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Synergies Between Coastal Management and Coal Mining: Approaches to Support a Sustainable Economy

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Abstract
Coastal and marine areas have ecological and economic potential for development and utilization across multiple sectors, including mining. However, the interaction between coastal management and coal mining operations often leads to adverse ecological consequences and socio-environmental conflicts that threaten sustainability. To address these challenges, integrated approaches are required to promote synergy between coastal management and coal mining practices. This review adopts an exploratory approach through comprehensive literature analysis, with data drawn from reputable scientific databases, including Scopus, Web of Science, MDPI, and PubMed. The selected studies were systematically identified and analyzed using qualitative descriptive techniques. Achieving sustainable management in both coastal and coal mining sectors requires a holistic perspective that incorporates sociocultural, economic, environmental, and governance dimensions. Environmentally friendly technologies, rehabilitation of degraded coastal and post-mining ecosystems, and empowerment of local communities are among the alternative strategies that can be implemented to align both sectors toward shared economic goals. Economic benefits can be enhanced by optimizing the collaborative potential of the coastal and coal mining sectors, particularly through the establishment of green employment opportunities, the development of ecotourism, and the sustainable utilization of natural resources. The realization of sustainable coastal and coal mining management relies on synergistic cooperation among mining companies, governmental bodies, academia, stakeholders, and local communities to promote a sustainable economy.

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1. Introduction

The industrial revolution significantly accelerated global energy consumption and triggered substantial land-use changes, primarily due to the expansion of energy extraction activities, which has led to widespread environmental degradation worldwide, including Indonesia. Positioned as a resilient economy in Southeast Asia, Indonesia is gifted abundant natural and mineral resources, with coal being among the most prominent. Coal and other mineral resources contribute approximately 5–8.21% of Indonesia's total gross domestic product (GDP) (Pratiwi *et al.,* 2021; Agustian *et al.,* 2021). The highest coal production in the country originated from East Kalimantan Province, which recorded an output of 294,252,801.68 tons in 2021 (East Kalimantan Statistics, 2022).

Coal is a vital fossil fuel used globally to supply both heat and electricity (Tretyakova *et al.,* 2021). It accounts for approximately 26% of the global primary energy consumption (Li *et al.,* 2022; Yao and Yu, 2023) and continues to serve as an essential energy source across multiple industrial sectors, ranging from construction and manufacturing to technological applications and even renewable energy development across the globe (Enemuo and Ogunmodimu, 2025). However, coal production processes also pose significant anthropogenic pollution risks to the environment, including aesthetics (e.g., litter), particulates (e.g., sediment), and toxic (e.g., chemical) pollution (Tretyakova *et al.,* 2021). In Indonesia, coal mining operations are predominantly situated in coastal regions, especially in East Kalimantan Province (Gani *et al*., 2021). These operations often utilize estuarine and marine areas for mining activities such as the transportation of mining materials (imports and exports), freshwater sourcing, and waste disposal (Tretyakova *et al.,* 2021; Xu *et al.,* 2024). The handling and transportation of large volumes of bulk and dusty cargo through ports is a major contributor to air pollution, which may also impact the marine environment (Tretyakova *et al*., 2021). Furthermore, environmental impacts, such as heavy metal contamination, acidification, sediment loading, salinization, de-oxygenation, and calcium depletion, have been reported to threaten aquatic ecosystem health (Beck *et al*., 2020).

Maintaining the health of aquatic ecosystems is fundamental to sustaining life on Earth and plays a vital role in supporting the livelihoods of coastal communities. The ocean's value can be understood across four major dimensions: as natural capital, as a good business, as integral to (Pacific) Small Island Developing States, and as small-scale fisheries livelihoods (Evans *et al*., 2023). These intercorrelated aspects emphasize the close connection between coastal resource management and extractive industries such as mining. Although both sectors offer substantial economic benefits, their coexistence often gives rise to tensions and environmental degradation that threaten ecological sustainability. Therefore, it is essential to explore integrated strategies to promote cooperation between coal mining operations and coastal management practices. This review aims to identify potential approaches that would enable synergistic efforts between the two sectors to achieve a sustainable economic model.

2. Method

This review explores the potential synergy between integrated coastal zone management and coal mining practices as a strategy to promote sustainable economic development. An exploratory research design was employed, utilizing a structured literature review from reputable scientific databases including Scopus, Web of Science, MDPI, and PubMed, which are widely recognized for hosting high-impact scholarly work. The literature search was conducted using targeted keywords such as: "sustainable coastal management," "coal mining management," "green mining," "economic aspects of coastal regions," "natural resource conservation in coastal area," "green technology" and "renewable energy sources." To ensure the relevance and currency of the review, the inclusion criteria were limited to full-text articles published in English within the past decade (2016–2025), with a clear focus on coastal and coal mining management and their implications for sustainable economic growth. Studies that were not aligned with the core themes of the review were excluded. The selected literature was analyzed using descriptive qualitative methods. Figure 1 presents the sequential framework adopted in this review, illustrating the methodological process used to evaluate the potential for synergistic integration between coastal management and coal mining.

