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INFLUENCE OF CIRCULAR ECONOMY BUSINESS PRACTICES ON OPERATIONAL EFFICIENCY IN THE MINING SECTOR IN TAITA TAVETA COUNTY, KENYA

[1] Richard Wandana Kibengo; [2] Karim Hassanali Omido, PhD & [3] Patrick Kimaku, PhD

[1] Scholar, Taita Taveta University,Kenya
[2] Professor, School of Business, Taita Taveta University, Kenya
[2] Senior Lecturer, School of Business, Taita Taveta University, Kenya

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ABSTRACT

The mining sector in Kenya, particularly in Taita Taveta County, has faced significant operational inefficiencies despite holding substantial mineral wealth including gemstones, limestone, and iron ore. This study examined the influence of circular economy (CE) business practices on operational efficiency in the mining sector in Taita Taveta County, Kenya, a region endowed with gemstones, limestone, and iron ore yet characterized by persistent inefficiencies. The research was anchored on Diffusion of Innovation Theory, Resource-Based View Theory, Institutional Theory, Stakeholder Theory, and Strategic Management Theory to explain CE adoption dynamics. Using a descriptive and correlational design, data were collected through structured questionnaires from registered mining firms, artisanal miners, county officials, regulators, and cooperatives. Descriptive and inferential statistics were applied to analyze relationships among CE practices, barriers, enablers, regulatory frameworks, and operational efficiency. Findings indicated moderate to strong adoption of CE practices, particularly in waste reduction, resource recovery, and energy efficiency. All independent variables showed significant positive relationships with operational efficiency, with barriers to adoption exerting the strongest influence, followed by regulatory frameworks, enablers, and CE practices. Key constraints included limited technical capacity, inadequate financing, weak regulatory enforcement, and resistance to change, while institutional support, leadership commitment, incentives, and technology emerged as major enablers. The study concludes that integrating CE principles enhances operational efficiency and offers policy and managerial implications for sustainable mining development.

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Keywords: *Circular Economy Practices, Material Flow Management, Resource Efficiency,Industrial Symbiosis, Operational Efficiency*

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INTRODUCTION

The global mining sector remains essential to economic growth and the supply of critical raw materials, yet it is widely associated with environmental degradation, resource depletion, and high levels of waste under the dominant linear "take–make–dispose" model (Calvo et al., 2021). This model conflicts with global sustainability and climate goals, prompting calls for more regenerative production systems (UNEP, 2023). The Circular Economy (CE) has emerged as a transformative alternative, seeking to decouple economic growth from environmental harm by minimizing waste, extending material lifecycles, and regenerating natural systems (Kirchherr et al., 2023). In mining, CE translates into practices such as waste valorization, tailings reprocessing, water recycling, energy efficiency, and industrial symbiosis, which have demonstrated both environmental and economic gains globally (Ghisellini & Ulgiati, 2020; Christis et al., 2022).

Globally, CE adoption varies across regions. The European Union leads through policy-driven frameworks like the Green Deal, while China integrates CE within national industrial planning and "Dual Carbon" goals (Kirchherr et al., 2023; Tseng et al., 2023). The United States relies more on corporate innovation and market-driven models (Bocken & Geradts, 2020). In Africa, CE practices are largely driven by resource scarcity, waste challenges, and employment needs, with growing policy recognition despite financing and infrastructure constraints (Ogunmakinde et al., 2022; World Bank, 2023).

Kenya is emerging as a regional CE leader through progressive policies such as the Sustainable Waste Management Act (2022) and the National Climate Change Action Plan (2023–2027), which promote resource recovery and Extended Producer Responsibility (GoK, 2022; NCCAP, 2023). However, environmental degradation, waste mismanagement, and operational inefficiencies persist, particularly in sectors such as mining (Abuya, 2020).

Although mining contributes about 1% to Kenya's GDP, it remains strategically important, especially in mineral-rich regions such as Taita Taveta County, known for gemstones, iron ore, and limestone (KNBS, 2023; Mutune et al., 2020). The sector faces inefficiencies related to outdated technologies, waste mismanagement, and limited capacity among small-scale miners (Ochieng & Wanjala, 2021). Integrating CE practices such as closed-loop water systems and tailings recovery offers potential to enhance cost efficiency, resource productivity, and environmental compliance (Omwenga & Gitau, 2021).

Despite growing policy support, empirical evidence linking CE business practices to measurable operational efficiency in Kenya's mining sector remains limited. This study therefore examines how CE adoption influences operational efficiency within the mining sector of Taita Taveta County, addressing a critical research gap and informing sustainable sector transformation.

Statement of the Problem

Kenya's mining sector holds considerable potential to drive industrialization, employment, and rural development, yet it contributes less than 1% to the national GDP (Kenya National Bureau of Statistics [KNBS], 2024). Taita Taveta County, home to vast deposits of gemstones, limestone, and iron ore, represents a critical node in this underperforming sector. Despite its mineral wealth, the region faces persistent inefficiencies in mining operations ranging from high energy and water consumption to poor waste management. For instance, studies show that over 60% of mined material in the region is discarded as waste, contributing to environmental degradation and economic loss (Wekesa & Njoroge, 2023). These inefficiencies directly affect the operational performance of mining enterprises, especially artisanal and small-scale miners (ASMs), who dominate the sector in the county.

