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Environmental impact evaluation of an oscillating water column

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Abstract. This study evaluates the environmental impacts of an oscillating water column (OWC) system used for renewable energy generation, employing Conesa's methodology. By conducting a comprehensive assessment, various environmental parameters, such as water quality and marine-coastal ecosystems, are thoroughly analyzed. The methodology entails a systematic approach to identify, assess, and prioritize potential impacts, ensuring a holistic view of the environmental implications. Through data collection and analysis, critical impacts, including changes in biodiversity, alterations in habitat conditions and variations in water quality indicators, are highlighted. The findings emphasize the importance of mitigating adverse effects, proposing practical recommendations that aim to balance energy production with ecological preservation. This research underscores the necessity of integrating environmental considerations into the development of marine renewable energy technologies, contributing to their sustainable implementation and fostering a harmonious coexistence between technological advancement and environmental stewardship.

Key words. Oscillating water column, Conesa's methodology, environmental impact assessment, renewable energy, marine technology.

1. Introduction

Renewable energy technologies are critical for reducing our reliance on fossil fuels and mitigating the environmental footprint of energy production [1]. However, it is essential to conduct thorough environmental impact assessments to ensure that these technologies do not introduce new environmental challenges. The development of energy generation technologies with a smaller environmental footprint is crucial for sustainable development, but it is important to acknowledge that all energy technologies have some impact on the environment [2].

Among the various renewable energy technologies, the oscillating water column (OWC) is a promising alternative for harnessing wave energy. Although wave energy is still in its early stages of development and requires further technological advancements for large-scale commercial deployment, it holds great potential, particularly for coastal communities. Wave energy, along with other renewable sources, such as solar, wind, small-scale hydropower, and marine energy, can contribute to a diversified and resilient energy mix. The global potential of wave energy is estimated at approximately 32×10^{12} kWh per year, nearly double the total global electricity generation in 2008 [3]. OWC technology involves a partially submerged structure with an air chamber above the water surface. Waves entering the chamber cause the water column inside to oscillate, compressing and decompressing the air above it. This airflow drives a bidirectional turbine connected to a generator, converting wave energy into electrical energy [4]. The key advantages of OWC systems include their ability to harness consistent wave energy, reduce greenhouse gas (GHG) emissions, and provide a renewable source of power [5]. Nevertheless, there are also potential drawbacks, including impacts on marine life, changes in sediment transport, and the need for robust structural materials to withstand harsh marine environments. Therefore, a key challenge in expanding the OWC device application is the uncertainty surrounding their potential impacts on coastal and marine ecosystems. These effects may occur throughout various phases, including the design, construction, operation, and decommissioning of the devices. Specifically, OWCs have the potential to alter coastal environments and contribute to noise pollution. However, they also provide notable advantages, particularly in terms of clean energy generation. Therefore, assessing both the environmental and socio-economic impacts of this technology is crucial to determine its sustainability and safety [6]. Additionally, such evaluations help bridge existing knowledge gaps regarding the broader implications of these systems on both nature and society.

The evaluation of the environmental impacts of OWC systems requires the use of robust methodologies. Various methodologies have been employed for environmental impact assessments (EIA), each one with its own strengths and limitations. Among them, Conesa's methodology stands out for its comprehensive approach to identifying, assessing, and prioritizing potential environmental impacts [7]. This methodology involves a systematic evaluation process that ensures a holistic view of the technology's environmental implications. Notably, detailed studies on the environmental impact of OWC systems are scarce in the literature, highlighting the need for comprehensive assessments to fill this gap.

Under this scenario, this study focused on conducting an EIA of the OWC system using Conesa's methodology. By applying this methodology, a thorough analysis of the environmental factors affected by the OWC system is provided, offering insights into both the benefits and challenges associated with its implementation. This research contributes to the sustainable development of marine renewable energy technologies by highlighting critical environmental impacts and proposing recommendations for their mitigation.

