Integrating Sustainability and Governance: A Cross-Case Synthesis of the ESEG Framework for Quarry Business Management

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Abstract

This study investigates how sustainability and governance principles can be systematically integrated into quarry management. The objectives aim to (1) examine the conceptual gaps in existing frameworks such as the Triple Bottom Line (TBL), Circular Economy (CE); (2) analyze international and Thai cases to identify governance lessons for sustainable practice; and (3) propose an integrated Environmental, Social, Economic, and Governance or ESEG framework for Thailand. Using document analysis and cross-case synthesis of six countries, the study identifies persistent fragmentation among environmental, social, and economic initiatives. Governance emerges as the coordinating mechanism that enables accountability, coherence, and long-term sustainability. Conceptually, the proposed ESEG framework advances sustainability theory by extending TBL and CE approaches; practically, it offers policy insights for improving enforcement, participation, and innovation. Limitations include reliance on secondary data and the need for empirical validation in operational quarry contexts.

Keywords: Sustainable quarry management, Sustainable development, Governance, Mining policy

Introduction

Quarrying is a resource-intensive industry that, when weakly regulated, often leads to land degradation, pollution, and social conflict. In Nigeria, weak enforcement has led to heavy-metal contamination, unsafe abandoned pits, and land instability, creating significant environmental and public-health risks (Nwachukwu, Ojeaga, & Gilbert, 2018).

Similar challenges appear across developing regions, including Thailand, where construction aggregates such as limestone and granite play a vital role in infrastructure development. The country currently has 327 licensed quarries covering about 143,000 rai (22,880 hectares), with reserves exceeding 8.3 billion metric tons (Department of Primary Industries and Mines, 2024). A survey in Takua Thung District found that although residents acknowledged some economic benefits, 95 percent demanded stronger dust and traffic controls (Kamlom & Nanthabut, 2020). Conflict at Khao Khuha quarry in Songkhla also reflected poor communication and limited participation (Whangsani, Doungsuwan, Isarata, & Onrak, 2022).

These experiences underscore that quarry governance in Thailand has long prioritized economic output over environmental and social safeguards. Weak enforcement and limited participation have eroded trust and produced reactive rather than preventive management. Globally, similar patterns are evident: frameworks such as the Triple Bottom Line (Azapagic, 2004), Circular Economy (Alarcón-Ruíz, et al., 2022; Oshim et al., 2024), and governance-based models (UNESCAP, 2009; Ogan, Ndekugri, Oduoza, & Khatib, 2016) have advanced sustainability theory but remain fragmented in practice.

This study addresses the gap by synthesizing theoretical insights and international case evidence to propose an integrated framework for sustainable quarry management, thereby extending existing concepts while providing practical policy guidance.

Accordingly, this study seeks to address the following question: How can sustainability principles be systematically integrated into Thailand's quarry governance framework? The study contributes both conceptually—by connecting sustainability and governance theories—and practically, by offering policy guidance for sustainable quarry development.

Objectives

1. To examine how existing sustainability frameworks apply to quarry management and identify their conceptual limitations.

2. To analyze international and Thai cases to extract governance-related lessons for integrated sustainability.

3. To develop and propose an integrated framework that advances sustainability theory by embedding governance as a coordinating mechanism, while providing policy guidance for sustainable quarry management in Thailand.

Literature Review

Sustainable Development Frameworks in the Mining Sector

Sustainable development refers to meeting current needs without undermining resources for future generations. The Mining, Minerals, and Sustainable Development (MMSD) initiative explained this through five forms of capital: natural, manufactured, human, social, and financial (IIED, 2002). The Triple Bottom Line (TBL) framework, highlighting economic, social, and environmental dimensions, has been widely used in mining research (Azapagic, 2004; Hilson & Murck, 2000). However, its implementation in extractive industries often remains theoretical, with weak integration into operational practice (Mancini & Sala, 2018).

Studies in Mexico's marble sector show continued inefficiency and conflict despite sustainability rhetoric, prompting calls for multi-sector collaboration such as the Triple Helix model (Alarcón-Ruíz et al., 2022). These lessons indicate that TBL offers conceptual balance but lacks institutional coordination, underscoring the need for governance-based integration.