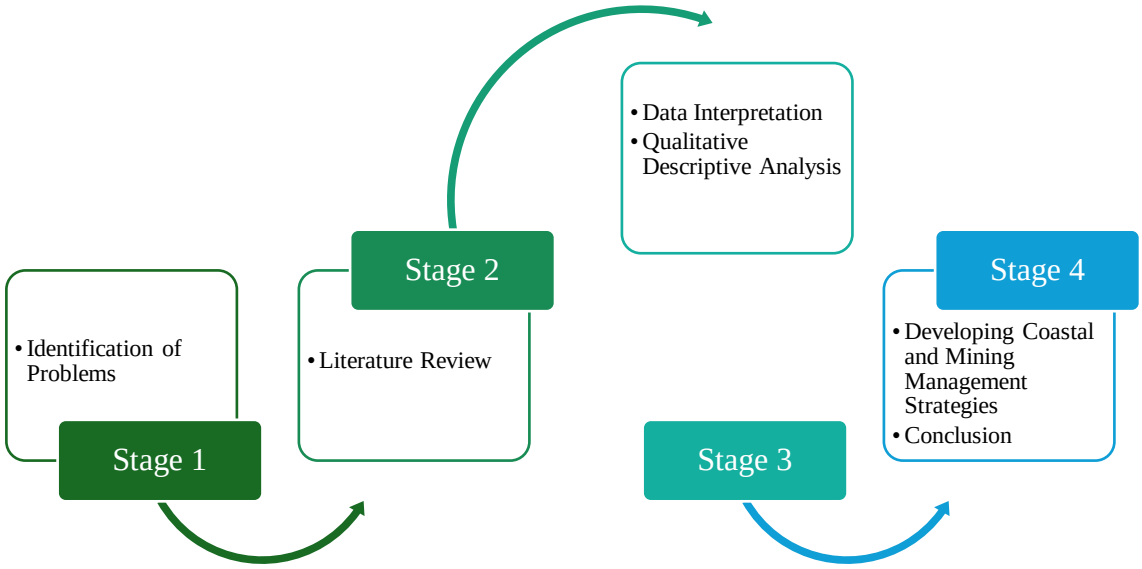

Figure 1. Stages of Writing a Review

3. Result and Discussion

3.1. Sustainable Management of Coastal Area

Coastal zones serve as transitional interfaces between terrestrial and marine environments, and are often marked by dense populations, including varied and dynamic economic activities. Additionally, these regions are characterized by a lack of clearly defined natural boundaries (Shampa *et al.*, 2023). Coastal areas are distinguished by their unique environmental features, including tidal movements, coral reef systems, barrier islands, shorelines, and exposure to storm events (Shampa *et al.*, 2023). These areas offer important ecosystem services and goods, such as nutrient storage and recycling, filtering pollutants from inland freshwater systems, access to exploitable natural assets, and natural defense mechanisms that protect coastal infrastructure against erosion and extreme weather events (Jennings *et al.*, 2020; Jennings *et al.*, 2024).

Coastal regions are important centers of demographic and economic concentration (Ramirez *et al.*, 2024). Coastal regions also have substantial ecological and economic significance and have historically benefited from physical and geographical advantages that support a range of economic activities, such as fisheries, forestry, mining, and groundwater resource use (Abdunnur and Mayulu, 2021; Yuan and Chang, 2023; Jiang *et al.*, 2023). Coastal communities rely heavily on these resources for their livelihoods, contributing to socioeconomic development (Jiang *et al.*, 2023). However, such activities often give rise to numerous conflicts of interest and significantly contribute to coastal environmental degradation. Consequently, the implementation of sustainable coastal management approaches is becoming increasingly important. Sustainability has garnered significant attention in the modern era owing to its importance in promoting social progress, economic growth, and poverty reduction. The principle of sustainability is inherently linked to the natural environment and human wellbeing (Onifade *et al.* 2024).

Achieving sustainable coastal management requires a holistic perspective that integrates the social/cultural, economic, governance, and environmental dimensions. This approach is essential for balancing high environmental quality, which ensures ecosystem service provision with positive social development outcomes, and a human-centered economic system, all within a fair and participatory governance framework, as opposed to one-driven limitless growth (Alencer *et al.*, 2020). Practical strategies for sustainable coastal management include Integrated Coastal Zone Management (ICZM), Marine Spatial Planning (MSP), and the Blue Flag Award (Ramy *et al.*, 2023).

Effective coastal management is particularly critical for Indonesians, as the country is a global maritime hub, with approximately 80% of its territory consisting of the ocean and a total shoreline length of 99,093 km (Gani *et al.,* 2022).

Indonesia possesses abundant aquatic resources, with East Kalimantan Province being one of the regions with extensive coastal and marine zones (Abdunnur, 2020). The province is gifted with rich biotic and abiotic coastal and marine resources, including renewable natural resources, largely due to its warm tropical climate, sufficient annual rainfall, and expansive coastal areas, which span approximately 181,871 ha in the Mahakam Delta. These conditions support diverse marine environments. The following section presents the classification of coastal and marine resources found in the East Kalimantan Province.

Table 1. Natural resources in the coastal and ocean areas of East Kalimantan Province.

Natural Resources	Category
Biotic (Living)	Fisheries, Mangrove, Coral Reefs, Seaweed, Seagrass, Plankton
Abiotic (Non-Living)	Minerals, Coal, Petroleum (Oil and Gas), Freshwater, Sea Salt
Renewable	Wind, Ocean Waves, Tidal Energy, Ocean Currents, Solar Energy
Artificial Resources	Marine infrastructures related to marine and fisheries
Environmental Service	Natural landscape, seabed surface to place underwater installations associated with marine and fisheries, and energy contained in the coastal areas

Source: Abdunnur and Mayulu, 2021; Ministry of Marine and Fisheries, 2016.

In economic terms, the fisheries sector plays a vital role in ensuring national food security, enhancing individual livelihoods, and generating foreign exchange revenue. Fish consumption accounts for approximately 60% of total animal protein intake among humans, highlighting its critical contribution to economic and nutritional stability (Shampa *et al*., 2023). Mangrove forests are another key biotic resource that supports coastal communities. These ecosystems, located within intertidal zones, represent dynamic habitats where marine, brackish, riverine, and terrestrial environments converge. Such ecological interactions create rich biodiversity, which coastal populations have long relied upon for various purposes (Abdunnur and Mayulu, 2021). Mangrove ecosystems provide a wide array of essential ecological services. These include a significant carbon sequestration capacity for climate change mitigation, coastal defense functions that support climate adaptation (e.g., against flooding, tidal surges, and storms), biodiversity preservation, and primary production that sustains coastal food webs. Moreover, mangroves support livelihoods through aquaculture and extraction of forest products (Abdunnur, 2020). In addition, the aesthetic and ecological characteristics of coral reefs and seagrass meadows offer strong potential for developing marine ecotourism destinations that attract both domestic and international visitors. Seaweed is widely recognized for its nutritional and health benefits and is utilized as a functional food ingredient. It also serves as a raw material for a range of value-added products, including those in the cosmetic industry, thereby offering significant economic opportunities.

If managed properly, non-living resources, artificial resources, and environmental services found in coastal areas (Table 1) can serve as natural capital that may be transformed into employment opportunities, infrastructure development, public services, and the expansion of the domestic private sector (Shampa *et al.,* 2023). Renewable resources in coastal areas hold significant potential for the production of ocean-based renewable energy, particularly in the form of wind, waves, tides, thermal biomass conversion, and salinity gradient energy. Among them, offshore wind energy is currently the most widely developed form of marine-based energy (Shampa *et al*. 2023). This indicates that coastal resources have strategic value with comparative and competitive advantages for development to enhance the welfare of coastal communities.

3.2. Coal Mining and Impacts on the Environment

The mining industry has both positive and negative impacts on the three pillars of sustainable development: economy, environment, and society (Jovanovic *et al.,* 2023; Ahmat *et al.,* 2024; Onifade *et al.,* 2024). The abundance of coal resources and the widespread scale of extraction activities

necessitate closer investigation to address the conflict between mineral resource exploitation and ecological preservation (Chen *et al*., 2025). Mining activities often result in significant land disturbances, as surface removal during extraction leads to the loss of vegetation and topsoil, thereby disrupting surface and subsurface hydrological systems (He *et al.,* 2023; Fang *et al.,* 2024; Thakur *et al.,* 2025). One of the main issues associated with such land degradation is soil erosion, which is commonly triggered by clearing of vegetation cover (He *et al*., 2023). Furthermore, mining activities are resource-intensive and require large volumes of energy and raw materials, while generating substantial waste and gas emissions (Dod *et al.,* 2024; Onifade *et al.,* 2024). The sector's dependence on conventional energy sources presents considerable environmental challenges, including its contribution to greenhouse gas emissions, which is estimated at 4–7% globally. These emissions are generated during various stages of mining activities, including direct processes such as drilling, blasting, loading and transportation, electricity usage, and logistical operations. In addition to emissions, mining activities contribute to declining water quality, reduced biodiversity, and adverse effects on the health and welfare of surrounding communities (Enemuo and Ogunmodimu 2025).