2. Materials and methods

The EIA is a key process for analysing the effects that a project or activity may have on the environment, with the goal of anticipating, mitigating, and addressing negative impacts. This procedure is structured into twelve major phases, enabling a comprehensive analysis of a project's impact on various environmental factors. A general description of each phase is stated [7]: 1. Project analysis and alternatives assessment, which provides a complete overview of the project's scope and characteristics. 2. Definition of the project environment, identifying the area in which the project will take place and providing a detailed description based on the most relevant aspects, such as climate, biodiversity, and water resources. 3. Preliminary assessment of environmental effects on various environmental factors. 4. Identification of the project's specific actions that could significantly impact the environment, including infrastructure construction, and resource extraction among other interventions. 5. Identification of potentially affected environmental factors, including air, water, fauna, flora, landscape, and natural resources. 6. Cause-effect relationship analysis to examine how specific project's activities may lead to environmental impacts. 7. Prediction of the impact magnitude in relation to the affected environmental factors. 8. Quantitative assessment of the environmental impacts. Impacts are quantified in measurable units (e.g., air pollutants, biodiversity loss, etc.), and a weighted sum of impacts is calculated. 9. Definition of preventive, mitigation, and compensation measures, along with the establishment of an environmental monitoring program to ensure the effectiveness of these measures. 10. Public participation process, involving citizens, social stakeholders, and relevant organizations to gather opinions and concerns regarding the project. 11. Issuance of the final report, summarizing the results of all previous phases. 12. Decision by the competent authority on whether to approve or reject the project based on the EIA findings.

The first six phases correspond to the qualitative impact assessment, while phases seven, eight, and nine focus on the quantitative evaluation. The first nine phases are part of the environmental impact study. If phases seven, eight, and nine are omitted, a simplified assessment is conducted. Fig. 1 presents a simplified procedural framework used to identify and assess the environmental impacts of an OWC.

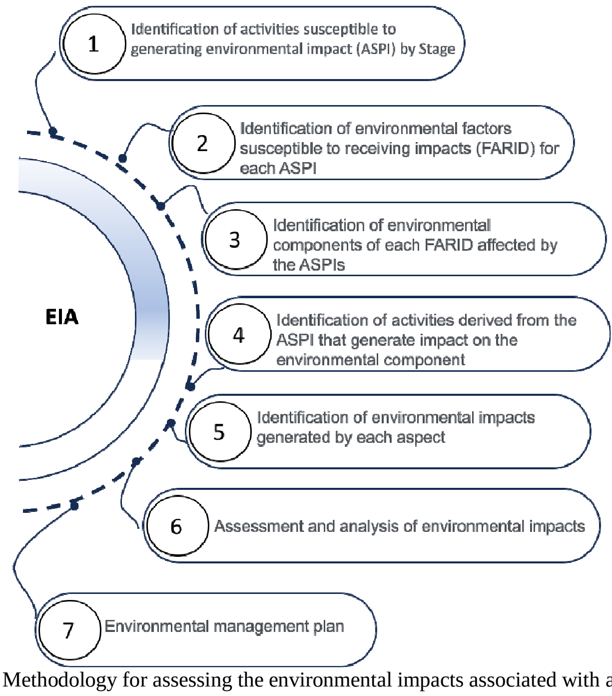

Fig. 1. Methodology for assessing the environmental impacts associated with an OWC

For the quantitative assessment of the environmental impacts generated by the activity, the methodology developed by V. Conesa was applied [7]. This approach is based on a cause-and-effect matrix, allowing the significance of impacts to be determined according to multiple environmental attributes. The methodology stands out for its quantitative and structured approach, providing a detailed analysis of the degree of alteration that an activity may generate on various environmental components throughout each project phase, from the design and installation to the operation, maintenance, and eventual decommissioning. The significance of each impact is determined by using Eq. (1), which weights various environmental attributes to provide an objective evaluation of the effects generated. In this equation, ± sign indicates if the impact is positive or negative, while the overall score is obtained by assessing key factors or attributes. The significance or importance of impacts is calculated in terms of impact intensity and its characterization, considering a set of qualitative attributes. A score is assigned to each factor, following the criteria established in Table 1.

$$I=\pm[3i+2EX+MO+PE+RV+SI+AC+EF+PR+MC] \quad (1)$$

The impact of an action on nature or its characteristics can be positive or negative, depending on the outcome it generates. A positive impact occurs when actions enhance environmental quality, such as implementing sustainable practices that promote biodiversity, reduce pollution, or preserve the ecosystems. These actions do not only protect the environment but also contribute to the well-being of future generations. Conversely, a negative impact refers to actions that lead to a decline in environmental quality (e.g., deforestation, air or water pollution, and habitat loss). These effects are harmful to both the ecosystems and the species that depend on them, including humans. The key difference between a positive and a negative impact lies in an action's ability to either preserve or degrade natural resources and biodiversity.