Circular Economy Approaches in Quarry Management

The Circular Economy (CE) provides another framework relevant to quarrying. CE promotes material reuse, waste reduction, and land rehabilitation to create closed production loops (Geissdoerfer, Savaget, Bocken, & Hultink, 2017; Su, Heshmati, Geng, & Yu, 2013). In the context of quarrying, this efficient resource use and valorization of stone by-products (Alarcón-Ruíz et al., 2022). One study demonstrated that quarry waste could be repurposed as raw material for paint production, reducing both costs and environmental impacts (Oshim et al., 2024), while in China and the European Union, CE-driven construction policies have improved material efficiency and reduced landfill dependency (Geng, Sarkis, Ulgiati, & Zhang, 2013; Kirchherr, Reike, & Hekkert, 2017).

These cases demonstrate the capacity of CE to simultaneously strengthen economic resilience and ecological protection. The incorporation of Industry 4.0 technologies, such as AI and machine learning, is increasingly recognized as a vital pathway to sustainable mining by enhancing operational efficiency, improving worker safety, and delivering better environmental outcomes (Chatterjee, Sindhwani, Manglad, & Hasteer, 2025; Haroon et al., 2025). Furthermore, this technological shift directly supports the Circular Economy dimension by converting vast amounts of mining waste, or tailings, into valuable resources, which requires robust regulatory frameworks to ensure successful implementation (Cotrina-Teatino & Marquina-Araujo, 2025). However, adoption remains uneven. Many small and medium-sized quarries face barriers such

as high technology costs, limited institutional support, and weak market incentives, echoing global findings that CE transitions require systemic policy alignment and cross-sector collaboration (Mancini & Sala, 2018). Consequently, CE is often discussed as a strategic goal but less frequently implemented in practice.

Governance and Accountability in Quarry Industries

Governance forms the institutional foundation for sustainable extractive industries, shaping how power, responsibility, and accountability are exercised in managing natural resources (Lemos & Agrawal, 2006). Core principles include rule of law, transparency, participation, accountability, and efficiency (UNESCAP, 2009). In quarrying, this means compliance with mining and environmental regulations, open disclosure, community participation in decision-making, and responsibility for damages. In Thailand, for instance, the application of participatory mechanisms—such as public hearings and joint monitoring—has improved community relations (Punyapat & Chanisara, 2022). International studies similarly highlight that effective environmental governance requires clearly defined goals, strict environmental standards, and mechanisms for meaningful stakeholder engagement (Hilson & McQuilken, 2014; Ogan et al., 2016). The polluter pays principle further reinforces accountability by ensuring that operators bear the true cost of environmental damage.

However, governance in practice often remains weak: enforcement is inconsistent, participation tends to be procedural rather than substantive, and transparency mechanisms are underdeveloped. Nonetheless, the adoption of digital technologies is enhancing transparency in CSR practices, providing new tools for accountability and stakeholder engagement that overcome traditional communication barriers (Haroon et al., 2025). Scholars therefore argue that embedding governance as a cross-cutting accountability mechanism is essential to achieving sustainable outcomes in the extractive sector (Bebbington & Unerman, 2020).

Synthesis and Research Gap

Overall, three main approaches dominate the sustainability literature in extractive industries: the Triple Bottom Line, the Circular Economy, and Governance-based frameworks. Each offers valuable insights but demonstrates distinct limitations. TBL stresses balance across environmental, social, and economic pillars yet often lacks concrete operational mechanisms to guide implementation (Azapagic, 2004; Mancini & Sala, 2018). CE emphasizes efficiency and material reuse but depends heavily on institutional capacity and policy incentives for adoption (Geissdoerfer et al., 2017; Kirchherr et al., 2017). Governance frameworks ensure responsibility

and compliance but are typically treated as external oversight systems rather than as integrative mechanisms (Lemos & Agrawal, 2006; Hilson & McQuilken, 2014). As a result, these approaches are frequently applied in isolation, producing fragmented sustainability outcomes within the quarrying sector.

These fragmented approaches lead to inconsistent sustainability outcomes. The literature reveals four interrelated gaps: (1) the lack of an integrated framework combining TBL, CE, and governance; (2) the absence of measurable mechanisms linking environmental, social, and economic performance; (3) limited contextual adaptation of global models to countries such as Thailand; and (4) weak theoretical connection between sustainability and governance, which are often treated separately.

Addressing these gaps requires an integrated model that embeds governance as a coordinating dimension across environmental, social, and economic systems. This study responds to that need through the development of the ESEG framework for coherent and accountable quarry management.