Mining operations generate substantial amounts of waste and pollutants that can lead to serious environmental and ecological destruction if not properly managed and regulated (Ahmat *et al*. 2024). Pollution associated with coal mining has been linked to climate change, the destruction of natural habitats, and a decline in biodiversity (Jovanovic *et al*., 2023). Additionally, the release of byproducts from mining activities can contaminate the environment and pose indirect threats to human health, representing a clear example of the negative social impact of the mining sector (Jovanovic *et al*., 2023).

Coal-mining activities conducted in coastal areas have substantial implications for water resources, influencing the geological environment, surface runoff, drainage systems, and groundwater recharge processes (Bai *et al*., 2024). The waste generated from mining includes solid waste (such as coal refuse), airborne emissions (e.g., methane), and wastewater discharge (Mitko *et al*., 2024). These operations directly affect water quality and sediment levels in the surrounding environment, leading to contamination of both surface water and groundwater, changes in quantity and availability (Finkelman *et al.,* 2021), and disruptions to groundwater flow patterns (Ahmat *et al.,* 2024). Coal extraction contributes not only to damage to surface aquifers, but also to shifts in water quality and volume (Bai *et al*., 2024). Subsurface mining can alter groundwater flow direction and elevation, whereas surface mining typically degrades surface water quality due to runoff into river systems. Over time, these impacts may lead to depletion of essential water resources (Finkelman *et al*., 2021). Declining groundwater levels, disruption of surface water systems, and contamination are common consequences of coal mining operations. Importantly, these impacts are not confined to freshwater ecosystems, but also extend to coastal and marine environments.

Coal mining activities in coastal zones have been shown to cause severe disruption to aquatic flora and fauna (Finkelman *et al*., 2021). Dust emissions produced during coal extraction, transportation, loading, unloading, and related activities contribute to pollution in both the atmospheric and marine ecosystems (Tretyakova *et al.,* 2021; Zhou *et al.,* 2023). The compounds in coal dust may chemically interact with seawater, potentially leading to ocean acidification (Finkelman *et al*. 2021). Coal mining also damages the habitat conditions of aquatic microorganisms by affecting parameters such as total organic carbon (TOC), dissolved oxygen (DO), pH, and the concentrations of nutrients and metals (Xu *et al*., 2024). Moreover, mining activities have been associated with elevated concentrations of heavy metals downstream of waste discharge points (Ali *et al*., 2018). Soil in mining areas is often contaminated with arsenic (As) and lead (Pb), while nearby groundwater typically exhibits significant levels of Pb contamination (Ahmat *et al*., 2024). Mercury from coal mining waste, which is disposed of in marine waters, tends to bind to sediments or suspended solids and can later mobilize and spread through aquatic systems over time (Huang *et al*., 2025). The release of hazardous chemicals and metals during mining results in air and water pollution, soil degradation, and negative impacts on nearby agricultural lands (He *et al*., 2023). Heavy metals such as nickel (Ni), iron (Fe), copper (Cu), and manganese (Mn) present in coal mining effluents can accumulate within water bodies, leading to bioaccumulation, which in turn threatens

water quality and affects ecological balance, food chains, and aquatic ecosystems (Ali *et al.*, 2018; Iqbal *et al.*, 2022; Mitko *et al.*, 2024). These contaminants are potentially digested by aquatic organisms that inhabit coastal waters (Ali *et al*., 2018).

Coal mining waste, whether from abandoned sites or from ongoing operations, often contains acidic, alkaline, and metal-based contaminants (Mitko *et al*., 2024). The discharge, spread, and anthropogenic accumulation of such pollutants can lead to the widespread degradation of surface water bodies and aquatic ecosystems (Mitko *et al*. 2024). These pollutants significantly reduce the marine biodiversity and threaten other coastal biological resources (Mitko *et al*. 2024). However, as environmental sustainability gains increased global attention, the mining industry has begun to adopt more responsible practices to reduce ecological harm. Mitigation strategies to reduce the environmental footprint of mining include (1) implementing green mining principles through environmentally friendly and renewable technologies, (2) integrating circular economy models to optimize resource use, (3) applying decentralized and modular mining approaches, (4) undertaking ecosystem restoration and biodiversity conservation efforts, and (5) fostering international collaboration to support sustainable mining practices (Onifade *et al*., 2024).

3.3. Synergy Between Coastal Area Management and Coal Mining

Coastal areas have substantial ecological and economic development potential (Abdunnur 2020). These zones can support a range of economic sectors, including tourism, seaports, inland ports, export-processing zones (Shampa *et al*., 2023), fisheries, industrial development, and mining activities (Ministry of Marine and Fisheries Affairs, 2025). Mining operations located within coastal areas are classified as part of designated mining zones under Regulation of the Minister of Marine and Fisheries Affairs of the Republic of Indonesia No. 23/PERMEN-KP/2016 on Coastal and Small Islands Management Planning (Article 20, paragraph 4). Mining activities in these zones should adopt green mining technologies to reduce energy consumption, minimize ecological disturbances, and mitigate environmental impacts to ensure its sustainability (Onifade *et al*., 2024).

Both coastal management and mining activities contribute to economic growth; however, they also present new challenges and, to some extent, accelerate the degradation of coastal ecosystems and habitats. Therefore, effective governance in these areas must consider coastal boundaries and land suitability, as each zone is characterized by distinct environmental features and resource availability (Abdunnur and Mayulu, 2021). Achieving and maintaining a sustainable balance between coastal, marine, and terrestrial systems requires an ecosystem-based approach that highlights the need for synergistic integration between the coastal and mining sectors. The concept of synergy has been widely applied across disciplines and sectors (Hao *et al*., 2022), and can also be utilized to manage the interactions between coastal governance and coal mining. A synergistic management approach offers an effective framework for mitigating environmental risks, while maximizing the potential of natural resources. Collaborative integration among coal mining companies, government agencies, academic institutions, stakeholders, and local communities is essential to achieve coastal and mining practices that align with sustainable economic goals. To operate this synergy in coastal and coal-mining governance, several supporting aspects are necessary.

