

BIODIVERSITY VS. CLIMATE RISK EXPOSURES OF RENEWABLE ENERGY FIRMS

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In recent years, there has been a growing interest in understanding the intricate relationships between the economy and the health of our planet, with researchers studying both climate risks¹ and, more recently, biodiversity risks.² While climate and biodiversity risks interact in important ways, they are conceptually distinct. In this paper, we highlight this difference by studying risk exposures of firms in the renewable energy sector.

Renewable energy plays a key role in reducing carbon emissions and mitigating climate change, with renewable energy sources such as solar, wind, and hydropower offering lower-carbon alternatives to fossil fuels.³ According to the International Renewable Energy Agency (IRENA), in order to meet the 2°C climate goal, the share of renewable energy in final energy consumption must increase from 19 percent in 2017 to 65 percent by 2050.⁴ Regulations and policies to support

1. See Giglio and others (2021), Stroebe and Wurgler (2021), Acharya and others (2023a), Hong and others (2020).

2. See Giglio and others (2023), Karolyi and Tobin-de la Puente (2022), Garel and others (2023), Dasgupta (2021), Flammer and others (2023).

3. See Ellabban and others (2014).

4. See IRENA (2019).

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this decarbonization of the energy mix involve various efforts to raise the relative costs of fossil fuels through carbon taxes, cap-and-trade systems, and subsidies to renewable energy.⁵ As a result, renewable energy companies are key beneficiaries of a tightening of climate policies and regulations: they should benefit from realizations of climate transition risks.

However, while renewable energy companies play a key role in mitigating climate change, renewable energy projects such as wind and solar farms can have negative impacts on ecosystems and biodiversity. As reviewed in Gasparatos and others (2017), the development and expansion of renewable energy infrastructure can contribute to the four key drivers of ecosystem change and biodiversity loss. First, habitat loss or alteration can occur when renewable energy projects require the conversion of natural areas into energy production sites. This can result in the disruption or displacement of native species and the destruction of critical habitats. Second, the construction and operation of renewable energy facilities can generate pollution, such as noise, light, and electromagnetic interference, which can disrupt the behavior, breeding patterns, and movement of wildlife. Third, an overexploitation of natural resources such as water or biomass can occur in the production of bioenergy or hydropower, potentially causing the depletion or degradation of ecosystems. Fourth, the introduction of invasive species can arise through the transportation and installation of renewable energy infrastructures. Consistent with this discussion, we study the risk disclosures in firms' 10-K statements and find that renewable energy firms report to be negatively affected by policies to protect nature and biodiversity: renewable energy companies should thus suffer from realizations of biodiversity transition risks.

To formally explore the risk exposures of renewable energy companies, we compare their climate and biodiversity transition risk profiles to those of otherwise-similar nonrenewable energy companies. To do so, we combine firm-level climate transition risk exposures from Sautner and others (2023) with firm-level measures of biodiversity risk exposures from Giglio and others (2023). We find that, on average, renewable-energy-related firms exhibit higher biodiversity risk exposures and lower climate transition risk exposures than nonrenewable energy firms.

We also assess the stock price response of renewable energy firms upon news about climate and biodiversity risk realizations. To do so, we form equity portfolios consisting of renewable energy companies

5. See Olabi and Abdelkareem (2022).

and test the correlation between the portfolio returns and innovations in indices measuring aggregate news about realizations of climate and biodiversity risks. We find that the correlations between the renewable energy portfolios and climate news indices are generally positive. This suggests that renewable energy firms tend to benefit from negative news or increased discussion related to climate change. Conversely, when assessing the co-movement with biodiversity news indices, we find negative correlations. This implies that renewable energy portfolios underperform upon the realization of biodiversity-related risks.

