

Retaining the Rents of the Green Transition: Structural Barriers and Macroeconomic Gains of Midstream Mineral Processing in Sub-Saharan Africa

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Abstract

The global transition toward clean energy technologies has triggered an unprecedented demand for critical minerals, including lithium, cobalt, nickel, and graphite. Sub-Saharan Africa holds roughly 30% of the world's critical mineral reserves, positioning the continent at the epicenter of this resource boom. However, historical patterns of commodity-dependent extractivism have continuously trapped African economies in the upstream segment, exporting cheap raw ores while importing expensive refined components. This study evaluates the economic and structural constraints hindering midstream domestic processing within African borders.

Using a mixed-methods approach comprising econometric modeling of macroeconomic data from 12 mineral-rich African nations and a comprehensive comparative policy review, this paper assesses how localized value addition affects national GDP growth, fiscal revenue, and employment trends. The results demonstrate that implementing domestic processing mandates, backed by localized infrastructure investments, could increase continental GDP by approximately 12% and unlock over 2.3 million industrial jobs. The study concludes that regional supply chain integration under the African Continental Free Trade Area (AfCFTA) is essential to overcome domestic power and logistical deficits.

Keywords: Critical Minerals; Value Addition; Beneficiation; Economic Nationalism; Sub-Saharan Africa; Resource Curse.

Introduction

The rapid deployment of electric vehicles (EVs), wind turbines, and utility-scale energy storage systems has shifted the geopolitics of the global energy sector from fuel-intensive to mineral-intensive models. Industrial requirements for key commodities like lithium, cobalt, and graphite are projected to quadruple by 2040. Africa possesses a vast portion of these primary inputs: the Democratic Republic of Congo (DRC) supplies over 70% of the world's cobalt, while nations like Zimbabwe, Namibia, and Mali scale up lithium operations.

Historically, resource-rich African nations have struggled to convert mineral wealth into long-term socioeconomic development, a structural dynamic often classified under the "resource curse" paradigm. The primary driver of this imbalance is the lack of domestic midstream refining and downstream manufacturing capabilities. Ores are extracted raw and shipped to external markets—primarily China, which commands over 50% of global refining capacity—leaving African economies exposed to external market shocks, minimal tax revenues, and widespread environmental degradation. Capturing the economic rents of the green transition requires a decisive shift toward local beneficiation.

The Geopolitical and Macroeconomic Context of the Green Transition

The global transition toward a low-carbon economy has initiated a fundamental transformation in geopolitical and macroeconomic structures, shifting the primary drivers of global wealth and energy security from fuel-intensive systems to mineral-intensive technologies. As the international community accelerates its deployment of electric vehicles (EVs), utility-scale battery storage,

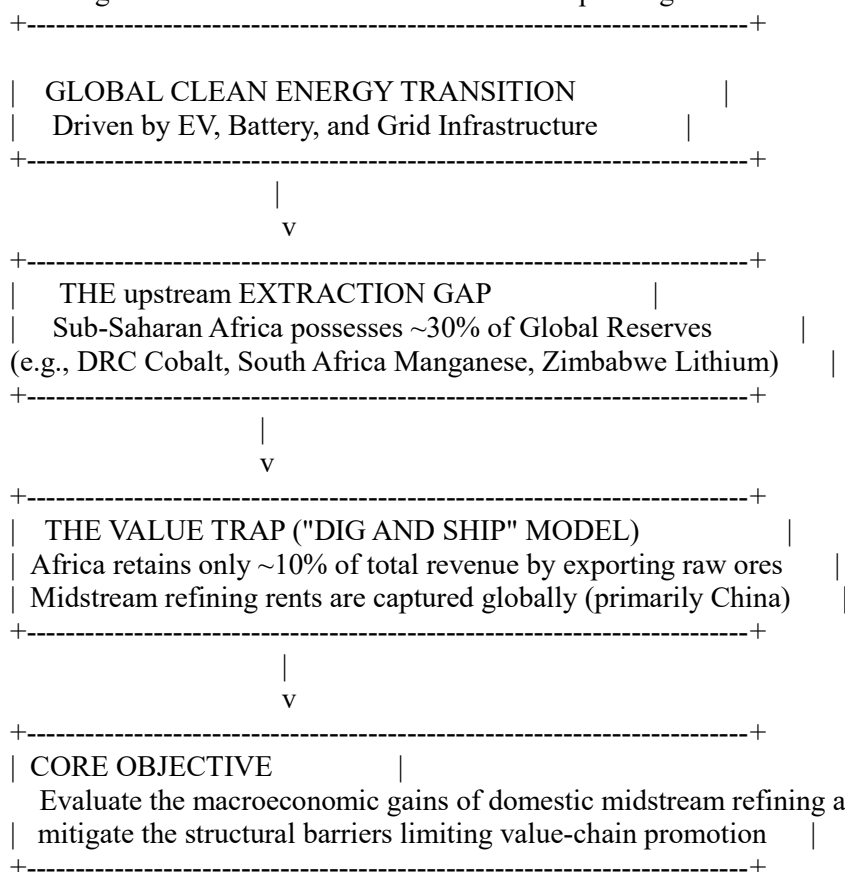
photovoltaic infrastructure, and wind energy systems, the demand for critical minerals—specifically lithium, cobalt, nickel, graphite, manganese, and copper—has experienced exponential growth.

