

Review

# Small-scale gold mining: Bottlenecks and structural impediments for realising the SDGs

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**Abstract:** The profound tension between immediate economic survival and long-term ecological preservation defines the complex sustainability landscape of small-scale gold mining in North Central Nigeria. This study interrogates the critical bottlenecks and structural impediments hindering the sector's transition from a small-scale survivalist activity into a robust driver of the United Nations 2030 Agenda for Sustainable Development. By analysing contemporary field practices and localized contextual factors embedded within this ancient socio-cultural activity, the research unpacks the multifaceted barriers to sustainability across economic constraints, social dynamics, and environmental degradation. Utilizing a rigorous, "deep-dive systematic methodology," an initial database of 197,391 articles was screened through a systematic funnelling process and targeted manual selection. This interdisciplinary analysis synthesizes the "three-pillar constraints" that obstruct the meaningful integration of the Sustainable Development Goals within the Nigerian small-scale gold mining sector. The findings offer actionable, evidence-based insights for policymakers, industry stakeholders, and local communities, emphasizing the necessity of tailored regulatory frameworks and collaborative governance models. Ultimately, this research bridges the gap between global sustainability targets and regional survivalist realities. It concludes by developing an original conceptual matrix of Parameters Recommended for Policy Optimisation, providing a strategic blueprint to dismantle structural barriers and advance sustainable development outcomes.

**Keywords:** Gold; mining; gold mining; sustainable gold mining; small-scale gold mining; artisanal gold mining; sustainable development goals; SDGs; Nigeria

## 1. Introduction

In North Central Nigeria, small-scale gold mining plays a crucial role in local economies, providing livelihoods for thousands (Ananeh-Frempong, 2021; Mimba et al., 2023; Ogan et al., 2016), and serving as a vital income source in rural communities (Ananeh-Frempong, 2021; Hevi et al., 2025; Ogan et al., 2016). The region's rich mineral resources have led to a rise in informal mining activities, primarily driven by economic necessity, weak livelihood alternatives, and broader structural inequalities within rural economies (Achina-Obeng & Aram, 2022; Hilson, 2020; Ogan et al., 2024). However, despite its economic significance, small-scale gold mining is often linked to substantial environmental

degradation (Antwi-Boateng & Akudugu, 2021; Arthur-Holmes & Busia, 2020; Cheng, Y. et al., 2023), including deforestation, water pollution, and land erosion (Borgatti, 2023; Buss & Rutherford, 2020), as well as social challenges such as unsafe working conditions with mine collapse (as shown in Fig. 1), labour vulnerabilities, and conflicts over resources (Abubakar, 2024; Antwi-Boateng & Akudugu, 2021; Buss & Rutherford, 2020). This is because developing a gold mining project requires defining the deposit's structure, its depth, and geometry, to guide extraction. However, disrupting these geological formations triggers natural hazards, causing catastrophic pit collapses or cave-ins, while fracturing mineralized rock exposes sulphides, generating toxic acid mine drainage that severely pollutes regional water systems (Skrzypkowski et al., 2023).



**Fig. 1.** Collapsed Gold Mine in North Central Nigeria (Source: BBC, Abubakar, 2024).

Intriguingly, while international attention increasingly shifts toward sustainable development, integrating sustainability practices into small-scale gold mining in North Central Nigeria becomes imperative (Ananeh-Frempong, 2021; De Pascale et al., 2023; Edegbene, 2023). The United Nations Sustainable Development Goals (SDGs) provide a framework for addressing global challenges, including poverty, inequality, and environmental degradation. Mining activities in North Central Nigeria intersect with several SDGs, particularly SDG 8, SDG 12, and SDG 13, reflecting the sector's dual role in economic development and environmental pressure (De Pascale et al., 2023; Edegbene, 2023; Erdiaw-Kwasie et al., 2024; IGF, 2025) (See Table 1). However, achieving these goals within the context of small-scale gold mining remains complex due to systemic challenges (Erdiaw-Kwasie et al., 2024; Garinas, 2023), including limited access to capital, weak institutional frameworks, and technological barriers that hinder the adoption of environmentally sustainable practices (Gorain et al., 2025; IGF, 2025; Kohio et al., 2024).

The research problem centres on the structural barriers to sustainability faced by small-scale gold mining in North Central Nigeria. Economic constraints, including limited access to finance, technology, and formal markets, restrict productivity and innovation (Garinas, 2023; Gorain et al., 2025; Kohio et al., 2024). Social challenges such as weak regulatory enforcement, inadequate labour protections, and the criminalisation–livelihood paradox observed in ASM contexts further complicate sustainability transitions (Dery Tuokuu et al., 2020; Devi et al., 2025; Koomson, 2018). These issues are reinforced by deeply embedded institutional inefficiencies, where governance systems shape risk exposure rather than merely regulating it (Krisnayanti, 2018; Levett et al., 2021; Malima, 2021). Environmental impacts, including mercury pollution, ecosystem degradation, and long-term

contamination of soils and water systems, further underscore the urgency for sustainable interventions (Cheng et al., 2023; Martinez et al., 2023; Mimba et al., 2023; Nkuba et al., 2022; North, 1990; Ogan et al., 2016).

Despite the sector's significance, a considerable knowledge gap exists regarding effective strategies for promoting sustainability in small-scale gold mining in North Central Nigeria. Much of the existing research focuses on large-scale mining or different geographical contexts, leaving the socio-technical dynamics of this region underexplored (Ananeh-Frempong, 2021; Achina-Obeng & Aram, 2022; Hilson, 2020). This study aims to address this gap by investigating the limitations and challenges of implementing sustainability practices in small-scale gold mining in North Central Nigeria and their alignment with global sustainability frameworks.

The relevance of small-scale gold mining to the SDGs is significant, offering insights into the intersection of economic development, social equity, and environmental sustainability. The sector's informal nature highlights the necessity for innovative, context-specific solutions that integrate governance reform, technological innovation, and community engagement, supported by global responsible sourcing and due diligence frameworks (OECD, 2016; Ondayo et al., 2024; Sonter et al., 2025; Sovacool et al., 2020). Integrating sustainability practices in this region could lead to improved livelihoods, reduced environmental degradation, and enhanced community resilience (as shown in Table 2). For instance, adopting cleaner technologies, improving access to finance, and strengthening institutional coordination could transform small-scale mining into a driver of sustainable development (Steckling et al., 2017; Tichauer et al., 2020; Tun et al., 2020). Realising these opportunities requires a comprehensive understanding of systemic barriers within the broader decarbonisation–resource extraction paradox shaping global mineral demand (UNEP, 2024; Villanueva Ubillús & Vila Benites, 2023; World Bank, 2022).