The circular economy (CE) offers a compelling framework to address these inefficiencies by promoting material recovery, recycling, and resource optimization. Globally, mining firms adopting CE practices have reported enhanced productivity and reduced operating costs. However, in Taita Taveta, the uptake of CE practices remains limited and fragmented. According to Muthoni and Kiptoo (2022), only about 22% of mining enterprises in Kenya engage in any form of material reuse or recycling, and this figure is even lower in rural counties like Taita Taveta. Factors such as low technical capacity, lack of financing, and insufficient policy enforcement hinder local miners from embracing circular models that could streamline operations and reduce waste. This gap between the potential of CE practices and their practical application highlights a missed opportunity for operational improvement and environmental sustainability.

Against this backdrop, this study seeks to explore the influence of circular economy business practices on operational efficiency in the mining sector, with a specific focus on Taita Taveta County. The problem lies in the minimal integration of CE strategies in local mining operations, despite growing policy interest and international examples of success. Without targeted interventions to promote circularity including training, access to green technologies, and regulatory incentives mining in Taita Taveta may continue to operate below potential, with high resource wastage and unsustainable practices. This study aims to fill the empirical and policy gap by assessing the extent to which CE practices influence operational efficiency in this strategically important mining region.

Objective of the Study

The purpose of this study is to show the Influence of Circular Economy Business Practices on Operational Efficiency in the Mining Sector: A Case Study of Taita Taveta County, Kenya. The study was guided by the following specific objectives;

- The study was guided by the following specific objectives:
- To assess the extent of adoption of circular economy practices in the mining sector within Taita Taveta County.
- To analyze the relationship between circular economy practices and operational efficiency in mining enterprises within Taita Taveta County.
- To find out the key barriers and enablers influencing the adoption of circular economy models in Taita Taveta’s mining sector within Taita Taveta County.
- To evaluate the role of regulatory frameworks and policy support in promoting circular economy practices in mining operations within Taita Taveta County.
- To propose strategic recommendations for enhancing the integration of circular economy principles to improve operational efficiency in the mining sector of Taita Taveta.

LITERATURE REVIEW

Theoretical Review

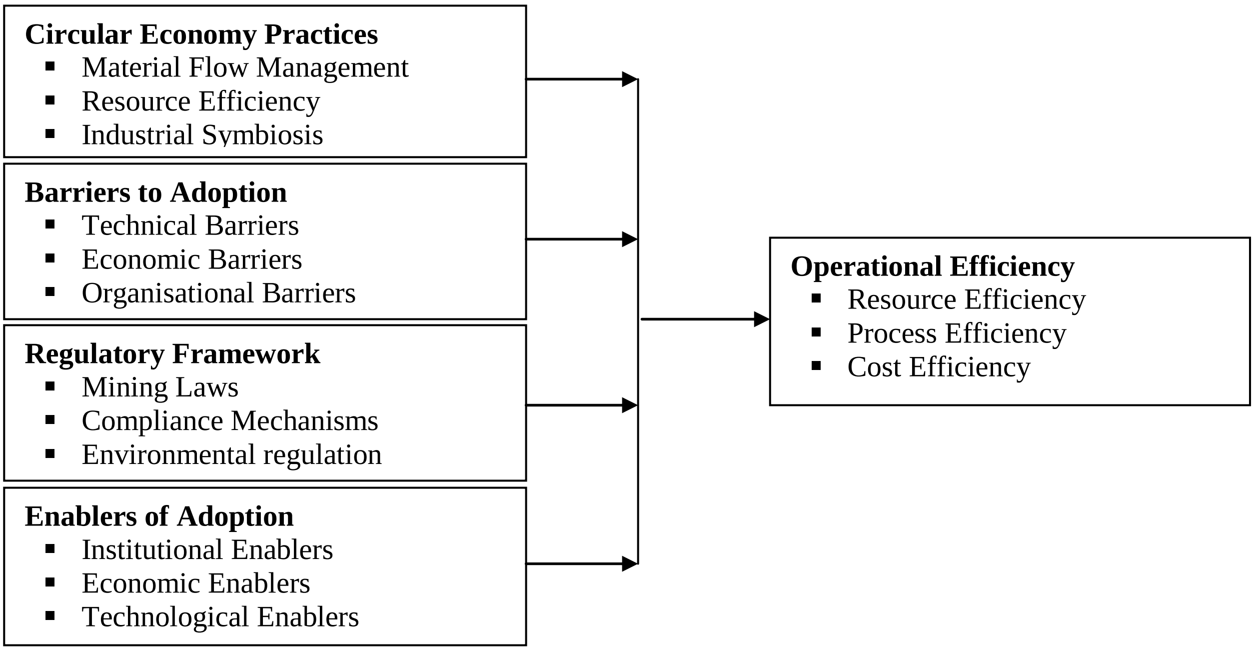
The study’s theoretical framing draws on complementary perspectives to explain both *why* circular economy (CE) practices diffuse and *how* they translate into operational efficiency in Taita Taveta’s mining sector. Diffusion of Innovation Theory explains uneven uptake of CE by classifying firms and miners into adopter categories (innovators through laggards) and emphasizing that adoption depends on perceived relative advantage, compatibility, complexity, trialability, and observability (Rogers, 2003). In Taita Taveta, limited demonstration projects, weak access to innovation networks, and the perceived technical complexity of circular technologies slow diffusion, especially among small-scale operators (Ngugi et al., 2022; Omondi & Baraka, 2021). The theory also highlights the role of communication channels and social systems; peer learning, community organizations, and pilot platforms supported by county or development partners can accelerate acceptance among early adopters and the early majority (Wanjiru & Kihara, 2023).

