

Review Article

Ethiopian Coal Deposits: Resource Development and Future Prospects

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Abstract

This review synthesizes the current state of knowledge regarding coal deposits in Ethiopia, a nation whose energy strategy has historically prioritized large-scale hydropower development. Moving beyond superficial resource inventories, this article critically examines within the tectonic framework of Permo-Carboniferous (Karoo) graben systems and Mesozoic rift basins. This study provides a meticulous analysis of Ethiopia's coal resources, which include approximately 297 Mt of registered coal reserves identified through systematic exploration, historical resource estimates of ~600 Mt, and recent government projections suggesting potential resources exceeding 1 billion tons subject to further delineation, and evaluates their quality and suitability for applications ranging from thermal combustion to advanced conversion technologies. Furthermore, it evaluates their quality and suitability for applications ranging from thermal combustion to advanced conversion technologies. The paper delves into the historical context and contemporary status of resource development, identifying systemic technical, infrastructural, and economic bottlenecks that have hindered exploitation. Within the global and national discourse on energy transition; that the strategic, responsible, and technology-enabled development of indigenous coal resources is not an anachronism but a critical component of Ethiopia's energy security and industrial modernization. This is contingent upon the integration of advanced clean coal technologies (CCT). While carbon capture utilization and storage (CCUS) remains economically prohibitive in the Ethiopian context presently, emission control technologies (ESP, FGD) offer immediate pathways for localized pollution mitigation. Analyzing coal's potential role in cement manufacturing (as a kiln fuel), direct reduction iron (DRI) if washed to <15% ash, and as a feedstock for synthetic fuels via CTL technologies. Ethiopian coal, if governed under stringent environmental regulations and technological upgrading, could provide the dispatch able base load and fiscal stability required to underwrite Ethiopia's longer-term transition to a renewable-dominated energy system.

Keywords

Coal Geology, Clean Coal Technologies, Energy Security, Sedimentary Basins, Carbon Capture

1. Introduction

Ethiopia's national energy strategy, as articulated in its Growth and Transformation Plans (GTP I & II) and National Electrification Program, has historically prioritized large-

scale hydropower, a focus mirrored in international development finance portfolios [1]. This sustained policy emphasis on hydropower has coincided with and likely contributed to the

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absence of any publicly available, government-endorsed strategic assessment of Ethiopia's coal resources. A bibliometric review of Ethiopian energy research (2000–2023) reveals that over 85% of peer-reviewed publications focus on renewable energy, with fewer than five articles specifically addressing the geology, economics, or policy of domestic coal resources [2]. This review synthesizes available geological, technical, and policy literature to evaluate whether Ethiopia's coal occurrences currently classified only as inferred or indicated resources merit strategic consideration within a diversified energy and industrial policy framework.

As global energy systems decarbonize, developing countries face acute trade-offs often termed the energy trilemma between supply security, cost competitiveness, and emissions reduction. Ethiopia is no exception. Although Ethiopia has committed to 100% renewable electricity by 2030, operational data from the Ethiopian Electric Power (EEP) indicate that seasonal variability of hydropower and the lack of utility-scale storage currently limit the reliability of solar and wind as sole baseload substitutes. This has prompted renewed technical interest in dispatchable domestic alternatives [3]. Domestic coal has been largely absent from Ethiopia's energy policy discourse since the 1990s, with no mention in the 2019 National Energy Policy. This silence, however, does not reflect an empirical assessment of its potential role under modern combustion or conversion technologies. This review critically examines whether advanced coal technologies specifically high-efficiency, low-emissions (HELE) combustion and potential co-firing with biomass could reconcile the use of indigenous coal with Ethiopia's climate commitments. In doing so, it reframes coal not as a default development pathway, but as a contingent and potentially transitional resource. This review therefore poses the following research question: Under what technical, economic, and regulatory conditions could Ethiopia's coal resources contribute to energy security without compromising its sustainable development goals? We evaluate this question through four lenses: resource geology, technology readiness, environmental trade-offs, and policy alignment.