**Table 1.** Core Research Problems.

Review Categories Considered	Details & Key Information
Primary Goal	Integrating sustainability practices into small-scale gold mining to meet global development standards.
Framework Used	UN Sustainable Development Goals (SDGs), specifically: <ul style="list-style-type: none"> <li>• <b>SDG 8:</b> Decent Work and Economic Growth</li> <li>• <b>SDG 12:</b> Responsible Consumption and Production</li> <li>• <b>SDG 13:</b> Climate Action</li> </ul>
Economic Barriers	<ul style="list-style-type: none"> <li>○ Limited access to capital and technology.</li> <li>○ Exclusion from formal markets.</li> <li>○ Resource constraints are hindering eco-friendly adoption.</li> </ul>
Social Challenges	<ul style="list-style-type: none"> <li>○ Weak enforcement of regulations.</li> <li>○ Inadequate protection for labour.</li> <li>○ Complex cultural dynamics.</li> </ul>
Environmental Impacts	<ul style="list-style-type: none"> <li>○ Mercury pollution.</li> <li>○ Deforestation.</li> <li>○ Soil degradation</li> </ul>

Summary Note: The core research problem highlights a complex intersection where economic and social systemic challenges prevent miners from transitioning toward environmentally sustainable interventions, despite the urgency of the ecological damage.

**Table 2.** Initial categories and roadmap for exploring SSGM’s sustainable development challenges.

Review Categories Considered	Details & Key Information
The Knowledge Gap	Most research is focused on large-scale mining and on different geographical regions, leaving the specific dynamics of North Central Nigeria underexplored.
Primary Objectives	<ul style="list-style-type: none"> <li>○ Investigate limitations/challenges of implementing sustainability.</li> <li>○ Evaluate alignment with Sustainable Development Goals (SDGs).</li> <li>○ Provide nuanced insights for a more equitable mining future.</li> </ul>
Sectoral Characteristics	High degree of informality and heavy reliance on local labour, requiring context-specific investigations, rather than “one-size-fits-all” solutions.
Proposed Interventions	<ul style="list-style-type: none"> <li>○ Technological: Adoption of cleaner mining technologies.</li> <li>○ Financial: Improved access to formal finance.</li> <li>○ Social: Involving local communities in the decision-making process.</li> </ul>
Expected Outcomes	<ul style="list-style-type: none"> <li>○ Improved local livelihoods.</li> <li>○ Reduced environmental degradation.</li> <li>○ Enhanced community resilience.</li> </ul>
Proposed Requirement for Possible Solutions	A comprehensive understanding of local barriers and a commitment to tailored strategies that reflect regional realities

Summary Note: The table highlights initial findings that signal that transforming small-scale mining into a driver for sustainable development is possible but hinges on moving away from generic models. Success requires bridging the gap between local informal practices and global SDG targets through innovation and community inclusion.

The relevance of small-scale gold mining to the SDGs is significant, offering insights into the intersection of economic development, social equity, and environmental sustainability. The sector's informal nature highlights the necessity for innovative, context-specific solutions that integrate governance reform, technological innovation, and community engagement, supported by global responsible sourcing and due diligence frameworks (OECD, 2016; Ondayo et al., 2024; Sonter et al., 2025; Sovacool et al., 2020). Integrating sustainability practices in this region could lead to improved livelihoods, reduced environmental degradation, and enhanced community resilience (as shown in Table 2). For instance, adopting cleaner technologies, improving access to finance, and strengthening institutional coordination could transform small-scale mining into a driver of sustainable development (Steckling et al., 2017; Tichauer et al., 2020; Tun et al., 2020). Realising these opportunities requires a comprehensive understanding of systemic barriers within the broader decarbonisation–resource extraction paradox shaping global mineral demand (UNEP, 2024; Villanueva Ubillús & Vila Benites, 2023; World Bank, 2022).

## 2. Literature review

### 2.1 Sustainability practices in small-scale gold mining

Sustainability in small-scale gold mining is a multifaceted issue that necessitates a balance between economic benefits, social equity, and environmental stewardship. In regions such as North Central Nigeria, small-scale gold mining predominantly occurs in informal settings, complicating the implementation of sustainable practices (see Table 3). The informal nature of these operations often leads to weak regulatory oversight and limited institutional capacity, which exacerbate the challenges associated with adopting sustainable methods (Cheng et al., 2023; Ogan et al., 2016; Sonter et al., 2025).

A pivotal sustainability practice involves the adoption of cleaner production technologies, as earlier mentioned, including gravity concentration and anti-cyanidation processing, which aim to minimise the use of hazardous substances such as mercury. Mercury use in gold extraction is particularly concerning due to its significant health risks and environmental contamination. Global initiatives, including the Minamata Convention, promote mercury-free technologies; however, their adoption is frequently constrained by high costs and limited technical expertise among miners (Borgatti, 2023; Buss & Rutherford, 2020; Steckling et al., 2017). Empirical studies indicate that artisanal and small-scale gold mining contributes substantially to global mercury emissions, with estimates suggesting that approximately 1000 tonnes of mercury are released annually due to inefficient mining practices (Abubakar, 2024; Sovacool et al., 2020; Tichauer et al., 2020). Furthermore, blasting operations severely alter the local terrain through mass land excavation and slope destabilization, and if unchecked, continuous explosive detonations can induce artificial seismic waves, fracturing surrounding rock strata and triggering localized ground vibrations that threaten structural stability (Skrzykowski et al., 2023).

Reclamation and rehabilitation of mined areas are

essential for mitigating environmental degradation. Effective restoration practices, such as reforestation and improved waste management, can help restore ecosystems affected by mining activities. However, weak regulatory frameworks, inadequate enforcement, and limited financial resources often result in minimal implementation of these practices in small-scale operations (De Pascale et al., 2023; UNEP, 2024; Villanueva Ubillús & Vila Benites, 2023).

Social sustainability practices, including community engagement and equitable distribution of mining benefits, are equally critical. Women play significant roles in artisanal mining economies but face structural barriers that limit their participation and access to resources. Addressing these inequalities through targeted training and inclusive policies can enhance social sustainability outcomes (Edegbene, 2023; Erdiaw-Kwasie et al., 2024; Koomson, 2018).

Health and safety measures are vital for improving working conditions in small-scale mining. Many miners operate in hazardous environments with limited access to protective equipment and healthcare services. Strengthening occupational safety standards and promoting health awareness can significantly improve miners' well-being and reduce exposure to risks (Garinas, 2023; Gorain et al., 2025; Steckling et al., 2017).