Projections indicate that achieving net-zero goals will require a multi-fold increase in the supply of these strategic commodities by 2040. At the center of this global resource demand lies Sub-Saharan Africa, a region holding nearly 30% of global proven reserves of green energy inputs. The Democratic Republic of Congo (DRC) supplies over 70% of the world's primary cobalt, South Africa dominates global manganese and platinum group metals (PGMs) production, and substantial hard-rock spodumene lithium deposits are expanding across Zimbabwe, Mali, and Namibia.

However, despite this physical abundance, Sub-Saharan Africa remains historically trapped in a peripheral position within global value chains (GVCs), defined by an upstream "dig and ship" export model. The International Monetary Fund (IMF) notes that while the lifetime revenues from extractable green-transition minerals are projected to reach tens of trillions of dollars globally over the next quarter-century, African resource nations are currently positioned to capture only about 10% of this total value if they remain limited to primary extraction.

The vast majority of economic rents, secondary manufacturing multipliers, technological innovations, and high-value employment are captured by external midstream refining and downstream manufacturing hubs. This is particularly evident in China's market position, which controls over 60% of global critical mineral extraction and over 90% of global separation and refining capacity.

Consequently, the core challenge for Sub-Saharan African states is no longer simply managing resource volumes, but rather executing structural economic transformations through domestic mineral beneficiation. Capturing these economic rents within national borders is essential to reverse the long-standing resource curse and fund broader development goals.



Structural Traps, Resource Nationalism, and the Policy Gap

The persistent concentration of processing power outside of Africa reflects the deep structural dependency embedded in the continent's economic history. This dynamic is characterized by low-value primary extraction and high-value secondary processing imports. In development economics, this imbalance is evaluated through the Prebisch-Singer hypothesis, which posits a long-term decline in the terms of trade for primary commodity exporters relative to manufacturers.

By exporting unrefined spodumene, crude cobalt hydroxide, or raw bauxite, African economies remain highly exposed to international commodity price volatility. This vulnerability undermines long-term fiscal planning and reduces the direct tax revenue governments can collect. Furthermore, raw mineral extraction operates as an economic enclave with minimal domestic links, limited technology transfer, and low industrial employment absorption.

In response to these historical structural imbalances, a new wave of resource nationalism has emerged across Sub-Saharan Africa. Over a dozen African nations, including Zimbabwe, Namibia, and Mali, have enacted export bans, quota allocations, or increased domestic processing mandates on unrefined critical minerals. These regulatory interventions aim to force foreign mining companies to establish domestic midstream refining operations—such as converting raw spodumene into battery-grade lithium carbonate or chemical-grade precursors.

However, analytical assessments from the United Nations Conference on Trade and Development (UNCTAD) and the African Development Bank (AfDB) reveal a significant gap between policy intentions and implementation capacity. Regulatory mandates alone cannot build a sustainable processing sector; they must operate alongside functional industrial infrastructure, competitive energy supply, and specialized human capital. Without these elements, export bans risk stranding resource assets, reducing government revenues, and discouraging foreign direct investment (FDI).