The Resource-Based View positions CE adoption as a strategic capability that can improve efficiency and competitiveness when it becomes a valuable, difficult-to-imitate organizational resource (Barney, 1991). Circular practices such as internal recycling, tailings reprocessing, and material-flow tracking enhance resource productivity and reduce input and waste-handling costs, supporting operational gains in resource-constrained environments (Mwikali & Otieno, 2022; Mutie & Njoroge, 2023). RBV further underscores organizational learning and culture as foundations for sustaining these capabilities, including intangible assets such as reputation and stakeholder trust (Kamau & Wekesa, 2024).

Institutional Theory complements these firm-level explanations by showing how regulative, normative, and cultural-cognitive pressures shape CE adoption (Scott, 2001). Inconsistent enforcement reduces regulative pressure, while rising community expectations around pollution and land impacts strengthen normative pressure, making CE a route to legitimacy and a “license to operate” (Kariuki & Otieno, 2022; Wambua & Mwenda, 2021). At the cognitive level, limited CE awareness can constrain proactive uptake, implying the need for targeted training and mindset shifts (Mutinda & Karanja, 2023).

Stakeholder Theory reinforces that CE transitions require inclusive engagement among regulators, communities, cooperatives, and firms to co-create practical guidelines and accountability mechanisms (Freeman, 1984; Mburu & Okello, 2021). Finally, Strategic Management Theory—particularly Porter’s value chain—helps locate where CE interventions (e.g., processing, waste handling, water loops) yield cost and productivity gains, positioning circularity as a performance strategy rather than compliance alone (Porter, 1985; Mutua & Njoroge, 2022; Achieng & Otieno, 2021).

Conceptual Framework



Independent Variables **Dependent Variable**

Figure 1: Conceptual Framework

Empirical Review

Recent empirical literature underscores a growing recognition of circular economy (CE) practices as a pathway to improving operational efficiency in extractive industries globally. In sub-Saharan Africa, where mining remains a vital contributor to economic growth, CE adoption is still nascent but expanding. According to Kiptoo and Barasa (2021)**,** Kenyan mining enterprises particularly artisanal and small-scale miners exhibit low to moderate adoption of CE practices such as material recovery, reuse of tailings, and eco-friendly extraction. Their study, based on surveys across several counties including Taita Taveta, revealed that while miners show willingness to shift towards CE models, the transition is hindered by limited technical capacity and weak institutional support.

Another critical dimension is the operational impact of CE practices in mining**.** Mutinda and Karanja (2023) conducted a quantitative study on mid-sized mining companies in Taita Taveta and Kilifi counties to assess how CE integration affects cost-efficiency, productivity, and resource optimization. They found a significant inverse relationship between waste generation and operational efficiency, with firms that practiced tailings reuse, water recycling, and energy efficiency reporting reduced operational costs and fewer machine downtimes. Their regression analysis confirmed that CE is not just an environmental imperative but a strategic tool for operational enhancement.

Moreover, studies emphasize that policy frameworks and institutional collaboration play a crucial role in enabling CE transitions in mining. Wambui and Dlamini (2022) compared CE adoption in Kenya and South Africa and found that while South Africa had more structured incentives and regulatory enforcement, Kenyan firms particularly in Taita Taveta struggled with unclear CE guidelines and inconsistent enforcement of environmental regulations. However, in areas where local governments and mining cooperatives partnered on community-led CE initiatives, operational performance improved. These findings highlight the need for contextualized and decentralized policy approaches to boost CE adoption.

Beyond institutional factors, knowledge gaps and organizational culture are also pivotal. Omondi and Wekesa (2024) identified that many miners, especially in Taita Taveta, equate environmental sustainability with regulatory compliance rather than innovation. Their study showed that firms that engaged in environmental training, benchmarking, and sustainability reporting performed better in CE alignment and operational outcomes. The researchers advocate for targeted capacity-building programs and peer-to-peer knowledge exchanges to help mining firms internalize CE principles as part of their strategic operations.

An additional layer to this discussion is the role of technological innovation in scaling CE practices. Muriuki and Mutua (2022) investigated the use of green technologies such as solar-powered crushers and gravity-based mineral separation in mining enterprises across Kenya. Their findings revealed that these technologies not only reduced carbon emissions but also significantly enhanced energy efficiency and lowered production costs. However, adoption was higher in firms with access to financing and technical partnerships, reinforcing the idea that technology is a key enabler but requires ecosystem-level support for widespread implementation.

Environmental and social benefits of CE are also gaining attention in empirical studies. Njuguna and Njoroge (2020) demonstrated how firms that invested in CE models experienced improved community relations, fewer environmental penalties, and higher compliance with the Environmental Management and Coordination Act. In Taita Taveta, mining companies that actively engaged in local water reuse projects and land rehabilitation programs gained social legitimacy and access to government tenders. These outcomes suggest that CE can contribute to both operational efficiency and social license to operate critical for the long-term sustainability of mining enterprises.

Finally, strategic positioning is a key driver of CE effectiveness**.** Wekesa and Muthoni (2023) argued that mining firms with clearly defined environmental goals embedded in their corporate strategies were more likely to integrate CE in a manner that supports business growth. Their longitudinal study across 15 mining enterprises in Kenya found that companies that viewed CE through a strategic lens aligned with Porter's value chain framework reported enhanced competitive advantage, streamlined operations, and improved adaptability to market shifts. This reinforces the value of aligning CE initiatives with core business strategies rather than treating them as peripheral compliance activities.

METHODOLOGY

This study adopts a descriptive survey design, complemented by correlational analysis, to examine how Circular Economy (CE) business practices influence operational efficiency in the mining sector of Taita Taveta County, Kenya. A descriptive design is appropriate for profiling current conditions, attitudes, and practices and for generating population-representative findings from a sample (Creswell & Clark, 2017; Mertens, 2024). Correlational techniques are then used to quantify relationships between CE practices (independent variables) and operational efficiency outcomes (dependent variable) through inferential statistics such as correlation and regression (Creswell, 2017; Kothari, 2009).

