hinder the granting of OWF permits, given current nature conservation legislation, as well as normative changes required to comply with the GBF targets. That jeopardizes OWF development, along with its climate and economic benefits. In fact, mandatory funding of nature restoration provides a level playing field, forcing all biding consortia to support nature restoration equally. It secures additional ecological space for OWF development and prevents consortia that aim only for the lowest price per megawatt to outcompete the projects committed to healthy marine ecosystems. Therefore, establishing licensing requirements for OWFs to deliver marine restoration funds generate benefits for nature, climate, and society at the onset of the greatest OWF investments in history (figure 2). Governments can realize this opportunity by jointly setting clear regional and international marine restoration goals embedded in OWF licensing requirements.

In conclusion, interlocking OWF development with marine restoration funding creates a positive chain reaction: renewable energy mitigates climate change while rebuilding marine life, contributing to multiple UN Sustainable Development Goals and the GBF. Applying this approach now, at the start of upscaling OWFs, would enable OWF development to address the root causes of marine biodiversity loss at larger scales. This can be achieved if governments arrange centralized and uniform nature-positive licensing procedures that boost restoration at wider scales than current projects. This approach could raise the standard for other blue industries, guiding nature-positive and climate-positive marine industrialization by example.

Estimating restoration budgets under uncertainty

All references and data are obtained by reviewing scientific and grey literature. The text below describes the calculations behind the data in the article. All calculations and analyses are meant as rough estimates at the time of publishing this article. Because outcomes heavily rely on the input obtained from the literature, the analyses should be updated with actual values in the future. We accept that variations are not always provided and that we must therefore work with a high level of uncertainty in our outcomes. See supplemental tables S1–S3 and the GWEC data table for sources, calculations, and results.

In table S1.1, we added a sensitivity analysis to illustrate how our findings relate to potential variations in the investment costs per gigawatt and expected global capacity in 2050. The analysis demonstrates the variability of outcomes by changing input parameters in linear calculations. This illustrates that a 10% increase or decrease in one or the other linearly changes potential restoration budgets. Restoration budget, depending on the percentage licensing fee on OWF investments, is far more relevant than other variables.

The analysis demonstrates that the political choices regarding the percentage of a licensing fee (1%–5%) are far more substantial than variations in investment costs or global capacity. In reality, investment costs could influence the global investments and therefore future capacity. Such analysis is not included in the methods because they go beyond the scope of this article and require more fundamental economics.

All other supplements contain linear calculations, and no sensitivity analyses were performed.

Calculations on global offshore wind farm development, investment and scale (supplemental table S1)

In the main text, we start by providing an overview of global offshore wind farm (OWF) development toward 2031 and 2050, highlighting the following: The (expected) global OWF capacity for 2021, 2031, and 2050 are taken from year reports of the Global Wind Energy Council (GWEC 2021, 2022), after consultation of other literature (IRENA 2016, 2019, 2021; WindEurope 2020). The net OWF growth for 2031–2050 is the capacity per continent needed to meet goals of the climate agreement in 2050 (GWEC 2021), without the expected capacity for 2031 (GWEC 2022). Consecutively, we calculated the expected global investment costs for 2021–2031 and 2031–2050, by multiplying the net increase in global capacity over those periods with the investment costs per gigawatt. In this, we used average OWF investment costs as forecasted for 2025, including transmission cost to the shore (NREL 2021). To regard foreseen but unpredictable cost falls and rises because of macroeconomic trends, we nullified cost fluctuations after 2025 (IRENA 2021, 2019; IEA 2021, NREL 2021, Volkskrant 2022). These calculations are the basis of figure 1.

We calculated the added number of turbines for 2021–2031 by dividing the average net increase of global OWF capacity per year, which is 31.5 GW (GWEC 2021, 2022), by the expected average turbine capacity of installed turbines for each year (NREL 2022). Because of a lack of data after 2027, we assumed the capacity of new turbines to increase with 1 megawatt (MW) per year, reflecting predicted increases in 2026 (1.2) and 2027 (1.0), but not the exceptional increase of 3.3 MW in 2025. This is because the report of the National Renewable Energy Laboratory (NREL) warns for such extrapolations as expected average turbine capacity may stop increasing. At the same time the NREL (2022) report stated that it takes several years for prototypes to reach serial production. In 2022, a 15-MW turbine was built, and a 16-MW turbine was prototyped (Buljan 2023a). Moreover, at the start of 2023, an 18-MW turbine was prototyped (Durakovic 2023). In our calculations we therefore rather used a conservative increase of the expected average turbine capacity after 2027 instead of capping the expected average turbine capacity to the level of 2027. The expected average turbine capacity increased from 8.3 MW in 2022 to 18.7 MW in 2031, see table S1.2.