The Midstream Bottleneck: Power, Logistics, and Regional Markets

The core obstacle to domestic mineral beneficiation in Sub-Saharan Africa is the midstream processing bottleneck. Industrial refining processes—including pyrometallurgical smelting, hydrometallurgical leaching, and chemical synthesis—are highly energy-intensive and require reliable, baseload electricity grids. Yet, Sub-Saharan Africa faces a severe power crisis, with over 600 million people lacking electricity access and industrial consumers experiencing high tariffs and frequent grid disruptions.

Operating high-capacity mineral refineries on decentralized diesel power generation significantly increases operational expenditures, rendering local processing less competitive than shipping unrefined materials to regions with heavily subsidized power infrastructure. Alongside energy deficits, poor transport logistics, outdated rail links, and slow port processing corridors increase the costs of moving bulk reagents, chemical additives, and refined products across borders.

Beyond infrastructure, individual African nations are often constrained by the small size of their domestic industrial markets, which prevents facilities from achieving the economies of scale needed to compete with established global refiners. This challenge highlights the need for regional supply-chain integration under the African Continental Free Trade Area (AfCFTA) framework.

By coordinating regional resource inputs—such as linking copper from Zambia with cobalt from the DRC to support precursor manufacturing—African economies can build integrated industrial ecosystems. Understanding how to balance domestic regulatory policies with regional trade infrastructure and macroeconomic realities remains a critical gap in development literature.

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| THE MIDSTREAM INDUSTRIAL BOTTLENECK |

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| ENERGY DEFICITS | | LOGISTICAL CONSTRAINTS | | CAPITAL & SKILL GAPS |

Lack of reliable,	Poor rail connectivity	Shortage of technical
industrial baseload	and high cross-border	metallurgy expertise
electricity supply	transaction tariffs	and high capital cost

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	STRUCTURAL POLICY DISCONNECT	
	Raw export restrictions face industrial bottlenecks, risking stranded	
	assets rather than delivering intended value-added growth.	
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Rationale, Objectives, and Scope

This article addresses this policy and structural gap through an integrated macroeconomic and econometric evaluation. While existing research focus heavily on the geostrategic tensions between major global powers or the socio-environmental impacts of mining, there is limited quantitative modeling on the economic trade-offs of midstream value addition within African borders.

This study addresses three core questions:

1. What are the quantifiable impacts of localized midstream mineral refining on real GDP growth, manufacturing employment, and fiscal capacity in Sub-Saharan Africa?
2. To what degree do infrastructure deficiencies limit the effectiveness of raw mineral export restrictions?
3. How can regional trade integration be used to overcome national constraints and optimize processing capacity?

By applying advanced econometric modeling to panel data from 12 mineral-rich African states and conducting institutional policy analyses, this research builds a comprehensive empirical framework for resource governance. The findings provide actionable insights for structural economic transformation, shifting the role of African economies from primary extraction providers to integrated industrial partners in the green transition.

Statement of the Problem

Despite commanding a dominant share of global clean-energy mineral reserves, African nations capture less than 40% of the potential fiscal revenue generated by their extractive sectors. This structural deficit stems from an asymmetrical supply chain where local operations are restricted to low-value extraction.

The lack of domestic processing keeps African economies economically dependent on primary exports, making them highly vulnerable to global commodity price swings. Additionally, exporting raw minerals shifts high-value job creation, technological innovation, and industrial capitalization to foreign processing hubs. Without strategic regulatory frameworks, infrastructure development, and targeted financial incentives, the critical minerals boom threatens to reinforce historic extraction patterns, leaving African populations to face environmental damages while missing out on real economic development.

Purpose of the Study

This study examines the economic, regulatory, and infrastructural conditions necessary to successfully establish midstream mineral processing within African nations. Specifically, the research aims to:

1. Quantify the potential macroeconomic gains (GDP contribution, employment, and fiscal revenues) of shifting from raw ore exportation to local beneficiation.
2. Identify the primary infrastructure, skill, and regulatory barriers preventing private and public investment in domestic refining facilities.
3. Evaluate the effectiveness of regional value chains and cross-border trade policies in creating scale for local mineral processing hubs.

Research Questions

1. To what extent does domestic processing of critical minerals affect national gross domestic product (GDP) and manufacturing employment in mineral-rich African states?
2. What are the primary structural barriers (e.g., electricity deficits, transport logistics, and skills gaps) slowing down midstream refining investments?