Table 1. Factors for determining the significance of the impact and their respective scores.

Criterion	Value	Significance
Intensity (i)	1: minimal impact, 2: medium impact, 4: high impact, 8: very high impact, 12: total destruction.	Degree of destruction in the affected area.
Extent (EX)	1: localized, 2: partial, 4: extensive, 8: total, 12: critical	Impact influence area concerning the surroundings
Moment (MO)	1: long-term (>5 years), 2: medium-term (1-5 years), 4: immediate (< 1 year), 8: critical (short-term)	Time between the activity causing the impact and the effect on the factor.
Persistence (PE)	1: fleeting (< 1 year), 2: temporary (1-10 years), 4: permanent (> 10 years)	Duration of the effect from its onset.
Reversibility (RV)	1: short-term (< 1 year), 2: medium-term (1-5 years), 4: irreversible	Possibility of natural recovery of the affected factor
Synergy (SI)	1: non-synergistic, 2: synergistic, 4: highly synergistic	Reinforcement of two or more simple effects.
Accumulation (AC)	1: simple, 4: cumulative	Progressive increase in the effect manifestation.
Effect (EF)	1: indirect, 4: direct	Cause-effect relationship.
Periodicity (PR)	1: irregular or discontinuous, 2: periodic, 4: constant or continuous	Regularity of the effect manifestation.
Recoverability (MC)	1: total or immediate (0 year), 2: recoverable (<1 year), 4: mitigable (10-15 years), 8: non-recoverable (>15 years)	Possibility of factor recovery through human intervention.

Each attribute provides crucial information about the magnitude and persistence of the impact. Intensity (i) is assessed based on the degree of affectation over a specific area, while extent (EX) determines the spatial reach of the alteration. The timing (MO) of the effect is relevant to understand whether the impact occurs immediately or is delayed over time. Persistence (PE) classifies the duration of the impact, differentiating between temporary or permanent effects, and reversibility (RV) assesses the recovery potential of the affected component. In addition, cumulative aspects and interactions between impacts are considered. Synergy (SI) measures the amplification that one impact can have on another, generating combined effects of greater magnitude, while accumulation (AC) quantifies the progressive growth of the impact over time. Furthermore, effect (EF) classifies the impact according to its direct or indirect nature, periodicity (PR) indicates how often it occurs, and recoverability (MC) analyses the possibility of restoring the original environmental state.

The proposed equation allows for the transformation of these attributes into numerical values, facilitating the categorization of the impact into different levels of significance: low, moderate, severe, or critical. In this regard, Conesa's methodology provides a comprehensive and objective evaluation of environmental impacts and serves as a key tool for prioritizing mitigation measures, ensuring that the most significant impacts are addressed with effective environmental management strategies. Therefore, the value resulting from the calculation of the impact significance using Eq. (1) should fall between 13 and 100. Based on the sign and magnitude of this value, the impacts are classified according to their significance level. For negative impacts, values between 13 and 25 are considered low or irrelevant, which means that the negative effects are minimal or negligible. Values from 26 to 50 are classified as moderate, indicating a noticeable but manageable negative impact. In turn, a value between 51 and 75 is categorized as severe, reflecting a significant negative effect that requires attention. Finally, values from 76 to 100 are considered critical, signalling major negative consequences that demand immediate action. On the positive side, values from 13 to 25 are classified as reduced, meaning that the positive effects are minimal but still beneficial. Values between 26 and 50 are considered moderate, indicating a noticeable positive impact. Values from 51 to 75 are high, reflecting strong beneficial effects; and values from 76 to 100 are very high, signifying extremely significant positive outcomes [7].

The environmental parameters can be categorized into five main groups: i) physic-chemical factors, which include elements such as air quality, water composition, and soil characteristics; ii) biological factors, encompassing flora, fauna, and ecosystem dynamics; iii) landscape factors, related to the visual and aesthetic impact on natural and urban environments; iv) social, cultural, and human factors, which consider the effects on local communities, historical heritage, and cultural values; and v) economic factors, addressing the influence on economic activities, resource exploitation, and financial sustainability.