The target population comprises key mining stakeholders in Taita Taveta, including licensed firms (large- and small-scale), artisanal and small-scale miners, county officials, regulators, environmental officers, community organizations, and mining cooperatives (Mugenda & Mugenda, 2003; Kombo & Tromp, 2009). A sampling frame will be developed from registered mining operations and stakeholder lists (Tracy, 2019; Johnson & Christensen, 2019). A sample size of 384 respondents will be determined using Fisher's formula at 95% confidence and 5% margin of error, with simple random sampling applied to select participants (Kline, 2015; Bryman, 2016).

Primary data will be collected using structured and open-ended questionnaires, supported by secondary sources (Gray, 2019; Mertens, 2014). Instruments will be pilot-tested (10% of the sample) and refined, with reliability assessed using Cronbach's alpha ($\alpha \geq 0.7$) and validity strengthened through expert review (Creswell & Creswell, 2022; Pallant, 2013). Data will be cleaned, coded, and analyzed using descriptive and inferential statistics, alongside content analysis for qualitative responses (Creswell & Poth, 2017).

FINDINGS AND DISCUSSION

Response Rate

Three hundred and eighty-four questionnaires were handed out to management employees from registered Mining Sector. From the 384 questionnaires distributed the study received 337 of them having been filled to satisfactory levels. As shown in Table 1, the questionnaires returned added up to 87.7% response rate that was taken to be excellent. This is because according Mugenda and Mugenda (2013), research achieves a response good enough to proceed with when it attains a 50% response rate, it is sufficient when it is at 60% any response above 70% is considered excellent..

Table 1: Response Rate

Questionnaire	Frequency	Percent
Returned	337	87.7
Un-returned	47	12.3
Total	**384**	**100.0**

Descriptive Analysis

In This subsection covers the findings on analysis of the descriptive statistics. The study focused on the main variables of the study which are discussed systematically. The variables are the independent variables which are Circular Economy Practices, Barriers to Adoption, Enablers of Adoption and Regulatory Framework and the dependent variable which is Operational Efficiency in the Mining Sector. The main descriptive statistics captured include standard deviation, mean, and percentages. Results were presented in tables and graphs.

Circular Economy Practices

The study examined the extent to which circular economy (CE) practices particularly resource efficiency and material flow management—enhance operational efficiency in the mining sector of Taita Taveta County. Findings indicate moderate to strong adoption of CE initiatives, with an overall mean score of 3.95 (SD = 1.17). Systems for tracking material inputs and outputs recorded a mean of 3.59, suggesting uneven implementation, especially between large-scale and artisanal miners, consistent with evidence that technological and financial constraints limit uniform adoption (de Sá & Korinek, 2021; Makhathini et al., 2023).

Waste minimization practices showed strong uptake (mean = 4.16), reflecting active efforts in tailings management and by-product recovery, which are associated with cost savings and improved efficiency (OECD, 2021; Bwapwa & Mtsweni, 2023). Respondents acknowledged persistent barriers to efficient material flow (mean = 3.93), including infrastructure gaps and coordination challenges (Hilson & Maconachie, 2020).

High agreement on optimizing raw materials, energy, and water use (mean = 4.11) and on the cost and compliance benefits of resource efficiency (mean = 4.13) aligns with research linking CE practices to enhanced environmental and financial performance (Lèbre et al., 2020; Korhonen et al., 2021). Collaboration for resource sharing (mean = 4.02) further supports industrial symbiosis as a driver of sustainable mining value chains (Fraccascia & Yazan, 2020).

Table 2: Mean And Standard Deviation Of Circular Economy Practices

Indicators	Mean	S D
What systems are in place to track and manage the input and output of materials in mining operations in Taita Taveta?	3.59	1.30
How effectively do mining firms minimize material losses across their value chains?	4.16	0.78
What challenges hinder efficient material flow management among artisanal and large-scale miners?	3.93	1.15
What measures have been adopted by mining companies to optimize the use of raw materials, energy, and water?	4.11	1.13
How does resource efficiency affect production costs and environmental compliance in the mining sector?	4.13	1.09
What are the key drivers motivating mining enterprises in Taita Taveta to improve resource efficiency?	3.96	1.21
What forms of inter-industry collaboration exist to facilitate resource sharing or reuse in mining operations?	4.02	1.20
Average	**3.95**	**1.17**

Barriers to Adoption

The second objective of the study was to examine the technical, financial, and organizational constraints affecting the adoption of circular economy (CE) practices in the mining sector in Taita Taveta County. The study assessed technical, financial, and organizational barriers affecting Circular Economy (CE) adoption in the mining sector of Taita Taveta County. Results indicate that technical limitations significantly hinder implementation (mean = 3.89), particularly due to inadequate processing technologies, monitoring systems, and recycling infrastructure—challenges widely documented in developing mining regions (Lèbre et al., 2020; Caldera et al., 2022). Similarly, lack of appropriate technology constrains waste reduction and resource recovery (mean = 3.88), reinforcing evidence that technology gaps impede tailings reuse and material valorization (OECD, 2021; Korhonen et al., 2021).

Despite these constraints, respondents perceived relatively high technical expertise among operators (mean = 4.01), suggesting that knowledge exists but is limited by resource availability (Bocken et al., 2021). Financial barriers were more pronounced: high capital investment costs (mean = 4.15) and limited access to finance (mean = 4.04) restrict CE integration, especially for artisanal miners (Hilson & Maconachie, 2020).