2. Geological Framework and Distribution of Coal Basins

The occurrence of coal in Ethiopia is intrinsically linked to Phanerozoic intracratonic sag basins and Paleogene-Neogene continental rift basins developed within the East African Plateau. These basins preserve the lithological and pale environmental records conducive to peat formation and subsequent coalification.

2.1. Tectonic and Stratigraphic Settings

Major coal-bearing sequences are located within six principal geological domains: the Ogaden Basin (Jurassic-Cretaceous), the Blue Nile (Abbaya) Basin (Oligocene-Miocene),

the Mugher Basin (Paleogene), the Yayu (Didessa) Basin (Eocene-Oligocene), the Delbi-Moye Basin (Pliocene), and smaller occurrences in the Gambela region [4]. The Ogaden Basin, a vast intracratonic depression in the southeast, contains significant coal measures, primarily within the fluvio-deltaic intervals of the Cretaceous Gumburo Formation. Minor, laterally discontinuous coal seams are also recorded in the underlying Uarandab Formation (Jurassic), but these are generally thin and of high ash content. These units represent fluvio-deltaic to lacustrine depositional environments where widespread peat mires developed under warm, humid climatic conditions [5]. The Blue Nile Basin, located in the northwestern plateau, hosts sub-bituminous coal seams within the Late Oligocene to Early Miocene sediments of the Chilga and Yetnora areas. These are younger, often lignitic to sub-bituminous coals formed in continental rift-associated lake basins [6]. The Mugher Basin, located south of the Blue Nile, hosts Paleocene-Eocene coal seams. However, these coals are characterized by elevated sulfur contents (avg. 3.2 wt.%) and high ash yields, rendering them currently sub-economic for power generation without beneficiation.

2.2. Paleoenvironmental and Paleoclimatic Controls

The formation of economically viable coal seams required a delicate balance of subsidence rates, plant productivity, and preservation conditions. The Mesozoic coals of the Ogaden correlate with periods of widespread shallow marine incursions and lush hinterland vegetation, while the Cenozoic coals of the northwestern plateau (e.g., Chilga) accumulated in fluvio-lacustrine depositional systems associated with rift-related subsidence. Organic matter preservation was facilitated by high water table conditions and localized anoxia within rapidly aggrading floodplain mires and shallow lake margins [7]. A robust understanding of these tectono-stratigraphic and paleoclimatic controls is essential for developing predictive exploration models. By integrating sequence stratigraphic frameworks with petrographic analysis, explorationists can identify maximum flooding surfaces and transgressive systems tracts intervals where accommodation space generation outpaced clastic influx, favoring thick peat accumulation.

3. Coal Petrography, Quality, and Classification

A critical barrier to the development of Ethiopian coal has been a lack of detailed, publicly available data on its fundamental material properties. Generalized statements about low quality are insufficient for engineering and economic planning.

3.1. Rank and Calorific Value

Ethiopian coals range stratigraphically and spatially from

lignite (e.g., Cenozoic intertrappean beds of the Blue Nile Basin; $R_o < 0.4\%$) to high-volatile bituminous coal (e.g., Jurassic–Cretaceous sequences in the Ogaden Basin; $R_o 0.5\text{--}0.7\%$). Vitrinite reflectance exceeding 0.8%, indicative of medium-volatile bituminous rank, has been reported locally in the Calub area [8], though these data require verification against current ASTM standards. Coals intersected in the Ogaden Basin drill holes are predominantly classified as high-volatile C bituminous to high-volatile B bituminous. Wolela [8] reported calorific values (daf) ranging from 5,500 to 7,000 kcal/kg. Utilizing the Parr formulas to convert dry, ash-free (daf) basis to moist, mineral-matter-free (mmmf) basis places the upper range of these coals firmly within the high-volatile C bituminous rank. Some samples at the lower end of the range (5,500 kcal/kg daf) may classify as sub-bituminous A, suggesting lateral or vertical facies variations within the basin [9].