The global footprint of OWFs for 2031 and 2050 is calculated by dividing the OWF global capacity by the average OWF capacity density. Average capacity densities of about 3–7 MW per km^2 are common in the United States and the European Union (Borrmann et al. 2018, Enevoldsen and Jacobson 2021). Also, the optimal spacing for 10- and 15-MW turbines in Europe is about 5 MW per km^2 (Bulder et al. 2018). However, shortage for space can increase average capacity densities up to 10 MW per km^2, despite increasing costs (Ballard 2022). Moreover, innovations may increase the average capacity density (Memija 2022). To provide a conservative estimation of the global OWF footprint and account for trends that higher future capacity densities, we used 10 MW per km^2 as an average (Borrmann et al. 2018, Ballard 2022). In 2050, this means a OWF global footprint of 200,000 km^2. To illustrate the sheer size of the OWF footprint in 2050, we compared the surface with the current footprint of global seaweed aquaculture (Duarte et al. 2021).

Calculations on funding marine restoration through OWFs licensing or leasing fees (supplemental table S2)

Within this article, we demonstrate how OWF development can fuel marine restoration via various fees applied during the OWF development process. Our calculations are based on a few examples from the Netherlands, Denmark, and the United Kingdom. The figures illustrate that centralized leasing and tendering make it possible to reserve 1%–5% of OWF investments for marine restoration.

We calculated the restoration budget from the tender of OWF Hollandse Kust West site VI (HKW6). We first multiplied the total number of points in the tender related to nature restoration by the value of one point in the financial bid (Staatscourant 2022). According to WindEurope 2020, Dutch investment costs could be as low as 2000 k$ per MW. In the Netherlands, transmission costs are not covered by the operator and so have been excluded from the investment costs in this example. We then compared this with the calculated investment costs of HKW6 and the full 2.1 GW OWF (including sites VII and VIII). This last comparison significantly underestimates the potential of a nature-inclusive tender, because only the tender for site VI depended largely on criteria relating to nature (mitigation and enhancement). For site VII, the primal selection criterium was system integration and for site VIII, which is expected in 2026/2027, it has yet to be decided whether ecology will be a selection criterium (Ministry for Climate and Energy Policy the Netherlands 2025). The restoration budget of HKW6 is about 17.8% of the investment costs for only site VI, or 5.9% of the investment costs of the full OWF. For a more international scenario, where investment costs would also include the grid connection, investment cost would be around 3000 k$ per MW, resulting in a restoration budgets of 12% for HKW6 or 4% for the full OWF.

The more recent Dutch tender (IJmuiden Ver Alpha), also included ecological selection criteria and a donation of US$9.9–US$19.9 million to a Dutch marine restoration program (Staatscourant 2023). In addition to tenders, newer site decisions of OWFs IJmuiden Ver Alpha and Beta and Nederwiek 1A require the installation of (artificial) reefs at 20%–40% of the turbine scour protections as prequalification criteria, also supporting wider nature positive developments (RVO 2023a, 2023b, 2024). In the IJmuiden Ver Alpha site, the consortium will even install reefs at over 75% of the turbines (Rijksoverheid.nl 2024). The full contribution of a new Dutch OWF to marine restoration is defined by the ecological plan of the winning bid and the obligations in wind site decisions, which address avoidance and mitigation of impacts next to solving knowledge gaps and wider ecosystem restoration.

For the Danish Thor OWF, US$426.2 million of US$2.36 billion (18%) investment costs were reserved as a licensing fee, although it is not specified how this money is to be spent (Engineer Offshore 2021). The budget illustrates that reserving 1%–5% of OWF investments is for nature restoration, which is feasible if it is supported by governmental policy.