Overall, our analysis suggests that it is important to carefully consider the potential conflict between a large-scale expansion of renewable energy production and the protection of nature and biodiversity when promoting various climate policy options.⁶ From an investors' perspective, our findings highlight that projects aimed at hedging portfolios against climate transition risk realizations may actually expose that investor to realizations of biodiversity transition risks.⁷

1. BIODIVERSITY RISK AND RENEWABLE ENERGY FIRMS

According to a recent report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, five direct drivers of change in nature have accounted for more than 90 percent of nature loss in the past 50 years.⁸ These drivers are land-use and sea-use alteration, pollution, invasive alien species, exploitation and utilization of natural resources, and climate change. Table 2, which is adapted from Gasparatos and others (2017), summarizes how renewable energy projects have a potential impact on biodiversity through several of these channels. Rehbein and others (2020) provide further discussions on these issues. In what follows, we summarize some of these mechanisms and explore the 10-K statements of renewable energy companies to understand the extent to which these effects on biodiversity expose renewable energy firms to biodiversity transition risks.⁹

6. See also a related discussion in Jackson (2011).

7. See also Giglio and others (2023).

8. See Brondizio and others (2019).

9. A 10-K statement is a comprehensive annual report filed by publicly listed companies with the U.S. Securities and Exchange Commission (SEC). It includes financial metrics as well as a discussion of risk factors. We collect firms' 10-K statements from 2001 to 2020 through the SEC's EDGAR database.

1.1 Land-use and Sea-use Change

Renewable energy companies' 10-K statements frequently describe a variety of mechanisms through which changes in land- and sea-use patterns from the construction of renewable energy projects and associated transmission networks can have negative effects on nature and biodiversity.

First, projects such as wind farms or solar power installations can directly cause the injury and death of various species. For example, wind turbines pose a risk for birds colliding with rotating turbine blades, and solar power plants with reflective surfaces have caused birds to be burned when flying over the plant. Similarly, turbine blades in hydropower installations can injure and kill fish. Second, the construction of renewable energy facilities and transmission lines can lead to habitat fragmentation and the disruption of the natural movement of wildlife. For example, large-scale solar installations can result in habitat fragmentation for bats,¹⁰ and wind farms can fragment habitats used by birds for nesting and foraging; they might also alter birds' flight patterns, potentially disrupting bird populations and leading to changes in species composition.¹¹ In offshore environments, the installation of wind turbines and associated infrastructure can disrupt the movement of fish, marine mammals, and invertebrates.¹² Hydropower projects such as large dams can alter the natural flow of rivers and create barriers to fish migration.¹³

Examples of firms in the renewable energy sector describing such impacts on biodiversity, as well as the associated regulatory transition risk exposures, include:

Our projects are also required to comply with the Migratory Bird Treaty Act (the "MBTA") and the Bald and Golden Eagle Protection Act (the "BGEPA"). Because the operation of solar energy projects could result in harm to endangered species or their habitats or could result in injury or fatalities to protected birds, federal and state agencies may require ongoing monitoring, mitigation activities, or financial compensation as a condition to issuing a permit for a project. [spoint3 Energy Partners, LP, 2017 10-K statement]

In particular, the Company's U.S. facilities are subject to the CWA [Clean Water Act] Section 316(b) rule issued by the EPA

10. See Tinsley and others (2023).

11. See Masden and others (2009).

12. See Riefolo and others (2016).

13. See Nieminen and others (2017).

[Environmental Protection Agency] that seeks to protect fish and other aquatic organisms by requiring existing steam electric generating facilities to utilize the BTA [Best Technology Available] for cooling water intake structures.[. . .] These standards require certain subject facilities to choose among seven BTA options to reduce fish impingement. [The AES Corporation, 2019 10-K statement]

In addition, laws relating to the protection of migratory birds and other wildlife could impact the development and operation of transmission lines and wind projects. [Portland General Electric Company, 2016 10-K statement]

Protection of the habitat of endangered and threatened species makes it difficult and more costly to perform some of PacifiCorp's core activities, including the siting, construction, and operation of new and existing transmission and distribution facilities, as well as thermal, hydroelectric, and wind generation plants. In addition, issues affecting endangered species can impact the relicensing of existing hydroelectric generating projects. This can generally raise the price PacifiCorp pays to purchase wholesale electricity from hydroelectric facilities owned by others, as well as reduce the generating output and operational flexibility, and potentially increase the costs of operation, of PacifiCorp's own hydroelectric resources. [PacifiCorp, 2005 10-K statement]

The habitat conservation plans (HCPs) received the support of the resource agencies, have been adopted by FERC [Federal Energy Regulatory Commission], and generally obligate the PUDs [Public Utility Districts] to achieve certain levels of passage efficiency for downstream migrants at their hydroelectric facilities and to fund certain habitat conservation measures. [Puget Energy, Inc., 2005 10-K statement]