Cross-case Synthesis of International and Domestic Evidence

This study adopted a cross-case qualitative synthesis to explore sustainable quarry management practices across six countries: Mexico, Malaysia, Greece, Nigeria, Kenya, and Thailand. The cases were purposively selected based on the availability of relevant studies, representation of both developed and developing contexts, and diversity in governance and environmental challenges (Yin, 2018**).**

The analysis relied on secondary sources, including Scopus-indexed articles, government and reports, and policy documents published between 2010 and 2024. Using thematic content analysis (Braun & Clarke, 2006; Thomas & Harden, 2008), the study coded and compared qualitative information from each case to identify recurring sustainability practices and policy measures. This process produced five cross-cutting themes—governance and enforcement, community participation and transparency, technological innovation and circular economy, land-use planning and rehabilitation, and occupational health and safety. All materials were publicly available and did not require ethical clearance. The following sections elaborate on these themes with examples drawn from international and Thai contexts.

Governance and Enforcement

Legal frameworks alone do not guarantee sustainability. Kenya's National Environment Management Authority (NEMA, 2016) has demonstrated the importance of enforcement by shutting down non-compliant quarries, showing that sanctions create compliance pressure despite short-term economic costs (Orimba, 2020). Conversely, Nigeria demonstrates that weak enforcement results in heavy-metal pollution, unsafe abandoned pits, and unstable land conditions, amplifying environmental and health risks (Nwachukwu et al., 2018). For Thailand, this underscores that well-crafted regulations must be paired with monitoring capacity, digital reporting, and credible sanctions to translate rules into outcomes.

Community Participation and Transparency

Trust and legitimacy depend on meaningful participation. In Malaysia, opaque licensing processes have fuelled community resistance (Jaafar & Tarmizi, 2019), while in Mexico, structured stakeholder engagement and Triple Helix collaboration have helped strengthen local acceptance (Alarcón-Ruíz et al., 2022). In Thailand, although the Minerals Act (Department of Primary Industries and Mines, 2017) requires public hearings, these often remain procedural rather than substantive. A survey in Phang Nga Province revealed that 95% of residents demanded stronger dust and traffic controls (Kamlom & Nanthabut, 2020), indicating that consultation must move beyond formality toward genuine responsiveness. Further evidence shows that CSR in Thailand's limestone mining sector remains largely compliance-driven and philanthropic, focusing on donations rather than long-term community engagement (Taesillapasathit & Piphatanangkun 2022). These patterns demonstrate that social responsibility practices are still reactive and disconnected from governance or sustainability planning, reinforcing the need for integrated frameworks such as ESEG to institutionalize participatory governance and community empowerment.

Technological Innovation and Circular Economy

Adopting cleaner technology and CE practices reduces ecological impacts and creates new value streams. Greece has adopted dust suppression and controlled blasting (Drakopoulos, Economou, & Grimani, 2012). Nigeria is exploring cleaner technologies, including improved waste management and dust control (Oshim et al., 2024). Mexico demonstrates CE potential by repurposing marble waste into industrial products such as cement inputs (Alarcón-Ruíz, Garcia-Santamaria, Mayett-Moreno, Fernandez-Echeverria, & Fernandez-Lambert, 2024). For Thailand, targeted measures such as tax incentives, concessional loans,

and technology transfer from universities could help SMEs overcome financial and technical barriers to adoption.

Land-use Planning and Rehabilitation

Spatial planning and closure strategies remain underdeveloped in many quarry contexts. In Malaysia, quarry clustering near communities and forests has intensified land-use conflicts (Jaafar & Tarmizi, 2019). Evidence from Nigeria shows widespread environmental degradation—including heavy-metal contamination, unsafe pits, and land instability—driven by weak enforcement (Nwachukwu et al., 2018). For Thailand, integrating licensing with strategic environmental assessments (SEA), hydrological risk mapping, and progressive rehabilitation obligations would ensure that mined-out land is restored for agriculture, forestry, or community use.

Occupational Health and Safety (OHS)

Worker safety is a core element of social sustainability. In Greece, mandates systematic risk assessments, OHS infrastructure, and mandatory training (Drakopoulos, Economou, & Grimani, 2012). Evidence from Mexico also shows persistent OHS risks, particularly noise exposure and poor lighting (Alarcón-Ruíz, et al., 2024). These measures institutionalize worker protection as part of the quarrying process. Thailand could strengthen its OHS regime by embedding regular safety audits, modern protective infrastructure, and annual health checks within ESG compliance requirements, aligning worker welfare with sustainability goals.

Table 1 Thematic synthesis of cross-country quarry management practices and lessons

Theme	Country	Key Practice / Outcome	Policy Insight
Governance & Enforcement	Kenya	NEMA enforced quarry closures to ensure compliance.	Strong enforcement and sanctions improve accountability.
	Nigeria	Weak enforcement resulted in heavy-metal contamination, unstable land, and abandoned pits.	Strengthening monitoring and enforce rehabilitation obligations
	Thailand	Enforcement under the Minerals Act remains limited.	Strengthen digital monitoring and penalty mechanisms.