Organizational factors also matter. Pro-sustainability culture (mean = 4.15), leadership commitment (mean = 4.01), and staff capacity influence adoption, while inadequate training and resistance to change (mean = 3.95) slow progress (Linnenluecke et al., 2020; Kirchherr et al., 2021). Overall, barriers remain substantial despite positive perceptions of CE profitability (OECD, 2021).

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Table 3: Mean and Standard Deviation Of Barriers to Adoption Indicators In Order Of Importance

Indicators	Mean	S D
What technical limitations hinder the implementation of circular economy practices in mining operations?	3.89	1.10
How does the lack of appropriate technology affect waste reduction and resource recovery in mining?	3.88	1.22
What is the level of technical expertise among mining operators regarding circular economy innovations?	4.01	1.11
How do capital investment costs affect the adoption of circular economy strategies in Taita Taveta's mining sector?	4.15	1.13
What financial constraints limit the ability of mining firms to integrate sustainable practices?	4.04	1.14
To what extent do mining companies perceive circular economy practices as financially viable or profitable?	4.06	1.09
How do internal organizational cultures influence the willingness to adopt circular business models?	4.15	1.03
What role do leadership and strategic alignment play in enabling or hindering CE adoption in mining?	4.01	1.12
How does inadequate staff training or change resistance impact CE integration in mining operations?	3.95	1.15
Average	**4.02**	**1.12**

Enablers of Adoption

The third objective of the study was to assess the institutional, governance, financial, and technological enablers supporting the adoption of circular economy (CE) practices in the mining sector in Taita Taveta County. Using a five-point Likert scale, the findings indicate strong agreement among respondents that institutional structures and governance systems support the adoption of circular economy practices, as reflected by a mean score of 4.08 and a relatively low standard deviation of 0.96, suggesting consistent perceptions across respondents. This finding aligns with contemporary studies which emphasize that clear regulatory frameworks, supportive governance mechanisms, and institutional coordination are critical enablers of circular economy transitions in extractive industries (Kirchherr et al., 2021; OECD, 2021).

Similarly, respondents agreed that partnerships with NGOs, cooperatives, and government bodies play a significant role in promoting CE integration (mean = 4.03), supporting existing literature that highlights multi-stakeholder collaboration as essential for capacity building, technology transfer, and the diffusion of sustainable mining practices, particularly in developing regions (Fraccascia & Yazan, 2020; Bansal et al., 2023). The study further revealed strong agreement that leadership commitment is central to driving CE adoption (mean = 4.11), reinforcing evidence that proactive leadership and strategic vision are necessary to embed circular principles into organizational culture and long-term planning (Masi et al., 2022; Kirchherr et al., 2021).

In addition, respondents acknowledged the availability of financial incentives and support schemes aimed at promoting CE adoption (mean = 4.17), indicating that policy-driven financial mechanisms such as grants, tax incentives, and development finance are increasingly influencing sustainability investments in the mining sector, a trend also observed in recent global studies (Caldera et al., 2022; OECD, 2021). Closely related to this, access to green financing and subsidies was perceived to significantly influence investment in circular technologies (mean = 4.16), supporting empirical evidence that access to affordable and sustainable financing reduces capital constraints and accelerates the adoption of cleaner and more resource-efficient technologies in mining operations (Korhonen et al., 2021; Zvarivadza & Nhleko, 2022).

While market pressures and cost-saving benefits were also acknowledged as motivators for CE adoption (mean = 3.92), the slightly lower mean suggests that regulatory and institutional drivers may be more influential than purely market-based incentives, a pattern consistent with studies showing that policy intervention often precedes market-led sustainability transitions in resource-intensive sectors (Lèbre et al., 2020; Bocken et al., 2021). The findings further indicate strong agreement regarding the availability of technologies that support resource efficiency and material recovery, which recorded the highest mean score of 4.26, reflecting growing access to processing innovations, recycling technologies, and waste recovery systems, as similarly reported in recent mining sustainability research (OECD, 2021; Makhathini et al., 2023).

Respondents also agreed that circular economy technologies are relatively accessible and affordable (mean = 4.11), although the higher standard deviation suggests variations across firm sizes, particularly between artisanal and large-scale mining operations, a disparity widely documented in the literature (Hilson & Maconachie, 2020; Caldera et al., 2022). Furthermore, the strong agreement on the role of digital innovation such as monitoring systems and automation in enabling CE practices (mean = 4.11) underscores the importance of digitalization in improving transparency, efficiency, and traceability of material flows, consistent with recent evidence highlighting digital technologies as key enablers of circular economy implementation in mining and other extractive industries (Linnenluecke et al., 2020; Korhonen et al., 2021).

Overall, the average mean score of 4.11 with a standard deviation of 1.07 suggests that institutional support, leadership commitment, financial incentives, and technological availability are perceived as strong enablers of circular economy adoption in the mining sector in Taita Taveta County, reinforcing global empirical evidence that effective governance, financing, and innovation ecosystems are essential for advancing circular economy transitions in resource-intensive industries (OECD, 2021; Kirchherr et al., 2021)..