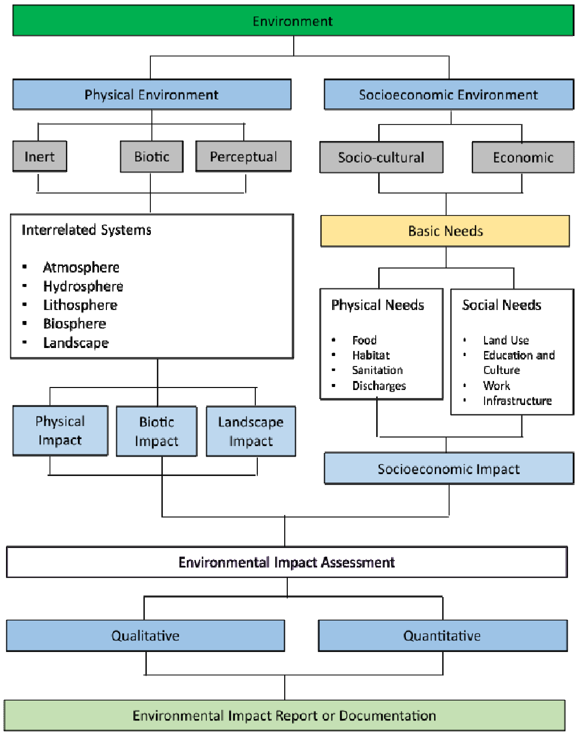

Fig. 2. Interrelationships of environmental factors in an environmental assessment. Adapted from [7].

Depending on the specific factor affected, the resulting impact can be classified accordingly. For example, if the landscape is altered, it constitutes a landscape impact; if the fauna is disrupted, it is a faunistic impact, and so forth. Understanding these distinctions allows for a more precise evaluation of the environmental consequences and the implementation of appropriate mitigation measures. In Fig. 2, inter-relationships of environmental factors from the perspective of EIA can be observed.

3. Results and discussion

3.1 Design and installation of an OWC

The assessment of the environmental and socioeconomic impacts of the OWC technology highlights a balance between ecological concerns and economic opportunities. While its deployment results in moderate environmental effects, including soil degradation (-25), erosion (-30), and land removal (-33), it also promotes economic growth, job creation, and local development. Machinery waste (-33) and potential oil spills (-35) contribute to pollution, emphasizing the need for strict control measures. Hydrodynamic changes, such as variations in wave intensity (-23) and energy (-24), are generally low to moderate but require ongoing monitoring. Additionally, air pollution from CO_2 emissions (-29), along with particulate matter (PM) and noise pollution, further underscores the necessity of mitigation strategies.

From a landscape perspective, the OWC installation alters visual perception and may reduce the presence of local fauna and flora. Biologically, the construction affects aquatic biota, leading to moderate disturbances in migratory patterns (-27), feeding (-25 marine, -28 terrestrial), and reproduction (-24 marine, -27 terrestrial). Seabed alterations (-27) and reduced photosynthesis (-21) suggest potential long-term ecological shifts, necessitating continuous environmental monitoring.

On the socioeconomic component, both challenges and opportunities arise. The disruption of tourism (-38), fishing (-35), and recreational activities (-31), along with the risks of collisions (-28) and the reduced navigable space (-18), highlight the importance of strategic coastal planning and stakeholder engagement. The impact on the landscape and the reduced access to recreational areas further contribute to negative effects on local industries. However, OWC technology also fosters economic benefits, particularly in job creation for construction workers (+47), engineers (+42), material transport (+32), and oceanographers (+45). Furthermore, employment opportunities for designers and operators, along with regional economic growth (+49), improved social relationships (+37), education (+38), and population growth (+36). This indicates that wave energy can drive long-term community development.

3.2. Operation phase of an OWC

During OWC operation, impacts on the soil include alterations in sediment transport and erosion, which are classified as moderate. In the aquatic environment, the device alters the energy and speed of the waves, resulting in effects on water turbidity and contamination. In the air component, noise generated at the surface and seabed is considered to have a moderate impact [8]. Table 2 presents the EIA during the operation phase of an OWC.
Various studies have analysed the acoustic impacts of wave energy converters (WECs) on marine ecosystems. Buscaino et al. and Henriques et al. highlighted that OWCs generate underwater noise, primarily at low frequencies (< 1 kHz), which could affect sensitive species such as cetaceans and fish, especially in quiet marine environments. Although these noise levels do not significantly exceed those of other human activities, site selection and the implementation of quieter technologies are crucial to mitigate these effects [9][10].