NEP is subject to numerous environmental regulations and guidelines related to threatened and endangered species and/or their habitats, as well as avian and bat species, for the ongoing operations of its facilities. [. . .] In addition to regulations, voluntary wind turbine siting guidelines established by the U.S. Fish and Wildlife Service set forth siting, monitoring, and coordination protocols that are designed to support wind development in the U.S. while also protecting both birds and bats and/or their habitats. [. . .] Complying with these environmental regulations and adhering to the provisions set forth in the voluntary wind turbine siting guidelines could result in additional costs or reduced revenues at existing or new wind and solar facilities and transmission and distribution facilities at NEP and, in the case of environmental laws and regulations, failure to comply could result in fines, penalties, criminal sanctions or injunctions. [NextEra Energy Partners, LP, 2019 10-K statement]

On November 22, 2013, Duke Energy entered into a settlement with the U.S. Department of Justice (DOJ) related to the incidental deaths of golden eagles and other migratory birds resulting from turbine collisions at four wind farms in Wyoming. Terms of the agreement include two misdemeanor violations of the Migratory Bird Treaty Act, payment of \$1 million in fines and restitution, five years' probation, and implementation of a migratory bird compliance plan. The agreement includes a ten-year non-prosecution agreement for future incidental deaths at four facilities. Duke Energy undertakes adaptive management practices designed to avoid and minimize additional avian impacts. [Duke Energy Corporation, 2013 10-K statement]

For example, the DOJ has alleged that certain NEER [NextEra Energy Resources] subsidiaries have violated the Migratory Bird Treaty Act (MBTA) and/or the Bald and Golden Eagle Protection Act (BGEPA) as a result of accidental collisions of eagles into wind turbines at the NEER subsidiaries' wind facilities without subsidiaries having permits under BGEPA for those activities. If NEER is unsuccessful in reaching a satisfactory settlement of this issue with the DOJ or if additional eagles perish in collisions with wind turbines at NEER's facilities without NEER having obtained permits for those activities, NEER or its subsidiaries may face criminal prosecution under these laws. [NextEra Energy, Inc., 2021 10-K statement]

1.2 Pollution

In addition to land-use and sea-use changes, renewable energy firms can have a negative impact on nature and biodiversity through causing pollution. For example, in the case of solar energy, the use of dust suppressants and herbicides to maximize sun access to solar panels can harm the surrounding ecosystems. Similarly, hydropower projects can contribute to pollution through changes in sediment loading and nutrient cycles. Geothermal energy projects can also result in pollution through the emission of hydrogen sulfide and boric acid.

Renewable energy firms are therefore generally required to comply with environmental laws and regulations to mitigate the impact of pollution on nature and biodiversity. Firms regularly mention these regulations as sources of biodiversity transition risks.

Our geothermal operations involve significant quantities of brine (substantially, all of which we reinject into the subsurface) and scale, both of which can contain materials (such as arsenic, antimony, lead,

and naturally occurring radioactive materials) in concentrations that exceed regulatory limits used to define hazardous waste. [Ormat Technologies, Inc., 2019 10-K statement]

Our businesses are subject to environmental laws and regulations, including, but not limited to, extensive federal, state, and local environmental statutes, rules, and regulations relating to [. . .] natural resources and health and safety (including, but not limited to, electric and magnetic fields from power lines and substations, and ice throw, shadow flicker and noise related to wind turbines) that could, among other things, prevent or delay the development of power generation, [. . .] require additional pollution control equipment, and otherwise increase costs, increase capital expenditures and limit or eliminate certain operations. [Avangrid, Inc., 2016 10-K statement]

EPA published the final national chronic aquatic life criterion for the pollutant Selenium in fresh water. NPDES permits may be updated to include Selenium water quality-based effluent limits based on a site-specific evaluation process which includes determining if there is a reasonable potential to exceed the revised final Selenium water quality standards for the specific receiving water body utilizing actual and/or project discharge information for the generating facilities. [The AES Corporation, 2019 10-K statement]

1.3 Invasive Species

In biomass energy production, the use of certain feedstocks can pose a risk of introducing invasive species. These feedstocks can propagate quickly, overpowering native vegetation and causing disturbances within local ecosystems. Consequently, regulations are in place to ensure bioenergy firms adhere to taking measures to prevent the introduction and proliferation of invasive species, and a tightening of these regulations exposes affected firms to biodiversity transition risks.