Table 4: mean and standard deviation of Enablers of Adoption

Indicators	Mean	S D
What institutional structures or governance systems support the adoption of circular economy practices in the mining sector?	4.08	0.96
How do partnerships with NGOs, cooperatives, or government bodies promote CE integration in Taita Taveta?	4.03	1.03
What role does leadership commitment play in driving the adoption of CE practices in mining enterprises?	4.11	1.02
What financial incentives or support schemes are available to promote CE adoption in the mining sector?	4.17	0.96
How does access to green financing or subsidies influence investment in circular technologies?	4.16	1.02
To what extent do market pressures and cost-saving benefits motivate CE adoption in mining operations?	3.92	1.15
What types of technologies are available to support resource efficiency and material recovery in mining?	4.26	1.08
How accessible and affordable are circular economy technologies for mining enterprises in Taita Taveta?	4.11	1.24
What role does digital innovation (e.g., monitoring systems, automation) play in enabling CE practices?	4.11	1.17
Average	**4.11**	**1.07**

Regulatory Framework

The fourth objective of the study was to examine the influence of regulatory frameworks and legal provisions on the adoption of circular economy (CE) practices in the mining sector in Taita Taveta County. The findings indicate that respondents generally agreed that current mining laws in Kenya support the integration of circular economy practices, with a high mean score of 4.24 and a relatively low standard deviation of 0.73, suggesting a strong and consistent perception of legal support for sustainable mining operations. This is in line with recent studies emphasizing that robust legislation and supportive regulatory frameworks are critical enablers of circular economy transitions in extractive industries, providing clear guidance for waste reduction, resource efficiency, and environmental protection (OECD, 2021; Kirchherr et al., 2021).

Respondents further indicated moderate familiarity with national and county-level mining regulations promoting sustainability (mean = 3.84), which reflects that while legal awareness exists among stakeholders, knowledge gaps may limit full compliance and effective CE implementation, a challenge similarly reported in contemporary studies on regulatory literacy and sustainable mining practices in developing regions (Hilson & Maconachie, 2020; Bansal et al., 2023). In terms of legal gaps, respondents agreed that existing mining legislation contains gaps that hinder CE implementation (mean = 4.18), supporting evidence that incomplete or outdated legal provisions can obstruct circular economy adoption by failing to mandate waste recovery, recycling, and sustainable resource management (Caldera et al., 2022; Fraccascia & Yazan, 2020).

Respondents also reported that current compliance and enforcement mechanisms moderately encourage CE adoption (mean = 4.06), reflecting the importance of regulatory oversight, inspections, and penalties in motivating sustainable operational behavior, consistent with recent studies showing that strong enforcement correlates with higher adoption rates of eco-friendly practices (Korhonen et al., 2021; Masi et al., 2022). Moreover, mining firms were observed to face challenges in meeting regulatory compliance related to resource efficiency and waste reduction (mean = 4.12), highlighting persistent barriers such as limited monitoring capacity, high compliance costs, and technical constraints, a situation also noted in studies of environmental governance in mining sectors across Africa (OECD, 2021; Hilson & Maconachie, 2020).

Respondents further acknowledged that regulatory monitoring strongly influences operational behaviors toward circularity (mean = 4.15), reinforcing literature that emphasizes the role of inspections, reporting requirements, and ongoing oversight in shaping firm practices (Lèbre et al., 2020; Kirchherr et al., 2021). Additionally, environmental regulations were found to shape the adoption of eco-friendly practices (mean = 4.09), while environmental impact assessment (EIA) requirements were recognized as promoting CE principles, albeit with slightly lower agreement (mean = 3.87), reflecting variability in compliance awareness and the effectiveness of environmental assessments in enforcing circular practices (Zvarivadza & Nhleko, 2022; Caldera et al., 2022). Finally, respondents agreed that regulatory support for pollution control and land rehabilitation enhances CE integration (mean = 4.09), consistent with global evidence showing that legal incentives and obligations for environmental stewardship encourage firms to adopt resource-efficient, low-impact practices (Korhonen et al., 2021; Bocken et al., 2021). Overall, the average mean of 4.07 with a standard deviation of 0.99 suggests that regulatory frameworks in Kenya are generally perceived as supportive of circular economy adoption, but awareness gaps, enforcement challenges, and legal limitations remain critical factors influencing the effectiveness of CE integration in the mining sector.

Table 5: Percentages, mean and standard deviation of Regulatory Framework

Indicators	Mean	S D
To what extent do current mining laws in Kenya support the integration of circular economy practices?	4.24	0.73
How familiar are mining stakeholders in Taita Taveta with national and county-level mining regulations that promote sustainability?	3.84	1.13
What legal gaps exist in current mining legislation that hinder circular economy implementation?	4.18	0.93
How effective are current compliance and enforcement mechanisms in encouraging CE adoption in mining?	4.06	1.06
What challenges do mining enterprises face in meeting regulatory compliance related to resource efficiency and waste reduction?	4.12	0.97
How does the level of regulatory monitoring influence operational behaviors of mining firms toward circularity?	4.15	0.95
How do environmental regulations shape the adoption of eco-friendly mining practices in Taita Taveta?	4.09	1.02
What role do environmental impact assessment (EIA) requirements play in promoting CE principles?	3.87	1.11
How does regulatory support for pollution control and land rehabilitation affect CE integration in the mining sector	4.09	1.03
Average	**4.07**	**0.99**

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Operational Efficiency in the Mining Sector

The dependent variable of the study was to assess the effects of circular economy practices on operational efficiency in mining firms in Taita Taveta County. The findings indicate that respondents generally agreed that mining enterprises utilize raw materials, water, and energy efficiently, with a mean score of 4.14 and a standard deviation of 0.80, suggesting high consistency in perceptions regarding resource management. This observation aligns with global studies emphasizing that effective input management is a key determinant of operational efficiency and sustainability in extractive industries (Korhonen et al., 2021; Caldera et al., 2022).