Henriques et al. found that the noise from air turbines in OWCs ranges from 90 to 110 dB, emphasizing the importance of optimizing turbine design [9]. In turn, Hutchison et al. studied the noise generated by an ISWEC and concluded that, while it does not affect snapping shrimp, noise can interfere with fish choruses at certain distances [11]. Nonetheless, at greater distances, the noise from ISWECs has minimal impact on fish.

The noise from WECs can cause behavioural changes and orientation issues in marine animals, and in extreme cases, physical injuries. Nevertheless, the noise generated by WECs is generally less intense than that from sources, including sonar or ships, and the low frequencies make it less perceptible to marine mammals [12][13].

The operation of WECs can also alter sedimentation patterns and benthic habitats, impacting marine ecosystems, such as coral reefs and invertebrate communities. These changes are caused by physical structures on the seabed that modify currents and sediment transport, leading to erosion or sediment accumulation in nearby areas. Various studies highlight the need to assess these impacts, especially in sensitive ecosystems, to mitigate ecological risks [14][15][16].

The operation of OWC converters can cause changes in sediment dynamics, potentially leading to coastal erosion or sediment deposition. Although these effects are usually localized and minor, alterations in beach profiles have been observed [11][17]. Additionally, some WEC designs aim to protect coastlines by reducing wave energy, creating shadow zones that help mitigate erosion [11][18]. While these effects can be significant at a local scale, they generally do not lead to substantial improvements in coastal morphology [19].

From an environmental and biological perspective, the OWC operation can impact water quality by altering wave height, direction, and sediment transport, particularly in the immediate vicinity of the device, although these effects diminish with distance [11][20]. Hydrodynamic changes may release pollutants trapped in sediments, posing toxic risks to marine organisms [21]-[23]. In addition, the use of hydraulic oils and lubricants in the device presents a pollution risk, potentially affecting phytoplankton photosynthesis and disrupting the marine food chain [21][24]. The generation of electromagnetic fields due to submarine cables may interfere with the navigation and orientation of species sensitive to these signals, though the impact depends on proximity and exposure duration [11][14][21]. OWC operation can also affect migratory and reproductive processes of marine fauna, as well as the development of corals and autotrophic species nearby. The potential mutilation or death of species in contact with the structure represents a moderate impact. Although OWCs have fewer moving parts than other WECs, offshore installations with anchoring lines may pose entanglement risks, particularly if abandoned fishing nets become trapped [11][25]. The device may also attract fish and birds, increasing the likelihood of collisions or entanglement, especially in turbid waters [19]. Regarding habitat integrity, OWCs can disrupt marine connectivity, promoting the colonization of invasive species and altering biodiversity [14][24]. Nonetheless, they can also serve as artificial reefs, providing shelter and increasing biomass in local benthic communities [11][20]. Their installation may impact the seabed, affecting benthic ecosystems and potentially leading to biodiversity loss [11].

Table 2. EIA during the operation phase of an OWC.

Activity susceptible to generating an impact (ASPI)	Environmental factor susceptible to be impacted (FARI)	Component	Environmental aspect	Environmental impact	Average score	Impact significance (I)
Operation of an oscillating water column	Abiotic	Soil	Sediment transport	Alteration of the soil morphology	-32	Moderate
				Changes in sediment transport patterns	-35	Moderate
				Soil erosion	-34	Moderate
		Air	Noise generation	Increase in sound pressure levels in the ocean surface	-29	Moderate
				Increase in sound levels on the seabed	-36	Moderate
		Water	Operation of an OWC	Changes in wave energy	-35	Moderate
				Changes in wave velocity	-21	Low
				Changes in wave intensity	-21	Low
				Increase in suspended sediments	-27	Moderate
				Water turbidity alteration	-28	Moderate
				Increase in sea water pollution	-26	Moderate
				Air quality decrease	-25	Moderate
				Changes in near-shore depth	-35	Moderate
				Seabed alterations	-32	Moderate
				Changes in water flow velocity	-15	Low