3.2. Proximate and Ultimate Analysis

Proximate analysis data reveals significant variability in ash yield, volatile matter, and fixed carbon. Proximate analysis indicates significant inorganic contamination. Mean ash yields for run-of-mine Mugher coal exceed 30% (db) [9], attributed to inter-seam mudstone and shale partings. Limited published washability data suggest that crushing to <10 mm and dense medium separation can reduce ash yield to 15–18%, though recovery rates remain undocumented. Regarding slagging, while high ash yields increase total ash load, the specific slagging propensity is controlled by the dominance of quartz and kaolinite over pyrite and siderite in Ethiopian coals, resulting in generally moderate ash fusion temperatures (AFTs > 1,250°C). Total sulphur content in Ethiopian coals exhibits a strong paleoenvironmental control. Coals of fluvial-limnic origin (e.g., Mugher, Chilga) typically contain < 0.8% total sulphur, predominantly in organic form [10]. In contrast, coals influenced by marginal marine conditions in the Ogaden Basin display elevated sulphur (>1.5%) with increased pyritic sulphur fraction. This distinction is critical; the predominance of organic sulphur in the former renders conventional physical desulphurization ineffective.

3.3. Petrographic Composition and Reactivity

Maceral analysis reveals that Ethiopian coals are typically vitrinite-dominated (40–70 vol%, mineral-free basis), with liptinite contents reaching up to 15% in Cenozoic deposits. While vitrinite and liptinite are classified as reactive macerals in coking and liquefaction contexts, the inertinite fraction in Ethiopian coals often contains significant semi-fusinite. Under high-temperature gasification conditions (>1,200°C), semi-fusinite exhibits partial reactivity, contributing to char conversion. The high volatile matter yields (40–50% daf) correlating with these maceral assemblages suggest that entrained-flow gasification may be a technically viable conversion route, though pilot-scale data are absent [11].

4. Resource Estimation and Economic Potential

Quantitative assessment of national coal resources constitutes a prerequisite for evidence-based energy policy and mineral development planning. Earlier assessments (e.g., Ethiopian Ministry of Mines, 1970s–1980s) relied on limited reconnaissance mapping. Subsequent systematic surveys by the Ethiopian Geological Survey, in collaboration with the Geological Survey of Finland, have improved spatial resolution and lithostratigraphic control. However, comprehensive geophysical and geochemical characterization remains incomplete [12].

4.1. Proven, Probable, and Inferred Reserves

The most significant quantified coal occurrences are in the Dagaga and Chichu areas of the Ogaden Basin. Measured and indicated resources are estimated at 300 million tonnes, with inferred resources exceeding 1 billion tonnes [12]. These remain classified as resources, not reserves, as no publicly available feasibility study demonstrating economic extraction under specified conditions has been completed. In the Blue Nile Basin, the Chilga area hosts an estimated 80 million tonnes of lignitic to sub-bituminous coal resources, characterized by high moisture (18–25%) and ash (12–20%) content. These coals have not been subjected to detailed washability or combustion efficiency studies required for reserve declaration [13]. The Mugher area hosts Ethiopia's only current coal mining operation, supplying approximately 25,000 tonnes annually to the adjacent cement factory. Systematic resource delineation remains incomplete, with historical drilling suggesting 15–20 million tonnes of medium-volatile bituminous coal. Jema remains underexplored with limited reconnaissance data only. Nationally, total in-place coal resources (measured, indicated, & inferred) are estimated at 1.5–2.5 billion tonnes [14].

4.2. Economic Geology and Mining Considerations

Economic viability is constrained by geological, infrastructural, and market factors beyond aggregate tonnage. Project finance requirements under Equator Principles and IFC Performance Standards impose additional technical and social due diligence thresholds not yet met by any Ethiopian coal project. Key constraints include: (i) seam thickness (averaging 1.2–2.0 m, compared to >2.5 m in major open-cut operations globally); (ii) cover depth (15–60 m at Chilga, >120 m at Ogaden); (iii) adverse stripping ratios; and (iv) structural discontinuities, including normal faulting with throws of 3–8 m documented in Mugher exposures. While shallow cover (<50 m) at Chilga and Mugher permits open-pit extraction, stripping ratios are poorly constrained. Preliminary exploration drilling suggests ratios of 8:1 to 15:1 at Chilga and 6:1 to 12:1 at Dagaga marginal to sub-economic under 2023–2025 thermal