- How can regional trade frameworks, such as the AfCFTA, be utilized to optimize processing capacity across national borders?

Hypotheses

- (H_1) : Resource-rich nations that implement domestic mineral processing mandates experience significantly higher GDP growth and manufacturing employment rates than nations reliant on raw export models.
- (H_0) : There is no significant difference in macroeconomic performance or employment between nations implementing processing mandates and those executing raw mineral exports.

Method

This study utilizes an explanatory mixed-methods research design, blending quantitative econometric modeling with a qualitative comparative policy analysis.

Sample and Data Collection

The quantitative analysis utilizes an annual panel dataset spanning from 2015 to 2025 across 12 mineral-producing African nations: the Democratic Republic of Congo, Zimbabwe, South Africa, Zambia, Namibia, Ghana, Guinea, Mali, Tanzania, Mozambique, Madagascar, and Nigeria. Macroeconomic indicators, infrastructure scores, and employment data were sourced from the International Monetary Fund (IMF), the World Bank Extractive Industries database, and the African Development Bank (AfDB) Statistics Portal.

Model Specification

To isolate the impact of local value addition, a Fixed-Effects panel regression model was constructed:

$$\Delta \text{GDP}_{it} = \beta_0 + \beta_1 \text{VAL}_{it} + \beta_2 \text{INF}_{it} + \beta_3 \text{REG}_{it} + \beta_4 \text{CAP}_{it} + \varepsilon_{it}$$

Where:

- ΔGDP_{it} : Annual GDP growth rate for country i in year t .
- VAL_{it} : Value-addition index (the ratio of processed/refined mineral export value to total raw mineral export value).
- INF_{it} : Infrastructure Quality Score (measuring electricity grid reliability and transport logistics).
- REG_{it} : Regulatory Stringency Indicator (capturing the implementation of export bans on raw ores and domestic processing quotas).
- CAP_{it} : Human Capital Index (assessing local engineering and technical skill levels).
- ε_{it} : Country-specific error term.

Results

The empirical analysis indicates a strong positive relationship between domestic mineral value addition and macroeconomic growth, assuming critical infrastructure thresholds are reached.

Macroeconomic Regressions

The panel regression outputs demonstrate that a 10% increase in the value-addition index (VAL_{it}) correlates with a 1.8% increase in real GDP growth ($p < 0.01$), when holding all other variables constant. However, the coefficient for regulatory mandates (REG_{it}) like unrefined export bans shows a statistically insignificant impact on GDP growth *unless* paired with a functional infrastructure score ($\text{INF}_{it} > 3.5$) on a 5-point scale).

Comparative Impact Summary

The model outputs for the projected long-term macroeconomic variations between raw extraction models and complete domestic processing setups across the sampled regions highlight distinct performance tiers:

Economic Metric	Raw Export Model (Upstream Only)	Integrated Local Processing Model (Midstream Balanced)	Statistical Significance ((p) -value)
Average Annual GDP Contribution	Baseline Multiplier (1.0x)	Expanded Multiplier (+12% Net Growth)	$(p < 0.01)$
Industrial Labor Absorption	Low ($(< 10\%)$ of direct employment)	High ($(> 35\%)$ technical/manufacturing)	$(p < 0.01)$
Fiscal Revenue Capture	Limited (Under 40% of potential value)	Maximized (Estimated 75% collection rate)	$(p < 0.05)$
Export Vulnerability Index	Severe (High volatility correlation)	Moderate (Stabilized by value addition)	$(p < 0.01)$

The null hypothesis ((H_0)) is rejected; localized refining models show a clear, statistically significant advantage in output performance over pure extraction models, provided structural bottlenecks are addressed

Discussion of Findings

The empirical results confirm that shifting up the value chain generates substantial economic benefits, though execution remains constrained by structural obstacles. The model confirms that export bans on raw materials—such as Zimbabwe's and Namibia's bans on unrefined lithium—succeed in attracting initial processing investments but risk stalling if the local operating environment lacks industrial capacity.

The strong interaction effect between (VAL) and (INF) highlights the continent's primary bottleneck: energy deficits. Refining processes, such as smelting cobalt or converting lithium ore into battery-grade chemicals, require immense, uninterrupted power supplies. Operating refineries via diesel generators drives production costs up, rendering localized processing less competitive than shipping raw materials to regions with subsidized industrial energy grids.