3.4. Collaborative Management

Cross-sector collaboration initiatives, joint ventures, and shared information platforms between the mining industry and coastal management actors offer valuable insights into collective efforts toward sustainability. Such partnerships foster more integrated and effective approaches to address environmental challenges. Collaborative efforts have the potential to produce innovative solutions for sustainable governance of coastal areas and mining operations. However, the inherently competitive nature of the industrial sectors may limit the openness and transparency necessary for successful collaboration, and this issue must be carefully considered. In this context, the government plays a crucial role in providing incentives and regulations for both coastal and mining practices, thereby facilitating the development of effective partnerships that align the interests and objectives of policymakers, coastal resource managers and mining enterprises.

1) Utilization of advanced technology

The utilization of advanced technologies presents an alternative pathway for enhancing the effectiveness of both coastal zones and mining management. The degree to which new technologies align with an organization's strategic objectives significantly influences its adoption level. Technologies that support long-term goals are more readily adopted by decision makers. Therefore, it is essential to conduct a thorough analysis to ensure that the selected innovations are not only appropriate but also strategically aligned with the overarching objectives of coastal and mining governance.

2) Establishment of synergetic model among mining enterprises, government, academician, stakeholders and communities

The involvement of government entities, academic institutions, stakeholders, and local communities plays a crucial role in effective management of coastal zones and mining activities. Fostering constructive relationships among these stakeholders can reduce tension and promote meaningful collaboration between the two sectors. Mining companies are encouraged to prioritize strong community engagement and adopt transparent reporting practices to enhance public trust and the social acceptance of their operations. The academic community serves as a key factor in facilitating synergy between coastal and mining governance through knowledge transfer, technological innovation, and the scientific investigation of natural phenomena. Academia also plays a central role in uncovering cross-disciplinary insights that can contribute to solving the complex sustainability challenges. Moreover, academic institutions are responsible for fostering equilibrium among human well-being, economic development, and the environment while also creating a center of excellence that promotes individuals' competencies to support mining and marine resource management.

3) Strengthening the role of government as a policy maker

Through authoritative mandates, the government plays a central role in formulating policies and enacting legislation that promotes sustainable management in coastal and coal mining operations. By establishing comprehensive regulatory frameworks, the government can help mitigate the adverse environmental and social impacts associated with resource extraction and ensure that the benefits become a national income. Financial incentives, such as tax relief or subsidies, can be introduced to encourage mining companies to adopt green technology and sustainable operational standards to promote the adoption of green technology in all sectors. Furthermore, governments can allocate investments in the research and development of green technologies, particularly in relation to coastal management and coal mining, which can drive innovation and facilitate the transition toward sustainability. A platform involving multiple stakeholders, including industry representatives, environmental experts, and community leaders, can be established collaboratively to ensure sustainable management of coastal and mining areas.

4) Establishing enforcement mechanisms to ensure sustainable management

A robust monitoring and enforcement framework is essential to ensure compliance with environmental standards, adherence to regulations, and consistent implementation of environmentally responsible practices in coastal and coal mining management. Enforcement mechanisms serve not only to maintain accountability among stakeholders, but also to verify alignment with agreed-upon strategies, thus promoting fairness and preventing unauthorized or illegal activities. Therefore, comprehensive enforcement is crucial. Strengthening regulatory and legal enforcement is a critical step toward achieving sustainable coastal and coal mining governance.

5) Strengthening stakeholders' engagement and transparency

Effective stakeholder engagement in coastal and coal mining management must consider diverse cultural, sociological, economic, and political contexts. Coastal and mining governance is not an isolated process, fostering integration, collaboration, and coordination among various stakeholders

in the coastal area, and integrating them with national development agendas. Leveraging digital technologies to collect and respond to public feedback has become a standard practice, enhancing communication channels, and reinforcing transparency. Transparency among stakeholders plays a vital role in building trust, ensuring accountability, and promoting sustainable practices in both sectors. Greater transparency fosters constructive collaboration by minimizing conflicts, enabling proactive problem solving, and encouraging compliance with existing regulations. Transparent decision-making processes are grounded in evidence-based policies, thereby reinforcing public trust and strengthening the legitimacy of governance systems.

6) Minimizing interest conflicts

The government holds a critical responsibility in identifying all key stakeholders, including political actors, administrative bodies, and non-public entities, and facilitating interactive platforms, such as seminars or workshops, to foster dialogue and mutual understanding among them. The active involvement of non-public stakeholders in policy-making processes can significantly reduce potential conflicts between coastal management and the coal mining sector. Mitigating such conflicts is a fundamental component of establishing synergy between sustainable coastal and mining governance. Therefore, integrated planning that anticipates and minimizes stakeholder conflict is essential (Shampa *et al*., 2023).

3.5. Sustainable Economy Practices in the Mining and Coastal Sectors

Mining operations and natural resource utilization in coastal regions, including marine ecosystems and their associated biodiversity, are major drivers of human activity, particularly economic development. These activities are expected to continue to address societal needs; thus, the implementation of sustainable economic practices within both sectors is critical. Sustainable economic practices aim to ensure the responsible management of natural resources while preserving healthy ecosystems that can support human well-being now and in the future. In regions where coal mining and coastal ecosystems intersect, several best practices can serve as models to achieve sustainable synergy. These include 1) application of environmentally friendly advanced technologies, 2) establishment of conservation zones, and 3) empowerment of local communities.

1) Application of environmentally friendly advanced technology

Coal mining operations situated in coastal areas must progress toward green mining by integrating new, advanced, and environmentally conscious technologies (Table 2). Green mining technologies are designed to establish sustainable mining models that balance resource extraction with environmental conservation. One of the focus areas within this framework is energy consumption, particularly the shift toward electric vehicles and renewable energy sources. The replacement of diesel-powered equipment with electric alternatives aims not only to lower greenhouse gas emissions but also to reduce operational costs, thereby improving energy efficiency. Another important aspect of green mining transition is the effective management of mining waste. Waste handling within a green mining framework constitutes a fundamental component of sustainable mining practices. Innovative waste processing methods, such as dry stacking of tailings and advanced recycling methods, have been increasingly explored for their ability to minimize the environmental harm associated with disposal practices. These technologies also enhance resource recovery and contribute to a reduction in the carbon footprint generated throughout the mining life cycle (Onifade *et al*., 2024).

The adoption and integration of renewable energy sources such as solar and wind power into mining operations can substantially reduce the industry's dependence on fossil fuels. This transition plays a vital role in lowering greenhouse gas emissions, while simultaneously enhancing energy security. Moreover, the utilization of advanced technologies, including smart sensors and automated equipment, contributes to improved operational efficiency by enabling the real-time monitoring and optimization of mining processes (Onifade *et al*., 2024). Environmental protection efforts within green mining also include ecological restoration strategies such as re-vegetation and water conservation, which are critical for mitigating environmental pollution (Bai *et al*., 2024).