Despite the recognised importance of these sustainability practices, their implementation remains inconsistent due to financial constraints, limited education, technological barriers, and weak governance structures. These challenges highlight that sustainability risks in small-scale mining are structurally embedded rather than purely behavioural, requiring integrated institutional and technological interventions (Gorain et al., 2025; Kohio et al., 2024; World Bank, 2022).

### 2.2 Economic, social, and environmental dimensions

The sustainability of small-scale gold mining is influenced by three interconnected dimensions: economic viability, social equity, and environmental protection. These dimensions are deeply interdependent and often overlap, creating complex challenges for achieving sustainable outcomes in the sector (Koomson, 2018; Martinez et al., 2023; Tichauer et al., 2020).

#### 2.2.1 Economic dimensions

Small-scale gold mining provides substantial economic benefits, particularly in rural areas where alternative livelihoods are limited. In North Central Nigeria, mining serves as a primary income source for many households, contributing to poverty alleviation and local economic resilience (Hevi et al., 2025; OECD, 2016; World Gold Council, 2026). However, these benefits are frequently undermined by unstable gold prices, limited access to credit, and exploitative informal trading networks (Devi et al., 2025; Mimba et al., 2023; World Bank, 2022). The informality of the sector restricts miners' access to financial systems and modern technologies, perpetuating reliance on inefficient and environmentally harmful practices (Achina-Obeng & Aram, 2022; OECD, 2016; World Bank, 2022).

**Table 3.** Comparison of Sustainability Dimensions in Small-Scale Gold Mining.

Dimension	Key Benefits & Roles	Primary Challenges & Risks	Barriers to Sustainability
<b>Economic</b>	Primary income for rural families.	Unstable gold prices.	Limited access to credit.
	Vital for poverty alleviation. Source of local livelihoods.	Exploitative informal trading networks. Financial instability.	Sector informality is preventing investment in clean tech.
<b>Social</b>	<ul style="list-style-type: none"> <li>• Potential for community empowerment.</li> </ul>	<ul style="list-style-type: none"> <li>• Community displacement &amp; land disputes.</li> </ul>	<ul style="list-style-type: none"> <li>• Unclear land tenure systems.</li> </ul>
	<ul style="list-style-type: none"> <li>○ • Labor-intensive (high employment).</li> </ul>	<ul style="list-style-type: none"> <li>• Health hazards (mercury exposure).</li> <li>○ • Gender inequality in resource ownership.</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of education and safety training.</li> </ul>
<b>Environmental</b>	• Potential for land restoration (if managed).	<ul style="list-style-type: none"> <li>• Deforestation and soil erosion.</li> <li>• Severe water pollution.</li> <li>• Threats to aquatic ecosystems.</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of waste management systems.</li> <li>• Financial inability to adopt mercury-free tech.</li> </ul>
	<ul style="list-style-type: none"> <li>○ Potential for improved life expectancy and community well-being.</li> </ul>	<ul style="list-style-type: none"> <li>○ <i>Acute &amp; Chronic Risks:</i> Mercury poisoning, respiratory issues, and physical injuries.</li> </ul>	<ul style="list-style-type: none"> <li>• Climate change impacts. <i>Knowledge Gap:</i> Lack of PPE (Personal Protective Equipment) and awareness of toxin bioaccumulation.</li> </ul>

**2.2.2 Social dimensions**

The social impacts of small-scale gold mining are significant and often complex, including community displacement, land conflicts, and social tensions. These challenges are frequently linked to unclear land tenure systems and competition for natural resources between mining groups and local communities (Dery Tuokuu et al., 2020; Devi et al., 2025; North, 1990). Health risks associated with prolonged exposure to mercury and other pollutants pose severe threats to miners and surrounding populations (Nkuba et al., 2022; Steckling et al., 2017; Sovacool et al., 2020).

Additionally, limited access to education and training constrains miners’ ability to adopt safer and more sustainable practices (Dery Tuokuu et al., 2020; Sonter et al., 2025; World Bank, 2022). Gender inequality is also prevalent, with women facing barriers to participation, resource access, and decision-making processes. Addressing these disparities is critical for achieving social sustainability and inclusive development outcomes (Edegbene, 2023; Koomson, 2018; Nkuba et al., 2022).

**2.2.3 Environmental dimensions**

Environmental degradation remains one of the most significant consequences of small-scale gold mining. Common issues include deforestation, soil erosion, and water pollution, all of which are intensified by the absence of effective environmental management systems (Biwa, 2020; UNEP, 2024; Villanueva Ubillús & Vila Benites, 2023). In North Central Nigeria, mining activities often

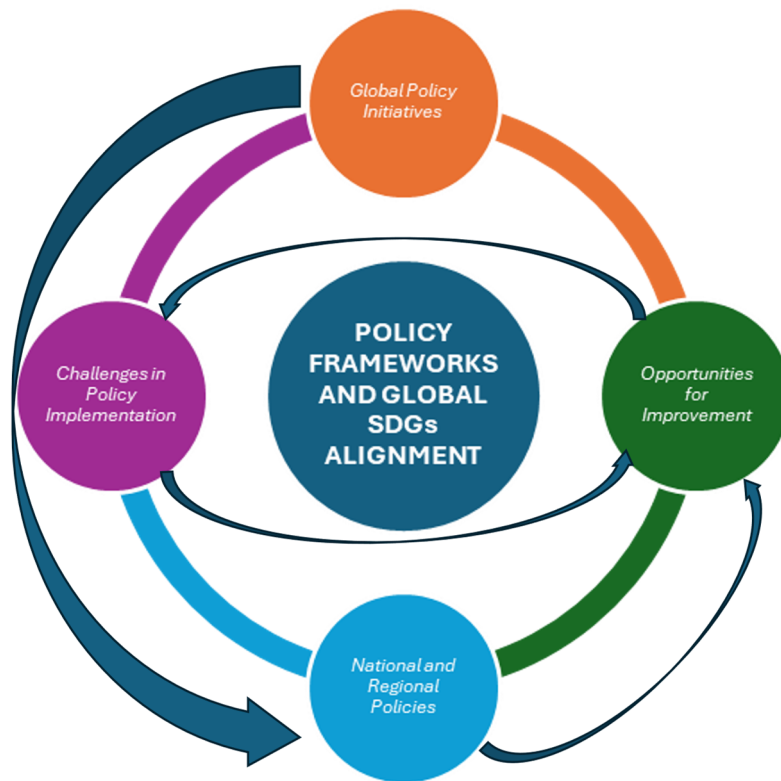
lack proper waste disposal mechanisms, resulting in severe mercury contamination that threatens ecosystems and human health (Levett et al., 2021; Malima, 2021; Steckling et al., 2017).