				Alteration in marine sediment transport	-26	Moderate
				Decrease in radiation	-23	Low
				Thermoclimate alteration	-24	Low
				Dissolved oxygen increase	+18	Reduced
				Temperature increase	-12	Low
		Landscape	Location of the OWC	Landscape alteration	-30	Moderate
				Extinction of some species of flora	-29	Moderate
				Extinction of some species of marine flora	-31	Moderate
				Reduction in wild flora growth	-30	Moderate
				Alterations of marine habitat development	-29	Moderate
	Biotic	Aquatic biota	Operation of an OWC	Reduction in zones for fish aggregation	-31	Moderate
				Thermoclimate alteration	-13	Low
				Alteration in marine fauna migration	-30	Moderate
				Alteration of marine fauna feeding processes	-31	Moderate
				Alteration of marine fauna reproduction process	-30	Moderate
				Alteration of coral development process	-32	Moderate
				Mutilation of aquatic species if they come into contact with the most dangerous parts of the structure	-29	Moderate
				Death of aquatic species if they come into contact with the most dangerous parts of the structure	-31	Moderate
				Alteration in the development of near-shore autotrophic species	-32	Moderate
				Alteration in the development of underwater autotrophic species	-29	Moderate
				Landscape alteration	-31	Moderate
				Reduction in radiation affecting the photosynthesis	-23	Low
		Wild biota	Operation of an OWC	Alteration of wild fauna reproduction process	-25	Low
				Relocation of flying animals living in the immediate area	-28	Moderate
				Relocation of terrestrial animals living in the immediate area	-26	Moderate
				Alteration in wild fauna feeding process	-29	Moderate
				Alteration in flying animals migratory process	-26	Moderate
	Socioeconomic	Economic	Alteration of coastal activities	Tourism alteration	-37	Moderate
				Landscape alteration	-31	Moderate
				Fuel consumption for transport of materials	-33	Moderate
				Decrease in areas for recreational use	-31	Moderate
				Alteration in fishing zones	-34	Moderate
				Decrease in the areas for extraction of aggregates	-29	Moderate
				Increase in the risk of collision and accidents	-33	Moderate
				Affectation of the navigable area	-31	Moderate
			Job creation	Increase in the development of the zone	+50	High
				Employment increase for Supervision Engineers	+44	Moderate
				Job growth in the region's energy sector	+48	Moderate
				Job creation for water column operators	+45	Moderate
				Increase in the quality of life	+53	High
				Improvement of economic conditions in the region	+49	Moderate
			Energy generation	Improvement of accessibility to the service	+59	High
				Increase in demand for the service (increase in customers)	+52	High
				Increase in the quality of life	+54	High
		Cultural	Energy generation	Improvement of social relationships	+46	Moderate
				Increase in educational levels	+40	Moderate
		Demographic		Population increase	+35	Moderate

From a socioeconomic point of view, OWCs may disrupt tourism and fishing activities, potentially causing conflicts in communities reliant on these sectors. However, they also offer significant benefits. The most positive impact is the increased access to energy services, which can improve regional quality of life and economic conditions [14][19][20]. The structures can also attract commercial species like lobsters, indirectly benefiting fisheries [19]. Community acceptance is crucial for successful implementation, requiring consultation and participation strategies to address concerns and maximize benefits [14][20]. Additionally, OWCs contribute to job creation in engineering, maritime construction, and oceanography among others, fostering economic growth [19][20].

Finally, OWCs play a crucial role in renewable energy production, offering a more predictable and energy-dense alternative compared to solar and wind power. Their ability to supply remote regions, including isolated islands, enhances energy independence and reduces reliance on fossil fuels [14]. Involving local populations in decision-making and highlighting the environmental and economic advantages can facilitate acceptance and integration into coastal communities.

3.3. Maintenance and decommissioning phases of an OWC

The main environmental concerns during the maintenance of an OWC are related to soil and water pollution due to liquid spills and wash water discharges. The impact on aquatic biota is also classified as moderate, as there may be potential effects on nearby marine flora and fauna [8]. From a socioeconomic perspective, the OWC maintenance continues to generate employment and improve living conditions in the area, though with a less significant impact compared to the installation and operation phases.