Under the 2007 Energy Independence and Security Act, the EPA is required to produce a study every three years of the environmental impacts associated with current and future biofuel production and use, including effects on air and water quality, soil quality and conservation, water availability, energy recovery from secondary materials, ecosystem health and biodiversity, invasive species, and international impacts. [Renewable Energy Group, 2012 10-K statement]

2. COMPARING BIODIVERSITY AND CLIMATE RISK EXPOSURES

After documenting that renewable energy firms frequently disclose substantial exposures to biodiversity transition risks, we next quantify these biodiversity risk exposures more formally and compare them across renewable and nonrenewable energy companies. We contrast our findings with the variation in climate risk exposures across the same set of firms.

2.1 Measuring Risk Exposures

The systematic measurement of firms' biodiversity transition risk remains in its early stages. Here we explore the 10K-Biodiversity-Regulation Score proposed by Giglio and others (2023) and available at www.biodiversityrisk.org. This binary variable takes a value of one if a company's 10-K statement in a given year includes at least two sentences related to biodiversity risk and one sentence related to regulatory biodiversity risk. A higher value indicates a higher biodiversity regulatory risk exposure. To measure firms' climate transition risk exposures, we use data from Sautner and others (2023). Specifically, we consider the and scores that count the frequency with which bigrams that capture regulatory climate risks are mentioned together with positive or negative tone words in one sentence in the earning call transcripts. A lower value in " $RGSentiment^{Pos}$ " and a higher value in " $RGSentiment^{Neg}$ " signify a higher climate transition risk exposure, suggesting that a firm would lose upon climate risk realizations.

2.2 Identifying "Renewable Energy Firms"

Transition risks affecting the production of renewable energy not only influence firms in the utilities sector that produce renewable energy directly. Instead, these risks could also affect, for example, the suppliers of such firms. For example, regulations to protect the environment do not just hurt utilities that produce solar energy but also suppliers of solar panels in the semiconductor sector. To determine which firms are affected by shocks to the production of renewable energy, we exploit the holdings of renewable energy ETFs such as

Invesco Global Clean Energy ETF (PBD), iShares Global Clean Energy ETF (ICLN), VanEck Low Carbon Energy ETF (SMOG), SPDR S&P Kensho Clean Power ETF (CNRG), Invesco Solar ETF (TAN), and First Trust Global Wind Energy ETF (FAN). We obtain portfolio holdings of these ETFs from Bloomberg from March 2023, focusing on North American common stocks.

2.3 Comparing Risk Exposures

To examine the average biodiversity and climate risk exposures of renewable energy firms in comparison to nonrenewable energy firms, we use the following cross-sectional specification:

$$Risk\ Exposure_i = \beta \cdot 1(Renewable)_i + Controls_i + \epsilon_i \quad (1)$$

where $Risk\ Exposure_i$ is one of the 10K-Biodiversity-Regulation Score, $RGSentiment^{Pos}$, or $RGSentiment^{Neg}$ of firm i . $1(Renewable)_i$ is an indicator for a renewable energy firm, set equal to one if it is held by at least one of the renewable energy ETFs. Table 1 shows the result. Columns (2), (4), and (6) include firm controls for size and book-to-market (B/M). Size is the logarithm of firm i 's market capitalization, and B/M is firm i 's book value divided by its market capitalization, winsorized at the 2.5 percent level. All measures are averaged over a five-year period between 2018 and 2022. The sample includes all firms for which both the Giglio and others (2023) and the Sautner and others (2023) measures are available.

We find that β is positive and significant for biodiversity regulatory risk exposure and positive mention of climate regulation bigrams, while it is negative and significant for negative mention of climate regulation bigrams. This finding suggests that renewable energy firms are substantially more exposed to biodiversity regulatory risk and less exposed to climate regulatory risk compared to nonrenewable energy firms. The positive coefficient on highlights that renewable energy firms are not only less exposed by regulatory climate interventions but also more likely to be beneficiaries of these regulations.

Table 1. Renewable Energy Firms and Risk Exposure

	<i>Biodiversity Regulation Risk</i>		<i>RGSentiment^{Pos}</i>		<i>RGSentiment^{Neg}</i>	
	(1)	(2)	(3)	(4)	(5)	(6)
1(<i>Renewable</i>)	0.026** (0.012)	0.029** (0.012)	0.017*** (0.002)	0.016*** (0.002)	-0.004*** (0.001)	-0.004*** (0.001)
LogSize		0.001 (0.001)		0.001*** (0.000)		-0.000** (0.000)
B/M		0.044*** (0.006)		0.003*** (0.001)		-0.001*** (0.000)
Observations	2,368	2,368	2,368	2,368	2,368	2,368

Source: Authors' calculations.