Efforts to mitigate these impacts include the promotion of mercury-free technologies and improved waste management practices; however, these interventions are often constrained by limited awareness, financial capacity, and institutional support (Borgatti, 2023; Tichauer et al., 2020; World Bank, 2022). Climate variability further exacerbates these challenges, increasing vulnerability to land degradation and resource scarcity.

The integration of economic, social, and environmental dimensions is therefore essential for achieving sustainable small-scale gold mining. This requires coordinated efforts among stakeholders, including miners, policymakers, and local communities.

**2.3 Policy frameworks and global SDGs alignment**

Policy frameworks play a central role in shaping the sustainability of small-scale gold mining (as shown in Fig. 2). However, in North Central Nigeria, regulatory systems are often weak or inconsistently enforced, leading to widespread informality and limited oversight (Sonter et al., 2025; OECD, 2016; United Nations Environment Programme [UNEP], 2024). Strengthening these frameworks is essential for promoting sustainable practices and aligning the sector with global Sustainable Development Goals (SDGs).



**Fig. 2.** Linkages for Policy Frameworks, Challenges & Opportunities (source: Author).

### 2.3.1 Global policy initiatives

International initiatives such as the Minamata Convention on Mercury and the Extractive Industries Transparency Initiative (EITI) have established important benchmarks for sustainability in mining. These frameworks promote environmental protection, transparency, and accountability in resource governance (as shown in Fig. 2). However, their effectiveness in regions such as North Central Nigeria is often limited by weak local implementation mechanisms and insufficient institutional capacity (UNEP, 2024; Villanueva Ubillús & Vila Benites, 2023; World Bank, 2022).

### 2.3.2 National and regional policies

Nigeria’s mining policies emphasise formalisation and sustainable resource management. However, enforcement remains a challenge, as many small-scale mining operations continue to function informally. Additionally, policy frameworks often lack provisions for financial and technical support, limiting miners’ ability to adopt sustainable practices (Ananeh-Frempong, 2021; Sonter et al., 2025; OECD, 2016).

Aligning small-scale gold mining with SDGs requires targeted interventions, including formalisation, improved access to finance, and the promotion of cleaner technologies (Antwi-Boateng & Akudugu, 2021; Tichauer et al., 2020; UNEP, 2024).

### 2.3.3 Challenges in policy implementation

Policy implementation in North Central Nigeria faces several challenges, including informality, low awareness of regulatory requirements, and governance inefficiencies. Corruption and bureaucratic barriers further weaken enforcement efforts, limiting the effectiveness of

sustainability policies (Dery Tuokuu et al., 2020; Ondayo et al., 2024; World Bank, 2022).

Another critical issue is the limited participation of local communities in policy development. Policies that fail to incorporate local perspectives often face resistance, reducing their effectiveness and sustainability (Koomson, 2018; Sonter et al., 2025; World Gold Council, 2026).

### 2.2.4 Opportunities for improvement

Despite these challenges, opportunities exist to strengthen policy frameworks and improve sustainability outcomes. Providing technical training and financial support can facilitate the adoption of cleaner technologies and safer practices. Public-private partnerships can enhance innovation, improve market access, and strengthen institutional capacity (North, 1990; Ogan et al., 2024; Tichauer et al., 2020).

Increasing transparency and accountability within the sector can build trust among stakeholders and ensure that mining revenues contribute to community development. Collaborative approaches involving government agencies, NGOs, and local communities are essential for overcoming systemic barriers and promoting sustainable small-scale gold mining (OECD, 2016; UNEP, 2024; Villanueva Ubillús & Vila Benites, 2023).

## 3. Methods

The study adopted an analytical research study style, which began with a systematic funnelling approach, supplemented by 20 mixed publications from the ongoing research, and was analysed after a manual selection of 30 articles considered appropriate and fitting for this study were identified.

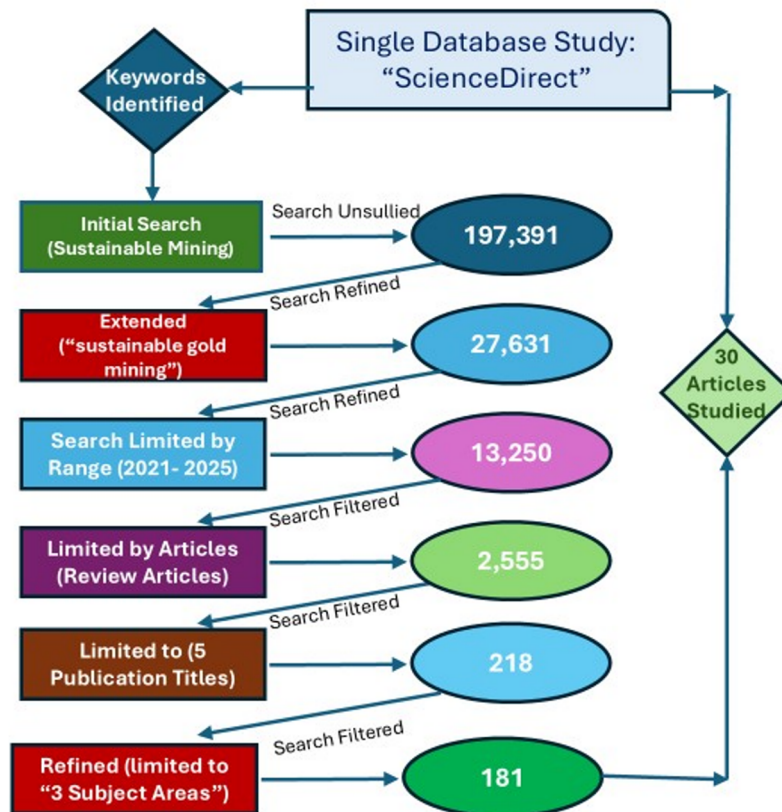


Fig. 3. Literature Search Strategy.

The majority of the articles that shaped the study were obtained from a systematic search on ScienceDirect, using the terminology “sustainable mining,” which produced an initial result of 197,391 articles. The search was refined by extending the search term to “sustainable gold mining,” yielding 27,631 articles. This baseline corpus was evaluated against established global mining trends and operational definitions (IGF, 2025; World Gold Council, 2026).