Efficient wastewater treatment methods, such as ion exchange, electrocoagulation, and nanotechnology, can be employed to prevent the release of hazardous substances, such as chromium, into the environment, which endangers the flora and fauna, thereby reducing environmental pollution (Onifade *et al*., 2024). These technological innovations not only enhance resource management and minimize energy consumption but also significantly improve occupational safety standards for mining workers (Onifade *et al*., 2024). Table 2 highlights several environmentally friendly technologies that are applicable to green mining equipment.

Table 2. Environmentally Friendly Technologies in Green Mining

Green Technology	Description
Electrification	The transition from diesel-powered equipment to electric or hybrid alternatives. Electric vehicles can be powered by renewable energy sources such as solar or wind, thereby eliminating emissions and reducing dependence on fossil fuels. The use of battery-powered electric vehicles in underground mining can reduce diesel emissions and improve underground air quality.
Hydrogen Technology	Hydrogen fuel offers a promising alternative to diesel engines, providing clean and efficient power for mining equipment. However, challenges related to hydrogen production and infrastructure need to be addressed. The use of hydrogen-powered mining trucks can significantly reduce greenhouse gas emissions from diesel engines.
Biodegradation Technology	Biodegradation technology can break down mining waste into less harmful substances, reducing environmental impact and facilitating resource recovery. Mining companies use bioleaching to process arsenic containing mine waste safely, in an environmentally friendly and cost-effective manner.
Water Management Systems	Efficient water management equipment can reduce water consumption by up to 80% and prevent water contamination, thus minimizing the environmental impact of mining operations.
Advanced Material Usage	The adoption of lightweight and durable materials in equipment design improves fuel efficiency, reduces energy consumption, and extends the lifespan of mining machinery.
Sustainable Material Handling	The implementation of environmentally friendly material handling systems, such as conveyor belts and material transport systems, helps reduce energy consumption and minimizes environmental impact.

Source: Onifade *et al*., 2024

Green mining, also known as sustainable mining, includes mining practices that prioritize environmental protection, economic viability, and social responsibility. Environmental protection efforts aim to reduce habitat destruction for flora and fauna as well as minimize soil, air, and water pollution. The social and economic dimensions of green mining technologies are considered to enhance community welfare and ensure economic sustainability. Economic viability seeks to balance environmental and social responsibilities while considering financial aspects to ensure the long-term feasibility of mining projects. This balance can be achieved through proper mining planning and investment in R&D to promote innovative mining technologies. Consequently, efficient operations can lower costs and losses while expanding profit margins. Green mining also emphasizes the welfare of local communities affected by mining operations by incorporating their aspirations and perspectives into decision-making processes and providing employment opportunities and training programs (Onifade *et al*., 2024).

Green mining technologies have the potential to create employment opportunities, raise incomes, improve health outcomes by reducing pollution, and foster positive relationships between mining companies and local communities. Stakeholder engagement and transparent reporting are essential for building trust and ensuring successful implementation of sustainable practices. Intensive policy and regulatory support are necessary to ensure compliance with environmental standards and to encourage investment in sustainable innovation. The green mining concept promotes a more environmentally friendly and safer working environment, while preserving coastal ecosystems. The

recycling systems and water management practices employed in green mining maintain natural water availability (Onifade *et al*. 2024).

The future of mining depends on compliance with good and legal mining practices to protect the environment and uphold social responsibility in regional development while contributing to the overall quality of life of local communities (Carvalho, 2017). The implementation of advanced environmentally friendly technologies aims to ensure both sustainability and operational efficiency. Sustainable management of natural resources in coastal areas and coal mining operations must adhere to the following principles: collaboration and integration of technical and economic activities to ensure (1) economic growth, (2) ecological protection of natural resources and the environment, and (3) social development, including workplace safety and community empowerment.

The management of natural resources in coastal areas and coal mining operations can adopt the principles of a circular economy, a concept that minimizes waste and recycles resources with the goal of achieving economic and financial prosperity alongside environmental quality improvement (Jose *et al.,* 2024). The circular economy framework includes the R-cycle principles (3Rs: redesign, refusal, and restorative practices). These R-cycle strategies are implemented to enhance the efficiency, sustainability, and profitability of resource utilization (Jose *et al*., 2024). An environmentally friendly economy emphasizes policies focused on reducing pollution and minimizing the use of non-renewable resources. It promotes the equitable distribution of resources by reinforcing social justice and community empowerment (Jose *et al*., 2024). In coastal regions, an environmentally friendly economy emphasizes the sustainable use of marine resources, while supporting the local economy and water resource management (Jose *et al*., 2024).

Environmentally friendly technologies are closely associated with the use of renewable energy sources (such as hydro, solar, and wind) because of their advantages in terms of operational margins, cost-effective energy supply, and low capital costs. However, their application must still consider specific needs (e.g., processes requiring high-temperature heat) as well as factors such as affordability, localization, and future resilience (Jose *et al*., 2024). The complex interactions among mining waste, the environment, aquatic and marine ecosystems, cultural shifts, technological advancements, and stakeholder involvement require that circular economy initiatives be aligned with other sustainable economic models to ensure meaningful sustainability (Jose *et al*., 2024). The application of sustainability principles promotes economic viability, ecological cleanliness, and social responsibility for the exploitation and processing of raw materials (Jovanovic *et al*., 2023).

The potential for renewable energy in the mining sector is wide, encompassing solar and wind energies, bioenergy, and hydropower. These technologies help reduce dependence on fossil fuels and mitigate environmental impacts, while potentially lowering long-term energy costs (Enemuo and Ogunmodimu, 2025). However, the implementation of integrated renewable energy and carbon footprint reduction strategies in the mining sector faces several significant challenges, including: 1) the integration of renewable energy into mining operations demands a consistent and reliable power supply around the time, whereas in reality, solar energy is limited to daytime availability and is susceptible to cloud cover; 2) fluctuating wind speeds and intensities, which can lead to inconsistent power supply and disrupt energy-intensive mining processes; 3) a shortage of technical expertise in renewable energy systems, which can hinder early implementation or integration and pose challenges for long-term maintenance and optimization; 4) challenges in energy storage and battery technology adaptation; 5) cybersecurity risks associated with smart grid technology; and 6) difficulties in accurately forecasting long-term energy prices and demand (Enemuo and Ogunmodimu, 2025).