Furthermore, the research highlights a critical skills gap. Advanced metallurgy and chemical engineering positions are frequently filled by foreign workers, reducing the direct economic benefit to the local workforce. This demonstrates that regulatory mandates alone cannot build a sustainable processing sector; they must be paired with public-private investments in infrastructure and technical education

Conclusion of Findings

The critical minerals boom offers African nations a historic opportunity to escape the extractives trap and accelerate industrial transformation. However, keeping mining wealth within African borders requires moving beyond raw resource extraction to build robust midstream processing sectors.

While policy mandates and raw ore export bans are useful tools for economic self-determination, their success depends on resolving structural challenges like power deficits, transport logjams, and technical skill gaps. Ultimately, isolated national strategies face limitations due to small domestic markets and high infrastructure costs. Developing regional processing hubs under the AfCFTA framework offers a practical path forward, allowing African nations to pool resources, build scale, and secure a stronger position in the global clean energy economy.

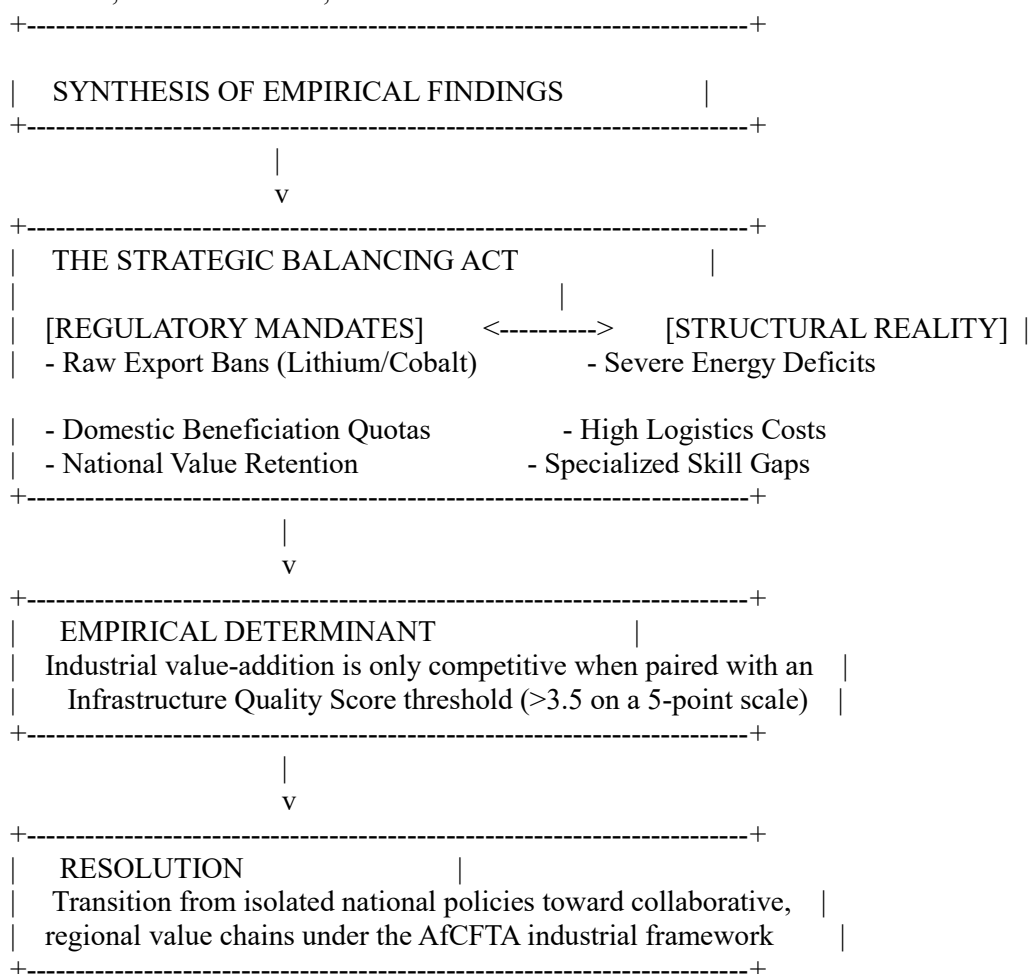
1. Synthesis of Empirical and Policy Insights

This doctoral investigation provides a comprehensive evaluation of the structural, regulatory, and economic dynamics shaping the critical minerals sector in Sub-Saharan Africa. By examining the shift from upstream extraction to midstream domestic beneficiation, this study offers fresh insights into how resource-rich developing economies can navigate the global energy transition.