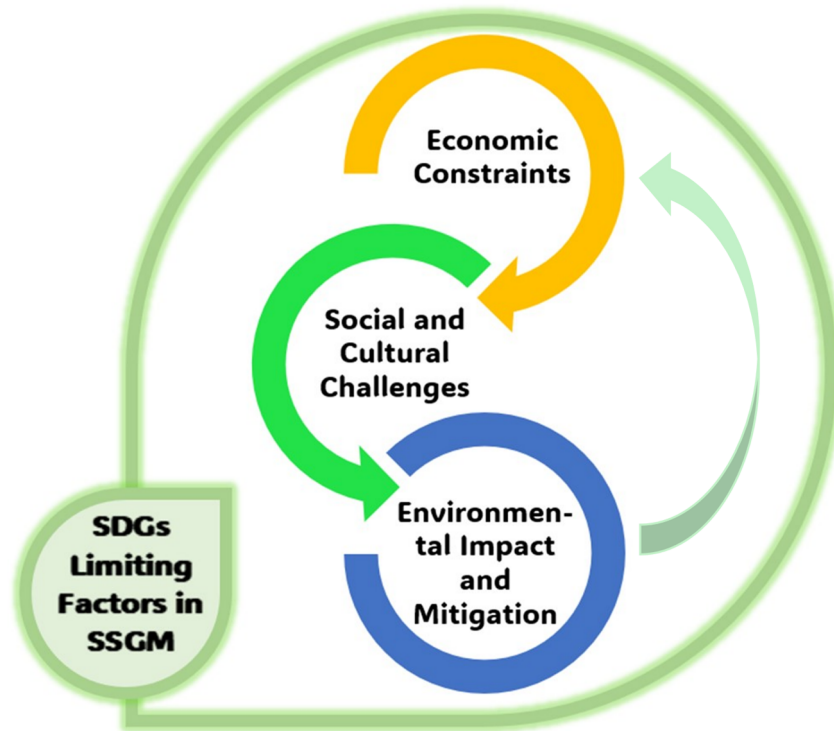
The search was then refined to 13,250 articles published between 2021–2025, this was further narrowed by limiting the scope to review articles only, resulting in 2,555, and then the search was limited to 218 articles across 5 relevant publication titles (journal titles including journal of cleaner production, journal of environmental management, renewable and sustainable energy reviews, environmental research, and earth-science reviews) which were further selected. To ensure academic rigor and data alignment, this corpus was further filtered by limiting it to 3 key subject areas within institutional subscription journals (subject areas were: “environmental sciences, social sciences, and earth and planetary sciences”), which left the search with 181 articles (EBSCO, 2025). Furthermore, 30 journal articles were then hand-selected based on keywords and explicit relevance to socio-technical and structural constraints (Abbott, 2026). In addition to the primary dataset, 20 foundational publications, consisting of policy papers, NGO reports, institutional materials, and various grey papers outside the established publication years (2021 – 2025), were also examined, ensuring that only the most contextually relevant articles were cited to map the environmental,

social, and policy realities of the sector (as shown in Fig. 3).

## 4. Results and discussion

### 4.1 Economic constraints

Small-scale gold mining in North Central Nigeria operates largely in an informal economy, limiting miners’ access to essential financial resources and formal markets and thereby leading them to make decisions that are not environmentally friendly. Such ecologically antagonistic decisions eventually impact their health, their farms, and their communities at large, which in due course leads to more economic constraints, and the paradox upholds the paradigm (as shown in Fig. 4) (Achina-Obeng & Aram, 2022; OECD, 2016). Another issue is that many miners rely on outdated equipment, probably due to lack of access and cost restraints, perpetuating inefficient and environmentally harmful methods such as mercury amalgamation (Cheng et al., 2023; Garinas, 2023). The lack of access to affordable credit or financial support prevents miners from investing in cleaner technologies or sustainable practices (Gorain et al., 2025; Kohio et al., 2024). Additionally, the volatility of gold prices in informal trading networks places miners at a disadvantage, reducing their ability to accumulate savings or reinvest in their operations (Devi et al., 2025; Villanueva Ubillús & Vila Benites, 2023). These constraints underscore the need for policies that formalize mining operations and provide financial assistance to small-scale miners (Hilson, 2020; Martinez et al., 2023).

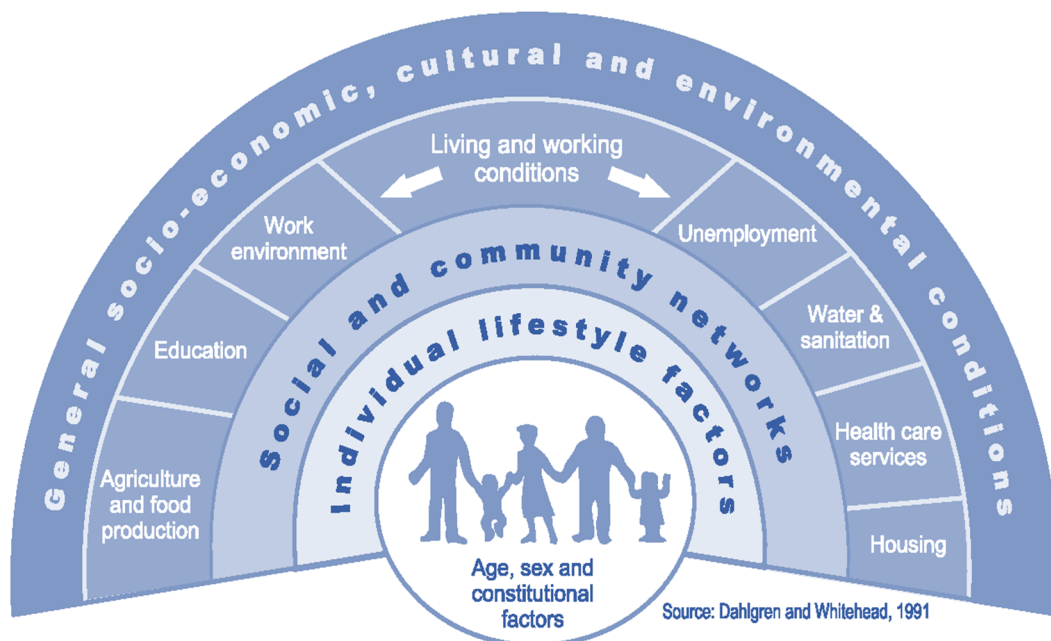


**Fig. 4.** A Paradigm of factors limiting the application of sustainability practices in small-scale gold mining (Source: Author).