Table 1 (continue)

Theme	Country	Key Practice / Outcome	Policy Insight
Community Participation & Transparency	Malaysia	Limited transparency in licensing caused public resistance.	Improve participatory processes and access to information.
	Mexico	Triple Helix collaboration enhanced stakeholder support.	Collaboration fosters shared responsibility.
	Thailand	Residents demanded stronger dust and traffic control.	Promote substantive rather than procedural hearings.
		CSR practices in limestone quarries were mainly compliance-based and philanthropic, with limited participation or long-term planning.	CSR needs to evolve from charity and compliance toward participatory and governance-based community engagement.
Technology & Circular Economy	Greece	Adoption of dust control and waste reuse improved efficiency.	Cleaner technology supports sustainability goals.
	Mexico	Waste reused in industrial products reduced costs and impacts.	CE transforms waste into value-added outputs.
	Thailand	SMEs face high costs for clean technology adoption.	Provide fiscal and technical support for SMEs.
Land-use & Rehabilitation	Malaysia	Quarry clustering near communities caused land-use conflict.	Integrate spatial planning in licensing.
	Thailand	Weak rehabilitation practices after closure.	Require progressive land restoration in permits.

Table 1 (continue)

Theme	Country	Key Practice / Outcome	Policy Insight
Occupational Health & Safety (OHS)	Greece	Mandatory risk assessment and safety training reduced injuries.	Embed OHS as part of ESG systems.
	Thailand	Limited safety audits and worker health checks.	Establish regular OHS audits and reporting.

The comparative evidence suggests that while many countries have introduced sustainability measures in quarry management, these efforts often remain isolated and fragmented. Environmental protection, community engagement, economic efficiency, and governance oversight tend to operate as separate domains, resulting in inconsistent outcomes and limited long-term impact. Most initiatives emphasize compliance or mitigation rather than systemic integration across dimensions. Evidence from Thailand's CSR-based quarry management model further highlights this fragmentation—social responsibility is often pursued independently of environmental or governance systems. This underscores the importance of embedding governance as the coordinating dimension, linking CSR, environmental stewardship, and economic accountability within a single integrated framework.

This pattern highlights a critical gap in current quarry governance: the absence of a coherent framework that connects environmental, social, economic, and institutional mechanisms into a unified management system. Addressing this gap requires moving beyond single-dimension approaches toward an integrated model that aligns sustainability objectives with governance practice—an issue explored in the following section.

Conceptual Framework for Sustainable Quarry Management

Building upon the thematic synthesis and the identified gaps, this section proposes a conceptual framework that integrates environmental, social, economic, and governance dimensions within a unified system. The framework draws on cross-case evidence and theoretical perspectives from sustainability, circular economy, and governance studies, emphasizing that current approaches remain fragmented across policy, industry, and community levels.

The proposed ESEG framework positions governance as a cross-cutting mechanism that links and coordinates the other three dimensions. Evidence from Kenya and Nigeria underscores the need for robust environmental controls and rehabilitation; from Greece (United Nations, 2010) and Thailand, the importance of worker safety and participatory decision-making; from Mexico, the economic potential of circular economy innovation; and from Thailand, the value of transparent and accountable governance. Together, these insights highlight that sustainability in quarry management depends on aligning environmental stewardship, social legitimacy, economic efficiency, and institutional accountability through an integrated governance process.

Conceptually, the framework advances beyond established models such as ESG, TBL, and CE by embedding governance within sustainability rather than treating it as an external oversight tool. This integration ensures coherence across sustainability dimensions, translating lessons from theory and comparative practice into a practical system that supports long-term accountability, transparency, and resilience in quarry management.

Each ESEG dimension is conceptually grounded and practically measurable. The environmental dimension draws from the TBL and CE, focusing on pollution control and rehabilitation. The social dimension reflects stakeholder and social license theories, emphasizing participation and worker safety. The economic dimension builds on sustainable value and circular innovation through efficiency and local benefit creation. The governance dimension, rooted in environmental and good governance theory, ensures accountability and coordination across all pillars, linking the framework into a coherent system.

Together, these dimensions form a unified governance-based approach that bridges theory and application. The following section discusses how this framework can inform policy design and industry practice, highlighting its implications for sustainable resource management in Thailand and comparable resource-dependent contexts.