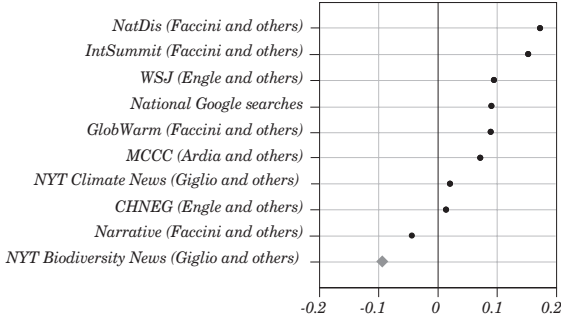
Notes: This table shows results from regression 1. *Biodiversity Regulation Risk* takes a value of one if a company's 10-K statement in a given year includes at least two sentences related to biodiversity risk and one sentence related to regulatory biodiversity risk. It is provided by Giglio and others (2023). *RGSentiment^{Pos}* is the relative frequency with which bigrams that capture regulatory shocks related to climate change are mentioned together with positive tone words in the transcripts of earnings conference calls. *RGSentiment^{Neg}* measures the relative frequency with which bigrams that capture regulatory shocks related to climate change are mentioned together with negative tone words in the transcripts of earnings conference calls. Both climate risk exposure measures are provided by Sautner and others (2023). We multiply the *RGSentiment^{Pos}* and *RGSentiment^{Neg}* by 100. The sample includes all firms for which both biodiversity and climate risk exposure measures are available. 1(*Renewable*) is an indicator for a renewable energy firm, set equal to one if it is held by at least one of the renewable energy ETFs described in the main text. *LogSize* is the logarithm of firm's market capitalization. *B/M* is firm's book value divided by its market capitalization, winsorized at the 2.5 percent level. For all measures, we average over 2018 to 2022. Significance levels: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

2.4 Hedging Climate and Biodiversity Risks

We also investigate the covariance of renewable energy firms' stock returns with news about climate and biodiversity risk realizations.

We begin by forming portfolios of the renewable energy firms identified as described above. Specifically, we construct a renewable energy portfolio that goes equally long for all the renewable energy firms. To capture aggregate biodiversity risk realizations, we study AR(1) innovations of the NYT-Biodiversity News Index developed by Giglio and others (2023). To capture climate risk realization, we work with AR(1) innovations in several climate risk news series proposed by Ardia and others (2020), Engle and others (2020), and Faccini and others (2021).

Figure 1. Climate and Biodiversity Hedge Performance of Renewable Energy Portfolio



Sources: As indicated.

Notes: Dot plot of monthly return correlations for the renewable energy portfolio with AR(1) innovations of various indices using data from 2010 to 2020. The dots in the top nine rows show the correlations with climate indices by Ardia and others (2020), Engle and others (2020), Giglio and others (2023), and Faccini and others (2021), and a national Google search index. See detailed discussion of these indices in Alekseev and others (2022). The diamond in the bottom row shows the correlation with the NYT-Biodiversity-News index developed by Giglio and others (2023). Each dot represents one correlation coefficient.

Figure 1 presents correlations at the monthly level between the returns of our renewable energy portfolio and various innovations of biodiversity and climate risk indices. The correlations between 2010 to 2020 indicate that renewable energy-related firms generally exhibit a positive correlation with climate news while demonstrating a negative correlation with biodiversity news. In other words, while these firms tend to gain from climate risk realizations, they suffer from biodiversity risk realizations, consistent with the direction of their risk exposures established above.

3. CONCLUDING THOUGHTS

Renewable energy firms are instrumental in combating climate change through their provision of clean and sustainable energy sources.¹⁴ Yet, it is important to recognize that these firms' activities can simultaneously contribute to nature and biodiversity loss. As a result, they are substantially exposed to biodiversity transition risk. As the world transitions to a low-carbon economy, it therefore becomes crucial for researchers and regulators to separately manage

14. See Acharya and others (2023b).

biodiversity and climate risks, potentially necessitating a reevaluation of existing climate-related policies and regulations in light of emerging biodiversity risks. To further advance the management of biodiversity risks, regulators should thus focus both on improving measurement and disclosure of these risks and on stress testing the financial system to realizations of these risks.