**4.2 Social and cultural challenges**

Cultural dynamics and social inequalities also pose significant barriers to the sustainable development of small-scale gold mining in the region (as shown in Fig. 4). Women, who often play necessary roles in mining activities, face systemic exclusion from decision-making processes and access to resources (Arthur-Holmes & Busia, 2020; Buss & Rutherford, 2020). Additionally, weak land tenure systems and disputes over resource

ownership fuel tensions between miners and local communities, hindering collaborative efforts toward sustainable practices (Dery Tuokuu et al., 2020; North, 1990). Health and safety are also critical concerns, as miners frequently work in hazardous conditions without access to protective equipment or adequate healthcare services (Abubakar, 2024; Steckling et al., 2017). Addressing these challenges requires culturally sensitive policies that empower marginalized groups and prioritize community engagement (Biwa, 2020; Koomson, 2018).



**Fig. 5.** General Socio-Economic, Cultural and Environmental Factors Influencing Sustainability (Adapted from: Dahlgren and Whitehead, 1991).

### 4.3 Environmental impacts and mitigation

Environmental degradation remains one of the most visible and pressing challenges of small-scale gold mining. Mercury pollution, deforestation, soil erosion, and water contamination are widespread, posing threats to ecosystems and public health (Krisnayanti, 2018; Mimba et al., 2023; Tun et al., 2020). Existing mitigation efforts are often limited by a lack of technical knowledge, financial resources, and regulatory enforcement (Nkuba et al., 2022; Sonter et al., 2025). While international frameworks such as the Minamata Convention advocate for mercury-free mining, their implementation in North Central Nigeria has been slow (UNEP, 2024). Strengthening enforcement mechanisms and promoting environmental awareness are critical steps toward mitigating these impacts (De Pascale et al., 2023; Erdiaw-Kwasie et al., 2024).

After exploring the literature and drawing inferences from the content analysis, three major areas stood out from the study that require attention as they could be strikingly beneficial to the sector (as shown in Fig. 5), and these will be discussed in sections 4.4 to 4.6, addressing some of the significant bottlenecks.

### 4.4 Addressing key barriers

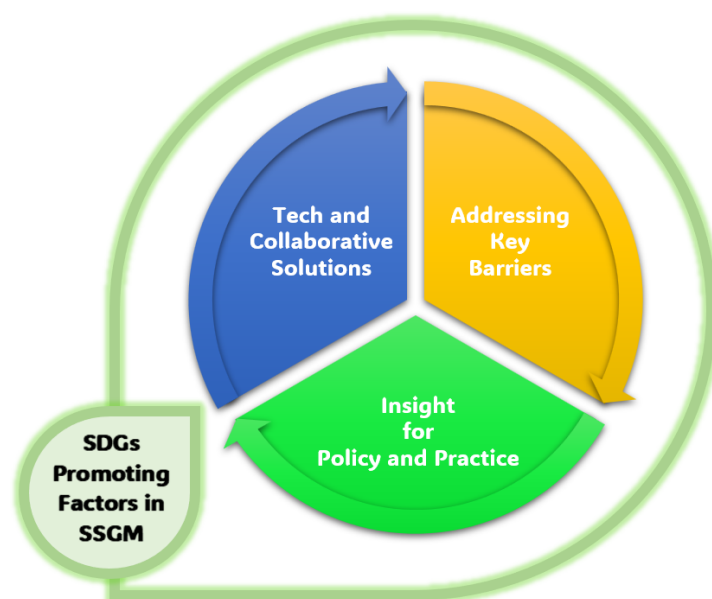
Overcoming the barriers to applying SDGs in small-scale gold mining requires a multi-faceted approach. Economic constraints can be addressed by creating financial inclusion programs, offering subsidized loans, and establishing cooperatives to pool resources (Ananeh-Frempong, 2021; Ogan et al., 2024). For social and cultural challenges, community-led initiatives that involve women and marginalized groups can foster inclusivity and collaboration (Buss & Rutherford, 2020; Koomson, 2018). Strengthened environmental regulations and incentives for sustainable practices can mitigate ecological impacts (as shown in Fig. 6) (Edegbene, 2023; Sonter et al., 2025).

### 4.5 Insights for policy and practice

Furthermore, it became evident from this analytical desk review that policies that formalize small-scale mining operations can facilitate the promotion and alignment of the sector with SDGs (as shown in Fig. 6) (Hilson, 2020; Martinez et al., 2023). We don't have to reinvent the wheel. Establishing clear land tenure rights and involving local communities in resource management can reduce conflicts and promote sustainable practices (North, 1990; World Gold Council, 2026). Public-private partnerships (PPPs) can be leveraged to provide miners with access to modern technologies and training, enabling them to adopt environmentally friendly and economically viable methods (Ogan et al., 2016; World Bank, 2022).

### 4.6 Opportunities for technological and collaborative solutions

The introduction of cleaner technologies, such as gravity concentration and cyanide-free processing, offers significant opportunities for reducing mercury use (Borgatti, 2023; Tichauer et al., 2020). However, these may remain far-fetched, except strategies are put in place to support and facilitate PPPs within the mining sector. PPPs organized by Government Institutions, specifically the Ministry of Solid Minerals Development (MSMD) in the case of North Central Nigeria, can play a pivotal role in financing and disseminating these technologies while ensuring market access for sustainably mined gold (as shown in Table 4) (Ogan et al., 2024; World Bank, 2022). Although, the PPP where the "Public Owns & Operate Assets" is the most time-consuming and would require the involvement of the largest number of parties, collaborative efforts on any scale that would involve the government agencies, NGOs, and local communities can meaningfully enhance knowledge sharing and foster a culture of sustainability in the mining sector, depending on the spectrum of the PPP that the institutions are willing to negotiate and implement (as shown in Fig. 7) (OECD, 2016; UNEP, 2024; Villanueva Ubillús & Vila Benites, 2023).



**Fig. 6.** Factors Highlighting the Benefits and Promoting the Application of Sustainability Practices in Small-scale Gold Mining (Source: Author).