These challenges require innovative solutions across the financial, regulatory, technological, and educational domains through a holistic approach. First, innovative financing models are essential for addressing the financial barriers associated with high initial capital costs. These include 1) power purchase agreements and leasing arrangements, which have gained traction by allowing mining companies to benefit from renewable energy projects without significant upfront investment; 2) the issuance of obligations to fund renewable energy projects at mining sites; and 3) government incentives that promote the adoption of renewable energy in the mining sector. Second, in terms of regulation, this involves i) developing clear policy frameworks specifically designed for renewable

energy in the mining sector, ii) establishing public-private partnerships, and iii) creating policies that encourage collaboration between governments, mining companies, and renewable energy providers. Third, in the technology domain, combining renewable resources with energy storage systems enhances power reliability through the deployment of hybrid systems that integrate wind and solar power, battery storage, and gas engines. Fourth, on the educational front, to overcome the shortage of technical expertise, industry-academia partnerships should foster accessible and tailored training programs related to renewable energy technologies. These should include mentorship programs and knowledge transfer initiatives from experienced professionals to new entrants (Enemuo & Ogunmodimu, 2025). Fifth, owing to the intermittent nature of solar energy, optimizing its utilization requires modern technologies such as global positioning systems (GPS) and sensor-based systems (Onifade *et al*., 2024). These technologies enable three-dimensional tracking of coal deposits, enhancing the precision of drilling and blasting operations while keeping coal separate from waste materials. Consequently, they help reduce environmental impacts and improve resource efficiency.

The high initial costs are justified by the long-term benefits and savings derived from reduced energy expenses and lower carbon tax obligations, making investments in green technologies economically viable. These economic advantages can attract investors, who are increasingly interested in funding environmentally responsible and sustainable projects, particularly as global markets become more sensitive to ecological and sustainability issues.

2) Establishment of conservation zone

An example of the best practices in natural resource management in regions with potential synergies between coastal areas and coal mining is the establishment of conservation areas. Conservation programs using protected area approaches represent a necessary first step in reducing habitat loss and fragmentation, safeguarding critical ecosystems essential for preserving biodiversity, and even protecting traditional cultures (Ramon *et al*., 2023). Protected areas are among the most important areas for nature conservation and landscape management (Ramon *et al*. 2023). Proper management of protected areas can benefit diverse life forms and provide numerous advantages for humanity as well as the sustainability of productive ecosystem functions (Ramon *et al*., 2023). Conservation through protected area approaches can also influence the social and economic dynamics of coastal communities, including improvements in community welfare. Marine conservation programmes contribute to enhanced well-being by alleviating poverty through improved security, opportunities, and empowerment.

The effective conservation of marine resources strengthens food security and community prosperity without compromising coastal ecosystems (Abdunnur and Mayulu 2021; Shampa *et al.* 2023). Conservation areas are designed to protect natural habitats and promote environmental sustainability while simultaneously offering opportunities for sustainable tourism (Skrtic *et al*., 2024). The natural beauty and resource diversity of these areas serve as key tourist attractions that potentially drive local economic growth. Coastal tourism development primarily focuses on the scenic landscapes, ecosystem characteristics, and sociocultural traits of local communities. The concept of sustainable tourism integrates environmental conservation with socioeconomic development and is a fundamental approach in coastal area management (Skrtic *et al*., 2024). Managing land-based activities to protect adjacent marine and coastal environments through marine protected areas is a logical strategy in both landscape- and ecosystem-based approaches (Ohsawa, 2025). There is a notable interconnection between conservation efforts and coal mining operations in coastal zones, which necessitates effective collaboration between stakeholders. Mining companies may have financial incentives to minimize biodiversity loss caused by their operations but often lack the necessary tools, guidelines, and support from conservation organizations to do so effectively. In contrast, conservation organizations possess essential expertise in biodiversity (Sonter *et al*., 2018).

3) Empowerment of local communities in resource management

Marine and coastal areas, including nearby mining zones, are rich in resources and provide essential ecosystem services that support community livelihood. However, the availability of these

resources must be matched by human capital readiness to ensure optimal management. This can be achieved through capacity-building programs and community empowerment initiatives that support long-term transformation toward sustainable coastal resource management (Evans *et al.,* 2023; Sutrisno *et al.,* 2023; Dushkova and Ivlieva, 2024). These programs focus on enhancing knowledge, skills, marine and financial literacy, technological capacity, and entrepreneurship in coastal communities. This approach aligns with the regulations of the Minister of Marine and Fisheries Affairs of the Republic of Indonesia. 23/PERMEN-KP/2016 on coastal and small island management planning, which mandates that community empowerment be conducted through human resource development, utilizing training and institutional strengthening through the formation of community conservation groups. Empowerment is considered as both a process and outcome involving 1) individual or psychological empowerment, 2) development of small mutual support groups, 3) community organization, 4) building partnerships, and 5) undertaking social and political action (Dushkova and Ivlieva, 2024).

Community empowerment requires locally adapted strategies to address the specific needs and challenges of each community. Programs that integrate local knowledge and cultural practices, along with monitoring and evaluation mechanisms, can be highly effective in achieving sustainable empowerment (Taniolo *et al.,* 2023; Dushkova and Ivlieva, 2024). The role of the government and supporting institutions in capacity building and community empowerment for managing resources in coastal and mining areas is crucial for improving good governance. Enhancing access to financial, technical, human, and other essential resources can promote the adoption of innovative solutions; enable the development of livelihoods and new market opportunities; and strengthen transparency and accountability in governance processes (Evans *et al*., 2023).

4. Conclusion

The mining industry in coastal areas is closely linked to coastal resource management and development of local economies. Sustainable economic benefits can be achieved by optimizing the synergy between the coastal and coal mining sectors through the creation of environmentally friendly employment opportunities, development of sustainable tourism, and responsible resource management. The adoption of clean and green technologies, along with conservation initiatives and community empowerment, presents a pathway for innovation in the integrated and sustainable management of coal mining and coastal zones. Integrating environmentally friendly green technologies into coastal and mining management not only addresses urgent environmental concerns, but also offers substantial benefits in terms of regulatory compliance, economic efficiency, industry leadership in sustainability, and community welfare. However, challenges persist, including conflicts of interest between industrial and conservation goals, a lack of supportive regulations for cross-sectoral collaboration, and limited financial and human resources. Addressing these challenges requires collaborative efforts involving government authorities, mining companies, local communities, and non-governmental organizations to develop mutually reinforcing solutions. Government policy support, incentives for companies that innovate in natural resource management, and community participation in decision making should be prioritized in coastal and mining governance. Moreover, multi-stakeholder collaboration among communities, governments, the private sector, and civil society and cooperation at regional, international, intergovernmental, multilateral, and private sector levels is essential to optimize resource management in coastal and mining areas.

References

Abdunnur and H. Mayulu. 2021. Policy on the development of integrated coastal and livestock areas based on geospatial data in East Kalimantan. Technium BioChemMed, 2(3):35-41. https://techniumscience.com/index.php/biochemmed/article/view/4202

Abdunnur. 2020. Manajemen pengelolaan ekosistem mangrove (peningkatan produktivitas ekosistem mangrove delta mahakam). (Management of mangrove ecosystem (enhancing the productivity of the Mahakam Delta mangrove ecosystem)). PT Raja Grafindo Persada. Depok.