In the United Kingdom, offshore wind developers pay annual option fees during the preparation phase. For the Round 4 Offshore Wind Projects, the fees total £879 million (US$1.1 billion) per year since 2023 (Buljan 2023b), all for the benefit of the nation. In previous years, the projects at the Flamborough and Filey Coast Special Protection Area site and the Dogger Bank Special Area of Conservation site already ran into environmental constraints because of potential effects on kittiwakes and sandbank features, respectively (Durakovic 2022). The Crown Estate stresses that it is imperative to find solutions to provide clean energy while recognizing the importance of protecting habitats and biodiversity (Durakovic 2022). As for the further development of the two sites the Crown Estate made use of the derogation process, therefore all environmental impacts must be fully offset through environmental compensatory measures (Durakovic 2022). This requires further investments in marine restoration by creating or restoring the same or similar habitats, as a contribution via wider marine restoration or measures that reduce pressures on the affected habitats. These plans are currently formulated under the supervision of the Crown Estate (The Crown Estate 2025b). These measures can be implemented and paid by the operators of the specific sites. However, as a more general contribution from OWF development for the appropriation of marine space and to balance OWF and marine restoration, a proportion of the annual option fee could be reserved.

The option fees will be paid for at least 3 and a maximum of 10 years and the fees will apply until the OWF projects are ready to enter into a lease for the seabed site (Buljan 2023b). If consortia pay the option fee on average for 5 years, the article states that they could be operational by the end of this decade, the sum amounts to US$5.5 billion. This is 23% of the estimated US$24 billion investment costs needed to build the total of 8 GW wind farms. Using part of the UK OWF leasing fee could yield a significant contribution towards passive and active marine restoration inside and outside the OWFs.

Marine restoration potential if fueled by a 1%–5% OWF licensing fee (table 1 and supplemental table S3)

We calculated which percentage of the costs for establishing marine protection until 2050 could be covered by a restoration budget fueled by a global 1%–5% OWF licensing fee. The yearly required costs for globally protecting 20%–50% of the oceans for 2022–2050 are based on Duarte and colleagues (2020).

We calculated the areas of stony reefs, oyster reefs, coral reefs, kelp, seagrass beds, mangroves, and saltmarshes that could be restored fueled by a 1%–5% licensing fee on OWF investments. We did so for an added 315 GW (2022–2031) and a total of 1944 GW added between 2022–2050. This results in potential restoration budgets from 9.5 (1% until 2030) to 292 million k$ (5% till 2050). To get a feeling for the effect of the restoration costs per squared kilometer we applied a worst case scenario in which the burgeoning industry of active restoration would not evolve and costs would remain at the same level as the purchasing power parity-adjusted costs (2010 international dollars per km^2) as was presented by Bayraktarov and colleagues (2016) and a best case scenario in which the costs due to future innovations drop to levels of the best practices presented in Saunders and colleagues (2020), wherein presented cost data were converted to US$ base year 2010 per km^2. So where we can, we compare 2010 prices, but the OWF investment costs are from 2021.

For kelp, best case data were only available in Saunders and colleagues (2020). Because worst case data were absent from Bayraktarov and colleagues (2016), we used data from Eger and colleagues (2022; supplement S3.2). On stony reefs, no data are present in either Bayraktarov and colleagues (2016) or Saunders and colleagues (2020). To be able to include this habitat, we calculated the costs of restoring stony reefs per kilometer for a worst case on the basis of costs and surfaces from Svendsen and colleagues (2022). These data have been transformed to US$ using the Danish krone to US$ ratio of January 2022. Both these data on stony reefs and kelp have not been transformed back to 2010 prices.

To get a feeling for scale, we compared the surface of the restored habitats per GW with the OWF footprint per GW (OWF footprint is 100 km^2; see the results in tables 1 and S1.1).

At last, we calculated to what extent a 1%–5% licensing fee between 2022 and 2050 could cover the required restoration costs until 2050 of seagrass beds ($840 billion), salt marshes ($250 billion), and mangroves ($16 billion) as presented by the UNEP *State of Finance for Nature* report 2022.

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Supplemental material

Supplemental data are available at *BIOSCI* online.

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