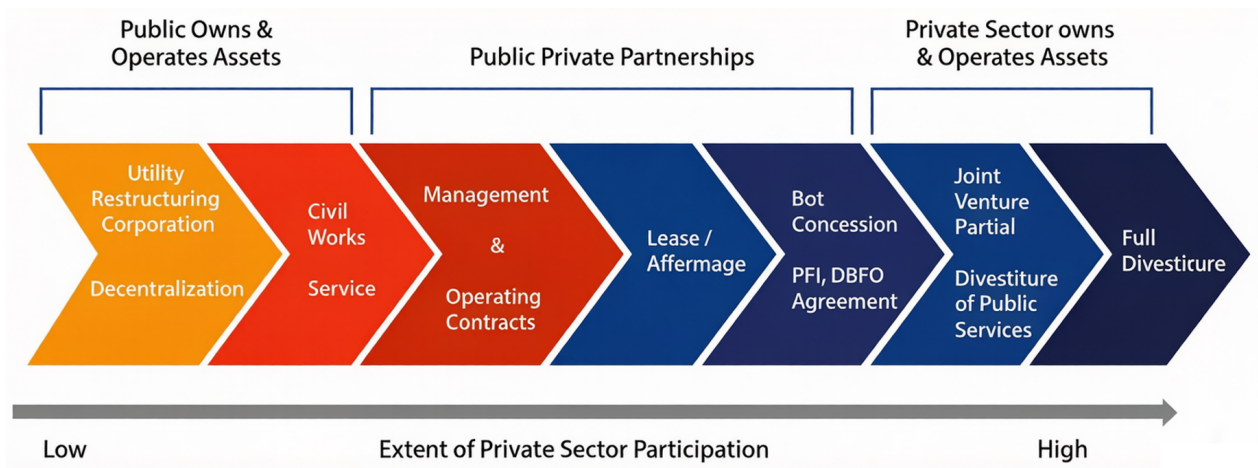


Fig. 7. Public Private Partnership Spectrum of Options (Adapted from: Delmon and Jeffrey. 2010).

## 5. Findings, policy recommendations, and future research

### 5.1 Summary of findings

This study has carefully highlighted the major limitations it identified above (see section 4). That said, the global gold demand is surging as the precious metal is now needed to produce new vital technological components such as microprocessors, electric vehicle electronics, aerospace engineering parts, edibles, and advanced medical diagnostics, due to its exceptional electrical conductivity, medical benefits, and corrosion resistance. This ultimately translates into the fact that mining will most likely continue into the foreseeable future. Hence, to address the limitations that focused on

the constraints of integrating SDGs into small-scale gold mining in North Central Nigeria, the study’s findings have tabulated sustainable solutions identified to address the key challenges and themes throughout the study. These crucial challenges, including inadequate financial resources, social inequalities, and safety issues (as shown in Fig. 1), are captured, alongside other significant environmental, social, governance, and technological bottlenecks. Deliberately, targeted interventions, such as formalisation, incentives, gender inclusion, financial support, community empowerment, and the adoption of cleaner technologies, have been suggested to present opportunities for sustainable development (as shown in Table 4). These suggestions would strategically move the practice of SSGM toward achieving the SDGs.

Table 4. Analytical Synthesis of Sustainability Practices in Small-Scale Gold Mining.

Key Challenges and Themes	Key Evidence from Literature	Observed Limitations	Theoretical Interpretation	Sustainable Solutions for North Central Nigeria
<b>1. Economic Role of ASM</b>	ASM provides livelihoods, income diversification, and rural economic stability [Achina-Obeng, R., & Aram, S. A. (2022); World Bank. (2022); World Gold Council. (2026)]	Informality limits productivity, access to finance, and market integration	Institutional theory: weak formal structures sustain informality	Formalisation pathways and financial inclusion mechanisms are required
<b>2. Environmental Degradation</b>	Mining is linked to deforestation, land degradation, and water pollution [Biwa, V. (2020); Jeevanandam, J., & Rodrigues, J. (2024); Khan, A. H. A., Budzyńska, S., Zine, H., Vázquez-Núñez, E., Talpur, S. A., Hassan, M., & Barros, R. (2025)]	Weak enforcement and a lack of restoration practices	Socio-technical systems: environmental harm is system-produced, not incidental	Introduce enforceable reclamation policies and incentivised restoration models
<b>3. Mercury Use &amp; Pollution</b>	Mercury is widely used; major global emissions from ASM [Devi, B., Mayes, R., & Grant-Smith, D. (2025); Sonter, L. J., et al. (2025); Sovacool, B. K., et al. (2020)]	Low adoption of alternatives due to cost and knowledge gaps	Technology adoption theory: innovation failure due to system constraints	Subsidised mercury-free technologies and training programmes needed

<b>4. Cleaner Production Technologies</b>	Gravity concentration and cyanidation reduce environmental harm [Dessertine, A. (2021); Steckling, N. et al. (2017)]	Limited uptake due to cost, technical expertise, and infrastructure deficits	Socio-technical transition theory: misalignment between technology and local systems	Develop cooperative models and shared processing facilities
<b>5. Governance &amp; Regulation</b>	Weak regulatory frameworks and fragmented oversight dominate ASM [Ogan, D. D., et al. (2016); Ogan, D. D., Moses, T., & Yenneti, K. (2024)]	Poor enforcement and institutional capacity gaps	Institutional theory: governance is a system driver of risk	Strengthen regulatory institutions and decentralised enforcement mechanisms
<b>6. Social Inequality &amp; Gender</b>	Women play key roles but face structural exclusion [Edegbene, O. (2023); Koomson, E. (2018); Nkuba, B., et al. (2022)]	Limited access to finance, decision-making, and training	Feminist political ecology: gendered access to resources shapes outcomes	Implement gender-inclusive mining policies and capacity-building initiatives
<b>7. Health &amp; Safety Risks</b>	High exposure to hazards: toxic substances, unstable pits, lack of PPE [Garinas, W. (2023); Gorain, S. et al. (2025); Sonter, L. J., et al. (2025)]	Limited safety awareness and absence of formal HSE systems	Risk theory: risk is structurally produced, not behaviourally incidental	Institutionalise HSE standards and embed safety training programmes
<b>8. Reclamation &amp; Environmental Management</b>	Reforestation and land rehabilitation improve ecosystems [Domingo, J. P. T., et al. (2024); Jeevanandam, J., & Rodrigues, J. (2024)]	Rarely implemented due to cost and weak policy enforcement	Governance gap: lack of incentives and accountability mechanisms	Introduce mandatory reclamation bonds and monitoring systems
<b>9. Technology Adoption Barriers</b>	Innovation exists, but uptake remains low in ASM contexts [World Gold Council. (2026)]	Financial constraints, low technical capacity, and distrust of formal systems	Diffusion of innovation theory: barriers are systemic, not individual	Promote cooperative financing and localised technology demonstration projects
<b>10. Global Sustainability Alignment (SDGs)</b>	ASM intersects with SDGs 8, 12, and 13 [Antwi-Boateng, O., & Akudugu, M. A. (2021); Tichauer, R. et al. (2020); UNEP. (2024)]	Lack of contextualised implementation strategies	Sustainability transitions theory: global frameworks poorly localised	Develop context-specific SDG integration frameworks for ASM
<b>11. Structural Nature of ASM Challenges</b>	Persistent inefficiencies across economic, environmental, and social domains [Hevi, S. S., et al. (2025); Hilson, G. (2020)]	Fragmented interventions fail to deliver systemic change	Systems theory: challenges are interconnected and self-reinforcing	Adopt integrated policy frameworks linking governance, technology, and community