coal price forecasts (USD 80-100/tonne FOB). No geotechnical optimization studies have been conducted to evaluate high wall stability or pit slope angles. Ogaden Basin deposits face prohibitive sovereign risk and infrastructure deficits. The region lacks paved roads, rail connectivity, reliable power, or perennial water sources. Security conditions remain volatile, with armed conflict and contested governance structures deterring exploration investment since 2007. Any commercial development would require: (1) A revised federal-regional revenue sharing framework; (2) Security guarantees underwritten by federal military deployment; (3) Capital expenditure exceeding USD 450 million for a 180 km rail spur, water pipeline, and process plant an investment exceeding the total historical foreign direct investment in Ethiopian hard rock mining [15].

5. Historical Development Attempts and Contemporary Status

Despite multiple exploration campaigns since the 1950s, Ethiopia has never achieved sustained commercial coal production [8]. This reflects a pattern of 'sporadic foreign interest without local institutional absorption.

5.1. Early Exploration and Abortive Projects

Systematic geological mapping and coal exploration in Ethiopia began in the late 1950s, led by the Ethiopian Institute of Geological Surveys (EIGS) in collaboration with UNDP and UNESCO. Artisanal coal extraction for brick firing and household use has been documented in Chilga and Mugher. The Mugher Cement Factory was initially engineered to utilise local coal, and a captive mine was developed in the late 1980s. Post-commissioning audits identified inconsistent calorific value (18–22 MJ/kg), high ash content (>30%), and frequent mill blockages as causes of operational failure. By 1998, the plant had fully transitioned to heavy fuel oil [16]. The Mugher failure exemplifies the consequences of institutional fragmentation between mining and industrial policy in Ethiopia.

5.2. Current Activities and Policy Stance

As of 2023, Ethiopia has no operational large-scale coal mine. Sporadic artisanal extraction continues in Chilga, Delbi-Moye, and Yayu, primarily for local brick production. Ethiopia's Growth and Transformation Plan II (2015–2020) referenced coal only once, under 'mineral development', without specific targets. The 2021–2030 National Energy Policy omits coal entirely, prioritizing hydropower, solar, and wind [17]. Although the Mining Proclamation No. 678/2010 provides a general licensing framework, Ethiopia lacks coal-specific environmental regulations and beneficiation standards. This regulatory gap, combined with the absence of coal from national energy strategies, has deterred private investment. The global

trend toward fossil fuel divestment, particularly after the 2015 Paris Agreement, has coincided with and likely reinforced waning international interest in Ethiopian coal exploration.

6. Technical and Non-technical Challenges to Development

Unlocking Ethiopia's coal potential requires a clear-eyed diagnosis of the multifaceted obstacles that have historically precluded success.

6.1. Geotechnical and Quality-related Challenges

Proximate analysis of coal samples from the Yayu Basin indicates ash content ranging from 25% to 45% (db) and inherent moisture from 8% to 15%, significantly exceeding the <15% ash threshold typically required for pulverized coal combustion without pre-treatment. Without beneficiation, the high-ash Yayu coal exhibits a gross calorific value (GCV) of approximately 4,200 kcal/kg, compared to > 6,000 kcal/kg for typical imported coal landed at Djibouti. At an import parity price of \$80/ton, the unwashed Ethiopian coal, even at zero mining cost, would incur a calorific-value penalty rendering it economically unviable for existing cement or textile plants. Coal seams in the Delbi-Moye Basin are typically 0.6–1.2 m thick and exhibit pinch-out geometry over lateral distances of <500 m, as evidenced by 15 exploration boreholes drilled by the Ethiopian Institute of Geological Surveys (EIGS, 2015). This geometry precludes longwall mining and necessitates bord-and-pillar methods with selective mining, increasing ROM dilution rates to an estimated 25-35%. A systematic review of the literature reveals no publicly available, peer-reviewed datasets quantifying trace element concentrations (Hg, As, Se, Pb) in Ethiopian coals. A single gray literature report by the United Nations Development Programme indicates elevated vanadium in the Chalali deposit, but modern ICP-MS analysis has never been published. This absence precludes quantitative environmental risk assessment and prohibits benchmarking against global coal quality standards [18].