Alencer, N. M. P., M. L. Tissier, S. K. Paterson, and A. Newton. 2020. Circles of coastal sustainability: A framework for coastal management. Sustainability, 12(12): 4886. DOI: https://doi.org/10.3390/su12124886

Ali, A., D. R. Sloane, and V. Strezov. 2018. Assessment of the impacts of coal mining in Sydney, Australia, on the aquatic environment using macroinvertebrates and chlorophyll as indicators. Int. J. Environ. Res. Public Health, 15(7): 1556. DOI: https://doi.org/10.3390/ijerph15071556

Ahmat, K., H. Lu, and H. Liu. 2024. A numerical study on impact of coal mining activity and mine water drainage on flow and transport behavior in groundwater. Water, 16(24): 3596. DOI: https://doi.org/10.3390/w16243596

Agustian, A., E. Ariningsih, K. S. Indraningsih, H. P. Saliem, E. Suryani, S. H. Susilowati, and E. Gunawan. 2021. Study of the utilization of ex-tin mining land for agriculture: analysis of land potential and constraints faced. IOP Conf. Series: Earth and Environmental Science, 648:012086. DOI: https://doi.org/ 10.1088/1755-1315/648/1/012086

Badan Pusat Statistik Provinsi Kalimantan Timur. 2022. Produksi batubara tahun 2021 (Coal production in 2021). Badan Pusat Statistik Provinsi Kalimantan Timur. https://kaltim.bps.go.id/id/statistics-table/2/MzYxIzI=/produksi-batubara.html

Bai, D., T. Wang, C. Li, and W. Wang. 2024. Impact of coal energy development on the surrounding environmental water resources carrying capacity. Desalination and Water Treatment, 319:100518. DOI: https://doi.org/10.1016/j.dwt.2024.100518

Beck, K. K., M. Mariani, M. S. Fletcher, L. Schneider, M. A. A. Lopez, P. S. Gadd, H. Heijnis, K. M. Saunders, and A. Zawadzki. 2020. The impacts of intensive mining on terrestrial and aquatic ecosystems: a case of sediment pollution and calcium decline in cool temperate Tasmania, Australia. Environmental Pollution, 265, 114695. DOI: https://doi.org/10.1016/j.envpol.2020.114695

Carvalho, F. P. 2017. Mining industry and sustainable development: time for change. Food and Energy Security, 6(2): 61-77. DOI: https://doi.org/10.1002/fes3.109

Chen, Y., X. Yu, D. Xu, and J. Peng. 2025. A spatial machine learning approach to exploring the impacts of coal mining and ecological restoration on regional ecosystem health. Environmental Research, 264 (2): 120379. DOI: https://doi.org/10.1016/j.envres.2024.120379

Dod, R D., S. S. Dhodare, J. Bhandari and S. Lalwani. 2024. Extraction of sand from the complex matrix of coal mining dump waste: A sustainable approach in Indian context. Cleaner Materials, 12: 100243. DOI: https://doi.org/10.1016/j.clema.2024.100243

Dushkova, D and O. Ivlieva. 2024. Empowering communities to act for a change: a review of the community empowerment programs towards sustainability and resilience. Sustainable, 16(19): 8700. DOI: https://doi.org/10.3390/su16198700

Enemuo, M and O. Ogunmodimu. 2025. Transitioning the mining sector: A review of renewable energy integration and carbon footprint reduction strategies. Applied Energy 384:125484. DOI: https://doi.org/10.1016/j.apenergy.2025.125484

Evans, L. S., P. M. Buchan, M. Fortnam, M. Honig, and L. Heaps. 2023. Putting coastal communities at the center of a sustainable blue economy: a review of risks, opportunities, and strategies. Front. Polit. Sci, 4: 1=14. DOI: https://doi.org/10.3389/fpos.2022.1032204

Fang, L., R. Gao, X. Wang, X. Zhang, Y. Wang, and T. Liu. 2024. Effects of coal mining and climate-evironment factors on the evolution of a typical Eurasian grassland. Environmental Research, 244:117957. DOI: https://doi.org/10.1016/j.envres.2023.117957

Finkelman, R. B., A. Wolfe, and M. S. Hendryx. 2021. The future environmental and health impacts of coal. Energy Geoscience, 2(2): 99-112. DOI: https://doi.org/10.1016/j.engeos.2020.11.001

Gani, I., A. Auliansyah, E. U. A. Gaffar, M. Muliai, Y. Aprianti, R. F. R. Rachmadi, and N. I. Agustina. 2022. Makasar strait area development in Indonesia based on the marine economy sector. Economies, 10(8): 195. DOI: https://doi.org/10.3390/economies10080195

Hao, Y., C. Sun, J. Wei, and A. Gu. 2022. Study on measuring and evaluating the synergy effect of regional coal mine emergency management in China based on the composite systems synergy model. Hindawi Geofluids: 1-10. DOI: https://doi.org/10.1155/2022/1845795

He, T., J. Guo, W. Xiao, S. Xu, and H. Chen. 2023. A novel method for identification of disturbance from surface coal mining using all available landsat data in the GEE platform. ISPRS Journal of Photogrammetry and Remote Sensing, 205: 17-33. DOI: https://doi.org/10.1016/j.isprsjprs.2023.09.026

Iqbal, M. P., F. J. Imadadienan, and G. Pius. 2022. The threat of coal mine expansion towards biodiversity in Kalimantan: in consideration of drastic reduction on coal production and prohibiting mine areas expansion to achieve climate goals and biodiversity. Perkumpulan Aksi Ekologi dan Emansipasi Rakyat (AEER), Jatam Kalimantan Timur. Jakarta. https://www.aeer.or.id/wp-content/uploads/2023/07/The-Threat-of-Coal-Mine-Expansion-Towards-Biodiversity-in-Kalimantan.pdf

Huang, Z. C., P. C. Lin, P. H. Lin, and S. H. Chuang. 2025. Impact of coal-fired power plants on suspended sediment concentrations in coastal waters. J. Mar. Sci. Eng, 13(3): 563. DOI: https://doi.org/10.3390/jmse13030563

Jennings, V., K. M. S. Antonio, M. J. Brown, L. Choice, Q. Simpson, I. Ford, H. J. Cho, P. Solis, A. Lacey, and D. M. Robinson. 2024. Place-based conservation in coastal and marine ecosystems: the importance of engagement with underrepresented communities. Sustainability, 16(22): 9965. DOI: https://doi.org/10.3390/su16229965

Jiang, L., T. Yang X. Wang, J. Yu, J. Liu, and K. Zhang. 2023. Research on integrated coastal zone management from past to the future: a bibliometric analysis. Fron. Mar. Sci, 10. DOI: https://doi.org/10.3389/fmars.2023.1201811

Jose, S. A., J. Calhoun, O. B. Renteria, P. Mercado, S. Nakajima, C. N. Hope, M. Sotelo, P. L. Menezes. 2024. Promoting a circular economy in mining practices. Sustainability, 16(24): 11016. DOI: https://doi.org/10.3390/su162411016