### 5.2 Policy recommendations

Although this research is largely composed of desk reviews, observations, and content analysis, the following recommendations are being presented for peer review, which can be further validated against the sustainability dimensions and themes of the study. They include: “Economic Support”, “Social Inclusivity”, “Environmental Regulations”, and “Public-Private Partnerships”. One of the primary challenges in implementing SDGs in SSGM is financial limitations. Many small-scale miners operate informally and lack access to credit, preventing them from investing in safer and more sustainable mining technologies. To address these issues, governments, financial institutions, and development agencies can establish financial inclusion programs tailored to artisanal and small-scale miners. These initiatives may include microfinance schemes, subsidized loans, and grants to encourage investment in mercury-free gold processing technologies, better mining equipment, and improved health and safety measures. Furthermore, forming mining cooperatives allows miners

to pool resources, share infrastructure costs, and collectively negotiate better market prices for their gold. By improving access to fair trade and ethical gold markets, miners can receive higher compensation for responsibly mined gold, reducing the financial burden of adopting sustainable practices.

Cultural norms and social structures were identified as factors that pose significant barriers to SDG implementation in SSGM, as many mining communities operate within traditional frameworks where certain groups, such as women, youth, and indigenous people, are marginalized. This research recommends that to overcome these challenges, inclusive community-led initiatives must be promoted. Strategically engaging local stakeholders in decision-making processes can significantly help develop solutions that ensure SDG-aligned policies are culturally appropriate and widely accepted. Furthermore, ensuring that women’s participation in mining cooperatives and leadership roles could play a part in shifting the paradigm, because, if women are encouraged to lead and take major

responsibilities, it can foster gender equity and economic empowerment. Additionally, education and awareness campaigns on sustainable mining practices can change attitudes toward environmental stewardship and occupational health and safety following some recommended parameters (as shown in Table 5).

It is imperative to emphasise that SSGM has a significant environmental footprint, including deforestation, water pollution, and soil degradation. Therefore, strengthening environmental regulations is vital. However, as established in the literature, enforcement remains a challenge in many regions where informal mining is prevalent.

This research argues that to bridge this gap, governments should provide incentives for sustainable mining practices, such as tax breaks for miners who adopt environmentally friendly techniques, access to green certification programs, and rewards for reclamation and rehabilitation efforts. Technological innovations such as bioleaching, phytomining, and gravity concentration can offer viable alternatives to traditional mercury-based gold extraction methods. Additionally, partnerships with NGOs and international organizations can facilitate training programs and resource distribution, ensuring that miners have the knowledge and tools to implement sustainable practices.

**Table 5.** Parameters Recommended for Policy Optimization to Boost Sustainability Practices in Small-scale Gold Mining Projects toward achieving the Sustainable Development Goals (Source: Author).

Parameters	Brief Justifications
Economic Support	Develop microfinance programs and cooperatives to provide miners with access to affordable credit and pooled resources.
Social Inclusivity	Implement policies that promote gender equity and community engagement in decision-making processes.
Environmental Regulations	Strengthen enforcement mechanisms and introduce incentives for sustainable practices, such as tax benefits for using mercury-free technologies.
Public-Private Partnerships	Leverage PPPs organised by the MSMD to promote cleaner technologies, improve market access, and support training programs for miners.

### 5.3 Directions for future research

Although the parent research on which this study is drawn is currently analysing collected data from over a hundred professionals and stakeholders in the sector, it also highlights the issues discussed. Hence, this study proposes that future research should explore the long-term impacts of sustainability initiatives in small-scale gold mining, focusing on their scalability and replicability in other regions. Studies should also examine the role of technology adoption in transforming mining practices and assess the effectiveness of policy frameworks in achieving SDG alignment. Collaborative research involving local stakeholders can provide deeper insights into context-specific challenges and opportunities.

### 6. Conclusions

The transition of Small-Scale Gold Mining (SSGM) in North Central Nigeria from an informal, high-risk activity to a cornerstone of sustainable development is not merely a regulatory challenge, but a multi-dimensional imperative. Achieving SDG integration within this sector requires a synchronized, multi-stakeholder effort involving governments, private sector investors, NGOs, and the mining communities themselves. Central to this transformation is the removal of systemic financial barriers. By formalizing the sector and improving access to credit, miners can move away from exploitative trading networks and invest in the “cleaner technologies” essential for both economic efficiency and environmental protection. Simultaneously, promoting social inclusivity, particularly by addressing gender disparities and clarifying land tenure, ensures that the benefits of mining are distributed equitably, reducing community conflict and fostering long-term stability.

Furthermore, environmental stewardship must be en-

forced not through punitive measures alone, but through innovation-led incentives. Strategies such as providing mercury-free processing equipment in exchange for environmental compliance can effectively mitigate deforestation and water pollution. Critically, this holistic approach must place the health and safety of the workforce at the forefront; by reducing toxic exposure and improving occupational standards, the sector protects its most valuable assets, its people.

Ultimately, prioritizing the synergy between human well-being and ecological preservation ensures that small-scale gold mining ceases to be a driver of degradation. Instead, with tailored strategies that reflect the unique realities of North Central Nigeria, SSGM can emerge as a responsible, economically viable sector that contributes meaningfully to the global 2030 Agenda for Sustainable Development.

### Author Contributions

D.D.O.: conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing, original draft preparation, visualization; T.M.: Supervision, software, resources; Y. K.: Supervision, validation review, writing review.

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### Data Availability Statement

Data are available by contacting the corresponding author.

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### Conflict of interest

D.D.O. is Project Manager of the UKRI & OfS widening participation research initiative, the That's Me! Project at the University of Wolverhampton. Founder of Pro-Earth & Environs, BRAIN & PaCMITE.

### Use of AI and AI-assisted Technologies

No AI tools were utilized for this paper.

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### Abbreviations

The following abbreviations are used in this manuscript:

- AI – Artificial Intelligence
- ASM – Artisanal and Small-scale Mining
- ASGM – Artisanal and Small-scale Gold Mining
- EITI – Extractive Industries Transparency Initiative
- EU – European Union
- IGF – Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development
- MSMD – Ministry of Solid Minerals Development (Nigeria)
- NGO – Non-Governmental Organisations
- OECD – Organisations for Economic Co-operation and Development
- PPP – Public-Private Partnership
- SDGs – Sustainable Development Goals
- SSGM – Small-scale Gold Mining
- UNEP – United Nations Environment Programme

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