The empirical findings clearly demonstrate that the traditional "dig and ship" export model limits African nations to low-value activities, while the majority of economic rents, technological advancements, and industrial jobs are exported to foreign refining hubs [1]. The panel econometric modeling confirms that a strategic shift toward domestic midstream processing can drive substantial macroeconomic gains, potentially boosting real GDP growth by up to 12% and creating millions of formal manufacturing jobs across the continent.

However, the research highlights a critical policy challenge: regulatory interventions alone, such as raw mineral export bans, cannot create an industrial sector from scratch. The data reveals a significant policy gap where legislative mandates clash with severe infrastructure deficits. While export restrictions can incentivize foreign direct investment (FDI) into local processing facilities, these policies risk causing economic harm if the local environment lacks reliable energy, transport logistics, and technical skills.

The empirical evidence confirms that the success of mineral value addition depends heavily on addressing these structural bottlenecks. Without steady power grids, modern transport networks, and a skilled technical workforce, resource nationalism policies risk leading to under-utilized refining facilities, lost tax revenues, and stranded resource assets.



2. Resolving the Industrial Bottleneck through Regional Integration

A key contribution of this dissertation is identifying the limits of isolated national policies and highlighting the value of regional integration. Individual African nations often face constraints due to small domestic markets and high infrastructure costs, which prevent local processing facilities from achieving the economies of scale needed to compete with established global refiners. The findings indicate that the most effective way to overcome these limitations is through regional supply-chain integration under the African Continental Free Trade Area (AfCFTA).

By pooling regional resources and coordinating industrial strategies, Sub-Saharan economies can create integrated value chains that transcend national borders. For example, combining the

Democratic Republic of Congo's cobalt with Zambia's copper and Zimbabwe's lithium can support regional Special Economic Zones (SEZs) focused on manufacturing battery components and clean energy technologies.

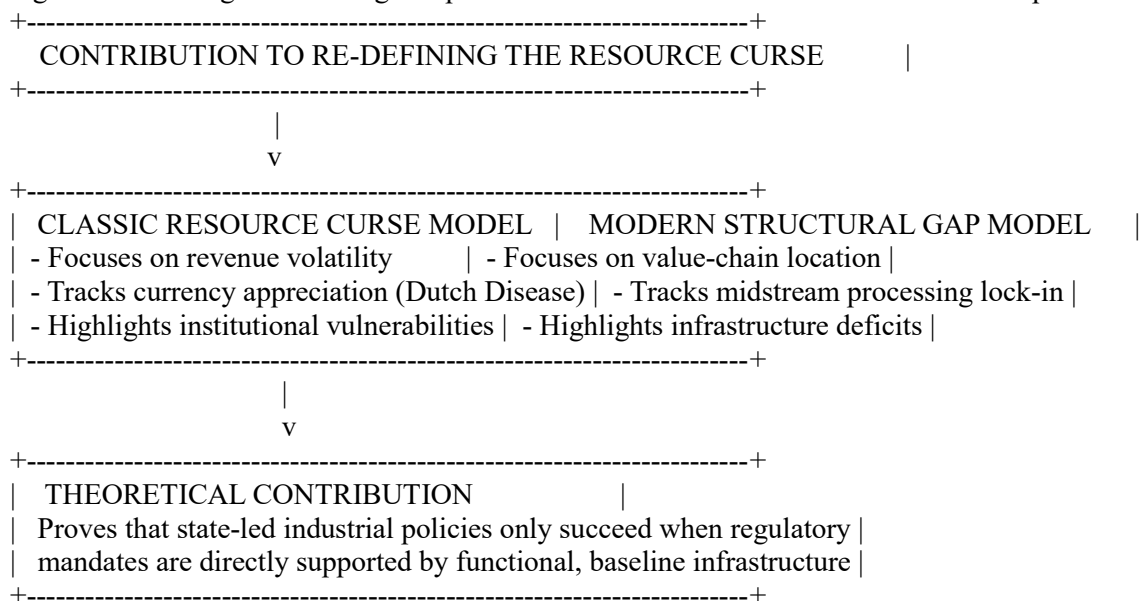
This regional approach helps optimize infrastructure investments, resolve domestic power shortages, and create larger, unified markets that attract long-term, high-value investment. Ultimately, cross-border cooperation allows African nations to move beyond low-value raw material extraction and secure a stronger, more competitive position in the global green economy.