6.2. Infrastructural and Logistical Deficits

The spatial disconnect between coal production zones (Ogaden, Delbi-Moye) and consumption nodes (Addis Ababa, Dire Dawa) impose a transport cost burden exceeding \$0.12/ton/km under current road freight tariffs. The Mekele coal deposit is located 780 km by road from Addis Ababa and 450 km from the Port of Djibouti. The Ogaden Basin deposits exceed 900 km from any existing railhead. Ethiopia's rail network density is 0.03 km/100 km², one of the lowest in sub-Saharan Africa, with no connectivity to coal basins. Trucking costs are estimated at \$0.08–\$0.12/ton/km on gravel roads (Class III-IV), compared to \$0.03/ton/km for rail in South Africa. This differential

would add \$60–\$90/ton to the delivered cost of coal in Addis Ababa, effectively doubling the mine-gate price. The Ogaden Basin is classified as hyper-arid (precipitation <200 mm/yr). Mean annual runoff is zero, and groundwater yields from the Jesomma aquifer are <2 L/s. A 500 MW USC coal plant would require ~50,000 m³/day for cooling, equivalent to the domestic water demand of a city of 500,000 people. Dry-cooling technology reduces water consumption by 80% but increases parasitic load and capital expenditure by 7–10% [19].

6.3. Economic, Financial, and Market Barriers

A 2 Mtpa Greenfield opencast coal mine in Ethiopia is estimated to require \$250–\$400 million in initial capital expenditure (CAPEX), excluding dedicated rail spur construction (\$80–\$120 million) and mine-mouth power plant development (\$1.2–\$1.8 billion for 600 MW subcritical). Total integrated project costs could approach \$2 billion, representing a significant financing hurdle given Ethiopia's sovereign credit rating (CCC) and global capital constraints on fossil fuels. Over 130 global financial institutions have adopted coal exclusion policies (e.g., exit from thermal coal mining). This 'de-risking' of coal assets has increased the weighted average cost of capital (WACC) for African mining projects to 14–18%, compared to 6–8% for renewables, rendering Greenfield coal projects financially unviable without concessional finance or sovereign guarantees. Ethiopia currently lacks a commodities exchange or transparent benchmark pricing for solid fuels. Of 12 pre-feasibility studies for coal projects conducted between 2005–2020, none proceeded to bankable feasibility stage, with investors citing 'absence of long-term off take agreements' and 'inability to hedge Ethiopian birr inflation' as primary deterrents. The landed cost of imported thermal coal (6,000 kcal/kg NAR) at Djibouti port is currently \$95–\$105/ton (CFR). Adding \$25/ton road freight to Addis Ababa yields a delivered cost of \$120–\$130/ton. Unwashed Ethiopian coal (4,200 kcal/kg) requires a 30% higher mass flow rate to achieve equivalent heat input. On a \$/GJ basis, imported coal retains a 15–20% cost advantage even before accounting for higher O&M costs associated with domestic coal combustion [20].

6.4. Environmental and Social License to Operate

Ethiopian EPA review of the 500 MW Yayu Coal Project (2009–2013) resulted in three rounds of resubmission over water quality concerns, delaying final permitting by 18 months. Community opposition, documented in 23 formal grievances, focused on resettlement compensation and perceived inadequacy of the ESIA public consultation period. A 2021 survey of 400 households in the Delbi-Moye woreda found that while 68% of respondents acknowledged changing rainfall patterns, only 22% linked coal mining to climate change. However, 74% expressed concern regarding groundwater contamination, indicating that proximate environmental risks, rather than global

GHG emissions, constitute the primary barrier to social licensing. A World Bank-compliant ESIA for a large-scale mining project in sub-Saharan Africa typically requires 18–30 months and costs \$2–\$5 million (0.5–1.5% of total project CAPEX). For the Ethiopian context, additional time should be budgeted for capacity constraints within the EPA review panel, which historically averages 270 days for permit decisions versus the statutory 90-day limit [21].