In turn, the decommissioning of an OWC involves notable environmental and socioeconomic impacts, particularly affecting soil, water, air quality, and biodiversity. The removal of materials can cause soil pollution and permanent morphological changes (-43), while landscape alterations may persist even after dismantling (-41) [8]. Nevertheless, natural recovery over time (+33) suggests a potential for ecological restoration. Air quality deteriorates due to increased emissions of CO_2 and PM from material transport (-34, -32), alongside noise pollution (-36) generated during the dismantling stage. Water contamination arises from oil spills, wash water discharge, and liquid leaks (-29, -30, -31), impacting marine ecosystems. Although sediment disturbance can temporarily affect benthic communities, their ability to recolonize mitigates long-term effects [19].

Both terrestrial and marine biota experience persistent disturbances (-29) during the decommissioning phase, but ecosystem resilience enables recovery (+31, +32). Additionally, the dismantling process may eliminate artificial reefs formed around the structures, reducing habitat availability for marine species [26]. Socioeconomic consequences include increased unemployment (-35) and reduced regional economic activity (-37, -45). However, some positive effects emerge during this step, such as job creation (+27) and increased demand for dismantling equipment (+26), partially offsetting the economic downturn. The loss of local employment may contribute to population decline (-30), emphasizing the need for transition strategies to support affected communities [26].

Despite its moderate overall impact, the decommissioning phase requires careful mitigation strategies. Pollution control, emission reduction, and ecosystem restoration efforts are critical to long-term environmental damage minimization while promoting a sustainable approach to energy projects [11][27].

3.4. Mitigation options

To mitigate the environmental impacts generated by the installation, operation, maintenance, and decommissioning of OWCs, it is crucial to apply several strategies that minimize the negative effects on the environment [28]. For abiotic impacts, it is recommended to implement soil stabilization techniques, revegetation, and the construction of barriers to reduce erosion and changes to the land's morphology. Additionally, it is essential to adopt spill response protocols for oil and industrial waste, along with the use of biodegradable lubricants and good maintenance practices. To prevent water pollution, containment barriers and absorbents can be used, while turbidity and sediment transport should be monitored using appropriate engineering techniques.

Regarding the air quality, noise generation can be mitigated through the installation of acoustic barriers and the use of optimized machinery. Reducing CO_2 emissions and PM can be achieved by prioritizing low-emission equipment and promoting clean energy during the construction and maintenance phases.

The landscape can also be affected; therefore, it is recommended to design these structures using materials and colours that blend with the environment. Reforestation plans should also be established to compensate for vegetation loss. In terms of biota, the disruption of migration and reproduction of marine species can be minimized by scheduling installation and maintenance activities during non-critical periods. Additionally, physical barriers and detection systems can reduce injury and mortality of marine organisms that meet the structure. It is also important to design OWCs in a way that minimizes disturbance to the seabed and facilitates habitat regeneration in affected areas. For fauna, buffer zones can be established, and biodiversity changes should be monitored to implement corrective measures when necessary.

Regarding socioeconomic impacts, planning the location of OWCs in areas where their impact on tourism is minimal is crucial, promoting ecotourism strategies related to the use of renewable energy. Safe navigation corridors should also be delineated, and the installation should be evaluated in areas with minimal interference with fishing activities. To enhance socioeconomic benefits, training programs can be developed to involve the community in the maintenance and operation of OWCs, generating local employment and strengthening economic development. Finally, when decommissioning, it is recommended to plan workforce relocation strategies for workers involved in the project. The implementation of these mitigation strategies would maximize OWC benefits while minimizing their negative impacts, ensuring a sustainable integration of this technology into marine-coastal ecosystems and communities [27].

4. Conclusion

The installation, operation, and maintenance of OWCs generate moderate environmental and socioeconomic impacts. While most negative effects, such as soil and water pollution, erosion, noise, and marine fauna alteration, are of medium magnitude, some key benefits stand out. These include improved access to energy, and economic growth, which have significant positive impacts, particularly in isolated communities. By providing electricity and reducing dependence on fossil fuels, OWCs contribute to lowering GHG emissions and improving overall environmental conditions.
Nevertheless, to ensure the sustainability of OWCs, mitigation strategies should be implemented. These include using cleaner technologies, developing environmental management plans, and conducting continuous monitoring. While OWCs represent a promising alternative for sustainable energy generation, minimizing their negative impacts and maximizing their economic and social benefits must remain a priority.

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