Respondents further indicated strong agreement on strategies employed to minimize resource input while maximizing output (mean = 4.25, SD = 0.69), reflecting the adoption of measures such as process optimization, energy-saving technologies, and water recycling, which are recognized as essential circular economy practices that enhance operational performance (OECD, 2021; Lèbre et al., 2020). Improved resource efficiency was also perceived to contribute to environmental and operational sustainability (mean = 3.86, SD = 1.09), supporting literature showing that reducing waste, conserving resources, and streamlining processes enhances both profitability and compliance with environmental regulations (Bocken et al., 2021; Springer, 2025).

Internal process improvements implemented by mining enterprises to enhance productivity were also acknowledged (mean = 4.03, SD = 1.17), suggesting that CE adoption promotes workflow optimization and operational consistency, as reported in studies on process innovation in resource-intensive industries (Makhathini et al., 2023; Fraccascia & Yazan, 2020). However, perceptions regarding the influence of CE practices on the speed, quality, and consistency of mining processes were moderately lower (mean = 3.50, SD = 0.96), indicating that while circular practices support efficiency, some operational challenges remain, particularly in integrating CE into production scheduling and quality assurance systems (Caldera et al., 2022; Hilson & Maconachie, 2020).

Process bottlenecks were highlighted as a significant constraint (mean = 2.39, SD = 1.33), reflecting difficulties in addressing legacy inefficiencies, equipment limitations, and workflow disruptions despite CE interventions, which is consistent with evidence from artisanal and small-scale mining contexts (OECD, 2021; Zvarivadza & Nhleko, 2022). On a positive note, the adoption of circular economy principles was reported to reduce operational costs (mean = 4.41, SD = 0.98), corroborating research indicating that recycling, reuse, and resource optimization generate tangible financial benefits and improve cost-efficiency (Korhonen et al., 2021; Bocken et al., 2021).

Nevertheless, cost-saving measures and improvements in financial performance and profitability showed mixed results, with mean scores of 3.10 (SD = 1.35) and 2.86 (SD = 1.57), respectively, suggesting that while CE practices contribute to operational efficiency, their impact on financial outcomes may be uneven across firms due to variations in scale, technology adoption, and capital availability (Fraccascia & Yazan, 2020; Hilson & Maconachie, 2020). Overall, the average mean score of 3.62 with a standard deviation of 1.10 indicates that respondents perceive circular economy practices as moderately effective in enhancing operational efficiency, highlighting both the benefits of CE adoption in resource utilization and process optimization, as well as the challenges that need to be addressed to fully realize financial and performance gains in the mining sector.

Table 6: Percentages, mean and standard deviation on measures of Operational Efficiency in the Mining Sector

Indicators	Mean	S D
How efficiently do mining firms in Taita Taveta utilize raw materials, water, and energy?	4.14	0.80
What strategies are employed to minimize resource input while maximizing output in mining operations?	4.25	0.69
How does improved resource efficiency contribute to environmental and operational sustainability?	3.86	1.09
What internal process improvements have mining enterprises implemented to enhance productivity?	4.03	1.17
How do circular economy practices influence the speed, quality, and consistency of mining processes?	3.50	0.96
What process bottlenecks exist, and how have CE practices addressed them in Taita Taveta's mining sector?	2.39	1.33
How does the adoption of circular economy principles impact operational costs in the mining industry?	4.41	0.98
What cost-saving measures have resulted from circular practices such as recycling or reuse?	3.10	1.35
To what extent has CE adoption improved the financial performance and profitability of mining operations?	2.86	1.57
Average	**3.62**	**1.10**

Inferential Statistics

Correlation and regression analysis are statistical methods used to examine the relationship between variables. Correlation measures the strength and direction of a linear association (via coefficient while regression quantified this relationship by creating an equation to predict the dependent variable based on one or more independent variables. The amount of dependent variable variation attributed to the behaviour of the independent variables was determined by computing a model summary.

Correlation Analysis

Correlation analysis was used to determine both the significance and degree of association and direction of the study variables. The Pearson correlation coefficient was used to determine the association between the variables which is denoted by **r**. Correlation coefficients (**r**) range from -1 to 1. A *0* signifies that the factor is not associated to one another, but a value of ±*1* indicates a strong positive relation, that the two parameters are in perfect association. The link between the two variables will get weaker, as the value of the **r** goes to *0*. A + sign indicates a strong positive relationship and a – sign shows a strong negative link. The direction of the association is represented by the sign of the **r**. (Creswell, 2017).

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Table 7: Correlation Matrix

Correlations		Operational Efficiency	Circular Economy Practices	Barriers to Adoption	Enablers of Adoption	Regulatory Framework
Operational Efficiency	Pearson Correlation	1				
	Sig. (2-tailed)					
Circular Economy Practices	Pearson Correlation	.651**	1			
	Sig. (2-tailed)	0.000				
Barriers to Adoption	Pearson Correlation	.680**	.532**	1		
	Sig. (2-tailed)	0.003	0.009			
Enablers of Adoption	Pearson Correlation	.612**	.360**	.444**	1	
	Sig. (2-tailed)	0.021	0.001	0.000		
Regulatory Framework	Pearson Correlation	.678**	.393**	.457**	.506**	1
	Sig. (2-tailed)	0.000	0.001	0.001	0.000	

** Correlation is significant at the 0.01 level (2-tailed)

Regression Statistics

The regression results indicate a strong positive relationship between the independent variables and the dependent variable ($R = 0.858$). The coefficient of determination ($R^2 = 0.735$) shows that 73.5% of the variation in the dependent variable is explained jointly by barriers to adoption, circular economy practices, enablers of adoption, and the regulatory framework. The adjusted R^2 of 0.729 confirms that the model retains substantial explanatory power after accounting for the number of predictors. The standard error of the estimate (0.223) suggests a relatively small prediction error. The Durbin–Watson statistic (1.959) indicates no serious autocorrelation problem.