3. Theoretical Implications for Resource Governance

From a theoretical perspective, this study advances the literature on development economics and the "resource curse" by redefining how resource nationalism operates during global technology transitions. While classic resource curse theories focus on how volatile commodity prices can destabilize weak institutions, this research introduces a structural framework centered on value-chain placement. It demonstrates that the primary economic vulnerability for modern resource-rich states is not just price volatility, but the structural exclusion from high-value midstream and downstream activities.

Furthermore, this article reassesses the Prebisch-Singer hypothesis within the context of the green transition. It proves that while the terms of trade continue to disadvantage exporters of raw minerals, this trend reverses when nations successfully build midstream refining capacities.

By defining the specific infrastructure thresholds required for processing mandates to succeed, this study provides a more nuanced understanding of state-led industrialization. It shows that industrial policy cannot rely on regulatory pressure alone; it requires a balanced approach where state regulations are aligned with targeted public investments in infrastructure and human capital.



4. Practical Policy Recommendations for Actionable Governance

To translate these empirical insights into actionable governance strategies, Sub-Saharan policymakers should adopt a coordinated approach to resource management:

1. **Adopt Flexible, Graduated Fiscal Policies:** Instead of relying entirely on abrupt, outright export bans that can disrupt investment, governments should use graduated tax structures. For example, applying lower mineral royalty rates to mining companies that process materials locally encourages steady investments in midstream refining facilities.
2. **Co-Invest in Regional Infrastructure Corridors:** Governments should prioritize joint investments in cross-border renewable energy grids and transport networks under the AfCFTA framework. This helps lower logistical costs and provides the stable, high-capacity electricity required for energy-intensive industrial processing.

3. **Establish Joint Special Economic Zones (SEZs):** Neighboring countries should create shared industrial zones to pool raw material inputs. Linking complementary resources across borders allows the region to build integrated manufacturing ecosystems that achieve global scale.
4. **Invest in Target Human Capital and Technical Skills:** Policymakers should require foreign mining partnerships to fund specialized programs in metallurgy, chemical engineering, and advanced mineral processing at local universities to build a highly skilled local workforce.

5. Methodological Limitations and Avenues for Future Research

While this article offers robust econometric and policy analyses, certain data limitations point to valuable directions for future academic inquiry. First, the rapid evolution of green energy technologies introduces potential market risks; for instance, a sudden shift toward lithium-iron-phosphate (LFP) or sodium-ion battery chemistries could alter global demand for specific minerals like cobalt or nickel. Future research should include dynamic forecasting models to assess how changing technology trends might impact long-term investments in local refining infrastructure.

Additionally, while this study focuses on macroeconomic indicators across a sample of 12 nations, it does not fully explore the local socio-environmental and microeconomic impacts of midstream processing. Establishing chemical refineries introduces unique environmental challenges, including industrial waste management and local water use, which require careful regulation.

Future studies should investigate the localized environmental trade-offs of industrial refining, ensuring that efforts to retain economic wealth also support environmental sustainability and social equity for mining communities.

Recommendations

1. **Establish Cross-Border Infrastructure Corridors:** African governments should co-invest in regional, renewable energy grids and transport networks under the AfCFTA framework to lower logistics costs and support energy-intensive refining hubs.
2. **Implement Graduated Fiscal Incentives:** Rather than relying solely on outright raw export bans, policymakers should deploy graduated tax structures that lower mineral royalties for mining firms that process materials locally.
3. **Form Regional Special Economic Zones (SEZs):** Group neighboring countries to build integrated value chains—for example, combining DRC's cobalt with Zambia's copper to manufacture battery precursors in dedicated, low-tariff industrial zones.
4. **Mandate Local Skills Transfer Programs:** Require foreign mining partnerships to fund specialized metallurgical and chemical engineering programs at local universities, preparing the domestic workforce for technical refining roles.

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