3.1 Measures and Disclosures

Unlike climate risk, which can be quantified to some extent through metrics such as carbon emissions, biodiversity risk poses unique challenges in measurement, assessment, and disclosure.

Recent research has proposed various methodologies to measure and assess biodiversity risk. These approaches include analyzing 10-K statements, conducting surveys, and utilizing information from biodiversity-themed ETFs holding.¹⁵ Additionally, third-party measures such as the Corporate Biodiversity Footprint have been applied to provide insights into companies' impacts on biodiversity,¹⁶ though the construction of measures provided by commercial vendors is often opaque. In terms of disclosure, efforts have been made to enhance transparency and reporting on biodiversity-related issues. One notable initiative is the Taskforce on Nature-related Financial Disclosures (2022), which aims to provide a framework for companies and financial institutions to disclose and manage their nature-related risks and opportunities. Additionally, organizations such as the Carbon Disclosure Project (CDP) have begun to include biodiversity-related information in their reporting frameworks.

While these initiatives represent important steps towards better disclosures of biodiversity risks, regulators should further focus on enabling firms to measure and disclose their biodiversity risks.

3.2 Stress Test

The recognition of potential risks posed by climate change to the economy has spurred central banks and regulatory authorities worldwide to assess and manage climate-related risks through climate stress tests.¹⁷ The risks associated with biodiversity loss, although

15. See Giglio and others (2023).

16. See Garel and others (2023).

17. See Acharya and others (2023a).

increasingly acknowledged, have received less attention in comparison. Recognizing the need to broaden the scope of environmental risks, the Network for Greening the Financial System¹⁸ acknowledges that environmental risks extend beyond climate change, prompting institutions such as De Nederlandsche Bank¹⁹ and Banque de France²⁰ to incorporate biodiversity risk into their stress testing systems. As our understanding of the potential materiality of biodiversity risks evolves, regulators and central banks may consider the inclusion of such risks in their stress-testing frameworks.

Table 2. Impacts of Renewable Energy Companies on Biodiversity

	<i>Habitat Loss & Change</i>	<i>Direct Mortality</i>	<i>Pollution</i>	<i>Invasive Species</i>
Solar energy	Land occupation by infrastructure; Habitat fragmentation by infrastructure and land preparation.	Bird collisions and solar ray burning; Attraction and disorientation of insects.	Dust suppressants and herbicides.	
Wind power	Land occupation by infrastructure; Downdraught generated by the spinning blades; migratory routes disruptions of birds and bats.	Birds and bats collisions with wind generators		
Hydropower	Upstream flooding and habitat fragmentation by plants and dams; Modification of water flow regimes; Obstacles to fish migration.	Fish passage into turbines.	Eutrophication caused by changes in sediment loading and nutrient cycles.	

18. See NGFS (2021).

19. See De Nederlandsche Bank (2020).

20. See Banque de France (2021).

Table 2. Impacts of Renewable Energy Companies on Biodiversity (continued)

	<i>Habitat Loss & Change</i>	<i>Direct Mortality</i>	<i>Pollution</i>	<i>Invasive Species</i>
Biomass energy and biofuels	Land use change resulting from the expansion of biomass feedstock and feedstock cultivation; changing size and shape of plants; alteration of landscape features; soil loss.		Eutrophication, acidification, and toxicity resulting from greenhouse gases (GHGs) and atmospheric/water pollutants generated through bioenergy production	Some biomass energy feedstocks might be invasive
Geothermal energy	Land occupation by infrastructure; changes caused by site clearing, road construction, well drilling, and seismic surveys.		Emission of toxic pollutants; elevated arsenic concentration in water and soil; noise and heat pollution	
Marine energy (tidal, wave, thermal, offshore wind)	Land occupation by infrastructure; operation of ocean energy devices that can disrupt bird and aquatic species' movement and feeding activity; alteration of the characteristics of the marine environment.	Fish entrapment caused by tidal barrages; fish mortality due to temperature shocks from upwelled cold water; bird collisions with offshore wind farms.	Chemical, noise, and electromagnetic pollution.	

Source: Authors' research.

Notes: Adapted from Table 3 in Gasparatos and others (2017), which also lists sources documenting evidence for the various impacts.

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