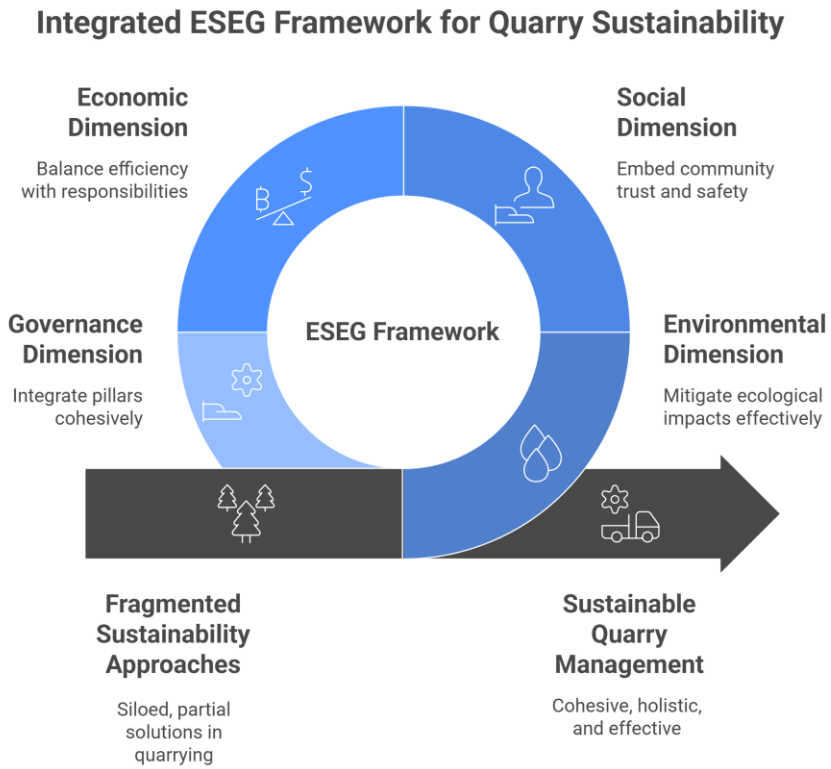

Figure 1 Conceptual framework for sustainable quarry management (ESEG model)

Discussion

The findings confirm that sustainable quarry management requires a systemic approach that integrates environmental, social, economic, and governance dimensions. This interpretation aligns with previous frameworks such as the Triple Bottom Line (Azapagic, 2004) and the Circular Economy (Alarcón-Ruíz et al., 2022; Oshim et al., 2024), yet extends them by embedding governance as the coordinating mechanism. While TBL focuses on balance and CE promotes material efficiency, both lack institutional linkage and accountability. The present study contributes by operationalizing governance as the element that connects and harmonizes these dimensions into a coherent system.

Compared with existing governance models (UNESCAP, 2009; Ogan et al., 2016), this study strengthens the empirical foundation by synthesizing evidence from multiple contexts. Cases from Kenya, Mexico, Malaysia, and Thailand illustrate that fragmented enforcement, weak participation, and insufficient technology adoption persist. However, when governance is designed as a coordinating process—linking regulation, participation, and innovation—it can transform isolated successes into sustainable outcomes. The framework

thus refines earlier theories of environmental governance and contributes to ongoing debates on integrated resource management in developing economies.

Conclusion

This study proposes an integrated framework that unites environmental, social, and economic pillars through governance as a cross-cutting mechanism. Conceptually, it advances sustainability theory by embedding governance within existing models such as TBL and CE, while empirically it synthesizes cross-country lessons into an actionable model for Thailand and other resource-based economies. Nevertheless, some limitations remain. The analysis relied primarily on secondary data and cross-case synthesis; therefore, causal relationships among ESEG dimensions were not empirically tested. Future research should apply the framework in quantitative or longitudinal settings to examine how governance coordination influences environmental and social outcomes across different quarry contexts.

Policy and Practical Implications

The framework suggests practical directions for policy and industry. Governments should strengthen enforcement through digital monitoring systems, establish progressive rehabilitation funds, and link license renewal to verified compliance. Industry actors, especially SMEs, should receive tax incentives and low-interest loans to invest in cleaner and circular technologies. Communities should engage in co-management and participatory monitoring rather than passive consultation, while academia and civil society can facilitate capacity building, data transparency, and independent evaluation.

These strategies can help transition quarrying from a purely extractive industry toward one that creates shared value through accountability, transparency, and sustainable resource use.

Future Research

Further research should develop measurable indicators for each ESEG dimension and empirically test their interrelationships. Comparative studies across different resource sectors could assess the framework's transferability, while integration with broader approaches such as the Social License to Operate or Quintuple Helix could enhance its theoretical robustness and policy relevance.

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