Table 8: Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
.858a	0.735	0.729	0.223	1.959
Predictors: (Constant), Barriers to Adoption, Circular Economy Practices, Enablers of Adoption ,Regulatory Framework				

Table 8 states that the null hypothesis of no serial correlation between residual terms is accepted given that the Durbin Watson statistic was 1.959 and within the acceptable range of 1.5 and 2.5. Therefore, there is no 1st order correlation between residual terms..

Regression Coefficients of the Study Variables

This regression equation model was used to fit the regression coefficient.

$$Y= \beta 0+ \beta_1X_1+\beta_2X_2+ \beta_3X_3+ \beta_4X_4+ \varepsilon.$$

Where, Y= Operational Efficiency in the Mining Sector, β_0= constant (coefficient of intercept), X_1= Barriers to Adoption s; X_2= Circular Economy Practices; X_3= Enablers of Adoption ; X_4= Regulatory Framework ; ε = error term.

From the findings presented below, the following regression equation was fitted;

Multiple regressions

$Y= 1.347 + 0.347 X_1 + 0.196 X_2 + 0.338 X_3 + 0.279 X_4$......................................v

Observing the equations, it can be noted that when all the other variables (Barriers to Adoption, Circular Economy Practices, Enablers of Adoption and Regulatory Framework) remain at constant zero, a constant value of 1.347 was held by the Performance of listed Mining Sector.

The regression results show that Barriers to Adoption had the largest standardized effect on operational efficiency ($\beta = 0.347$, $p = 0.001$), suggesting that effectively identifying and mitigating adoption barriers significantly enhances operational performance. This finding is consistent with recent studies highlighting that overcoming technological, financial, and organizational obstacles is critical for successful implementation of sustainable and circular practices in mining and extractive industries (Caldera et al., 2022; Makhathini et al., 2023).

Regulatory Frameworks also significantly influenced operational efficiency ($\beta = 0.338$, $p = 0.018$), indicating that supportive policies, enforcement mechanisms, and incentives drive resource efficiency, compliance, and improved production outcomes. This aligns with prior research asserting that well-structured regulations create an enabling environment for sustainable practices and operational excellence in resource-intensive sectors (Prieto-Sandoval et al., 2021; Zvarivadza & Nhleko, 2022).

The study further found that Enablers of Adoption positively impacted operational efficiency ($\beta = 0.279$, $p = 0.013$), reflecting the importance of leadership commitment, staff training, access to technology, and organizational support in facilitating circular economy initiatives. These findings corroborate the view that internal enablers are crucial determinants of operational success, as organizations with well-developed capabilities are more likely to implement effective and sustainable resource management strategies (Lèbre et al., 2020; Bocken et al., 2021).

Finally, Circular Economy Practices themselves were also significant predictors of operational efficiency ($\beta = 0.196$, $p = 0.041$), confirming that adoption of circular strategies such as recycling, reuse, and process optimization contributes directly to enhanced performance, reduced operational costs, and improved environmental outcomes. This result echoes contemporary literature emphasizing the operational and strategic benefits of circular economy integration in mining and manufacturing industries (Geissdoerfer et al., 2022; Prieto-Sandoval et al., 2021).

Table 9: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.347	0.258		5.221	.000
	Barriers to Adoption	0.347	0.103	0.439	3.369	.001
	Circular Economy Practices	0.196	0.077	0.226	2.545	.041
	Enablers of Adoption	0.338	0.138	0.402	2.449	.018
	Regulatory Framework	0.279	0.108	0.327	2.583	.013

a. Dependent Variable: Operational Efficiency in the Mining Sector

CONLUSION AND RECOMMENDATIONS

Based on the findings, the study concludes that effective adoption enablers, supportive regulatory frameworks, management of adoption barriers, and implementation of circular economy practices are critical determinants of operational efficiency in the mining sector in Kenya. Strategic leadership plays a pivotal role in aligning organizational systems, structures, and processes with strategic objectives to enhance efficiency. The study further concludes that leadership is central to integrating various organizational components, fostering unity of purpose, and ensuring effective strategy implementation. Additionally, compliance-oriented and inclusive regulatory frameworks, when well implemented, contribute significantly to improved operational performance. Overall, the study establishes that operational efficiency in the mining sector is achieved through a combination of strong leadership, effective regulation, innovation adoption, and sustainable operational practices.

Based on the study findings and conclusions, several recommendations are proposed. First, mining firms should allocate adequate financial, human, and technological resources to support the adoption of innovative and sustainable practices. Timely release and efficient utilization of resources are essential for ensuring smooth operational processes. Second, organizations should strengthen ethical standards and embed sustainability principles within their organizational culture to enhance stakeholder trust and long-term performance. Third, policymakers and regulators should review and strengthen regulatory frameworks to ensure they are supportive, inclusive, and responsive to industry dynamics. Finally, mining sector leaders should invest in capacity building and change management initiatives to address barriers to adoption and enhance operational efficiency.

Suggestions for Further Research

The study was limited to the mining sector in Kenya; therefore, future research should replicate the study in other sectors such as manufacturing, energy, and other service industries to establish comparable trends. Further studies may also adopt alternative research designs, including experimental, causal, or longitudinal approaches, to deepen understanding of the relationships examined. Additionally, future research should explore the impact of digital transformation on operational efficiency and leadership practices within the mining sector. Finally, there is a need for further studies on the role of stakeholder engagement, including regulators, communities, and customers, in enhancing operational efficiency and sustainable performance in the mining sector.

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