Jovanovic, V., S. Stankovic, and V. Krstic. 2023. Environmental, social and economic sustainability in mining companies as a result of the interaction between knowledge management and green innovation-the SEM approach. Sustainability, 15(16): 12122. DOI: https://doi.org/10.3390/su151612122

Kementerian Kelautan dan Perikanan. 2025. Peraturan Menteri Kelautan dan Perikanan Republik Indonesia Nomor 23/PERMEN-KP/2016 tentang Perencanaan Pengelolaan Wilayah Pesisir dan Pulau-Pulau Kecil (Regulation of the Minister of Marine and Fisheries Affairs of the Republic of Indonesia Number 23/PERMEN-KP/2016 regarding Coastal and Small Islands Management Planning). https://jdih.kkp.go.id/Homedev/DetailPeraturan/598

Li, Y., H. Cen, T. Y. Lin, Y. N. Lin, and Y. H. Chiu. 2022. Sustainable coal mine and coal land development in China. Resources Policy, 79: 103092. DOI: https://doi.org/10.1016/j.resourpol.2022.103092

Mitko, K., P. Dydo, A. K. Milewski, J. B. Badura, A. J. Kolon, T. Krawczyk, A. Cieplok, M. Krodkiewska, A. Spyra, G. Gzyl, A. Skalny, B. Konczak, M. Balazinska, P. Labaj, A. Tetlak, M. Kyriazi, and S. Klempetsani. 2024. Mine wastewater effect on the aquatic diversity and the ecological status of the watercourses in Southern Poland. Water, 16(9): 1292. DOI: https://doi.org/10.3390/w16091292

Ohsawa, T. 2025. Unveiling arguments on national system reforms of marine protected areas by extractive marine users in three maritime countries. Front. Mar. Sci., 12. DOI: https://doi.org/10.3389/fmars.2025.1446357

Onifade, M., T. Zvarivadza, J. A. Adebisi, K. O. Said, O. D. Olupona, A. I. Lawal, and M. Khandelwal. 2024. Advancing toward sustainability: the emergence of green mining technologies and practices. Green and Smart Mining Engineering, 1(2):157-174. DOI: https://doi.org/10.1016/j.gsme.2024.05.005

Pratiwi., B. H. Narendra, C. A. Siregar, M. Turjaman, A. Hidayat, H. H. Rachmat, B. Mulyanto, Suwardi, Iskandar, R. Maharani, Y. Rayadin, R. Prayudyaningsih, T. W. Yuwati, R. Prematuri, and A. Susilowati. 2021. Managing and reforesting degraded post-mining landscape in Indonesia: a review. Land, 10(7):658. DOI: https://doi.org/10.3390/land10060658

Ramirez, C. J. C., V. Chavez, R. Silva, J. J. M. Perez, and E. R. Arriaga. 2024. Coastal management: a review of key elements for vulnerability assessment. J. Mar. Sci. Eng, 12(3): 386. DOI: https://doi.org/10.3390/jmse12030386

Ramon, C. M., J. M. Nunez, P. G. Alulema, Y. M. Zambrano, R. H. Chavez, C. B. Milanes, C. A. Guadalupe, P. B. Guisnan, and M. T. Villacis. 2023. A review to update the protected areas in ecuador and an analysis of their main impacts and conservation strategies. Environments, 10(5): 79. DOI: https://doi.org/10.3390/environments10050079

Ramy, N. E., D. Nachite, G. Anfuso, and S. Azaaouaj. 2023. The sector analysis as a coastal management tool for sustainable tourism development on the mediterranean coast of Morocco. Sustainability, 15(16): 12581. DOI: https://doi.org/10.3390/su151612581

Shampa, M. T. A., N. J. Shimu, K. M. A. Chowdhury, M. M. Islam, and M. K. Ahmed. 2023. A comprehensive review on sustainable coastal zone management in Bangladesh: Present status and the way forward. Heliyon, 9(8): e18190. DOI: https://doi.org/10.1016/j.heliyon.2023.e18190

Skrtic, M. M., S. Tisma, and D. Grgurevic. 2024. Conservation under siege: the intersection of tourism and environmental threats in croatian protected area. Land, 13(12): 2114. DOI: https://doi.org/10.3390/land13122114

Sonter, L. J., S. H. Ali, and J. E. M. Watson. 2018. Mining and biodiversity: key issues and research needs in conservation science. Pr. Biol. Sci, 285(1892): 20181926. DOI: https://doi.org/10.1098/rspb.2018.1926

Sutrisno, A. D., Y. J. Chen, I. W. K. Suryawan, and C. H. Lee. 2023. Building a community's adaptive capacity for post-mining plans based on important performance analysis: case study from Indonesia. Land, 12(7): 1285. DOI: https://doi.org/10.3390/land12071285

Taniolo, S., C. Pieretto, and D. Camana. 2023. Improving sustainability in communities: Linking the local scale to the concept of sustainable development. Environmental Impact Assessment Review, 101: 107126. DOI: https://doi.org/10.1016/j.eiar.2023.107126

Thakur, T. K., D. K. Patel, S. Saini, A. Thakur, S. L. Swamy, S. Bakshi, A. Kumar, F. M. Husain, and R. Kumar. 2025. A geospatial analysis of coal mine overburden reclamation: land use, carbon stock, biomass, and soil genesis in chronosequence plantations. Journal of Geochemical Exploration, 271: 107674. DOI: https://doi.org/10.1016/j.gexplo.2025.107674

Tretyakova, M. O., A. I. Vardavas, C. I. Vardavas, E. I. Iatrou, P. D. Stivaktakis, T. I. Burykina, Y. O. Mezhuev, A. M. Tsatsakis, and K. S. Golokhvast. 2021. Effects of coal microparticles on marine organisms: a review. Toxicology Reports, 8: 1207-1219. DOI: https://doi.org/10.1016/j.toxrep.2021.06.006

Xu, Z., L. Zhang, Y. Gao, X. Tan, Y. Sun, and W. Chen. 2024. Effects of coal mining activities on the changes in microbial community and geochemical characteristics in different functional zones of a deep underground coal mine. Water, 16(3): 1836. DOI: https://doi.org/10.3390/w16131836

Yao, Q and L. Yu. 2023. Advances in coal and water co-mining. Energies, 16(6): 2666. DOI: https://doi.org/10.3390/en16062666

Yuan, W and Y. C. Chang. 2021. Land and sea coordination: revisting integrated coastal management in the context of community interest. Sustainability, 13: 1-13. DOI: https://doi.org/10.3390/su13158183

Zhou, G.,Y. Xu, Y. Wang, L. Zheng, Y. Zhang, L. Li, B. Sun, S. Li, and Y. Zhu. 2023. Study on MICP dust suppression technology in open pit coal mine: preparation and mechanism of microbial dust suppression material. Journal of Environmental Management, 343(1):118181. DOI: https://doi.org/10.1016/j.jenvman.2023.118181