7. A Paradigm Shift: Strategic Applications Beyond Conventional Power

While coal-fired power generation particularly subcritical pulverized coal plants has historically been the dominant mode of coal utilization, its viability in Ethiopia is constrained by environmental commitments, stranded asset risks, and the availability of cheaper renewable alternatives. This suggests the need to explore alternative value chains for domestic coal resources. A paradigm shift is required to identify niche, high-value applications that align with national development priorities and mitigate environmental impacts.

7.1. Coal as an Industrial Feedstock

The most immediate and strategic application is in energy-intensive industries. Cement Production: Ethiopia's booming construction sector drives cement demand. Clinker production is highly thermally intensive. Preliminary assessments suggest that Ethiopian lignite and sub-bituminous coals could partially substitute imported petcoke in cement kilns, potentially reducing foreign exchange expenditure, which exceeded USD 80 million in 2022. However, the economic viability depends on coal quality, transport logistics, and capital investment in emission control systems, which remain unverified at scale. This application can tolerate a wider range of coal quality than power generation [22]. Steel and Metallurgy: The government's ambition to develop a domestic steel industry would require coking coal or alternative reduction agents. Although Ethiopian coals are not suitable for conventional cokemaking, they may be considered in integrated steelmaking routes involving syngas-based DRI, provided that gasification technology can accommodate high-ash, low-rank feedstock's a technical challenge not yet demonstrated in Ethiopia [23]. Alternatively, coal could serve as a thermal energy source in ferroalloy smelting, though this would require pilot-scale validation.

7.2. Synthesis Gas and Chemical Production

This represents the most innovative and potentially transformative pathway. Through gasification, coal can be converted into a mixture of carbon monoxide and hydrogen (syngas). Coal gasification offers a potential pathway for domestic ammonia and urea synthesis, which could reduce fertilizer,

import dependency currently over 95% provided that the leveled cost of production is competitive with international market prices and alternative green ammonia routes [24]. Liquid Fuels: Fischer–Tropsch synthesis of liquid fuels from coal (CTL) has been commercially implemented only in South Africa, under exceptional geopolitical and economic conditions. For Ethiopia, the capital investment (exceeding USD 100,000 per barrel per day), water intensity, and life-cycle GHG emissions render CTL economically prohibitive and environmentally contradictory to national climate commitments, even with hypothetical CCUS integration [25]. Methanol and Derivatives: Methanol from coal gasification is a platform chemical for numerous industrial processes.

8. Community-scale and Niche Applications

Decentralized coal-fired micro-grids using CFB technology have been proposed in theory for resource-constrained settings, but no operational examples exist in Africa. In Ethiopia, the logistical burden of coal transport to remote deposits, combined with falling costs of solar battery mini-grids, makes this option economically uncompetitive and environmentally regressive.

The Imperative of Clean Coal Technologies (CCT) and Carbon Management.

To make any of the above pathways socially and environmentally acceptable, they must be designed from the ground up with CCT and carbon management as core pillars, not as afterthoughts.

8.1. Pre-combustion and Combustion Technologies

Coal Washing/Beneficiation: Mandatory to reduce ash and sulphur, improving efficiency and reducing downstream emission control burdens. High-Efficiency Combustion: For power generation, supercritical (SC), ultra-supercritical (USC), and advanced ultra-supercritical (A-USC) steam cycles should be prioritized. While subcritical plants average ~33–35% efficiency (LHV basis), modern USC plants achieve 42–45%, and A-USC demonstrators have exceeded 48% efficiency. For industrial heat, modern kiln and furnace designs maximize heat recovery. Advanced Gasification: While Integrated Gasification Combined Cycle (IGCC) enables pre-combustion capture and lower flue gas treatment costs, its deployment for power generation has stalled due to high capital expenditure and operational complexity. Gasification remains commercially viable primarily for chemical feedstock (e.g., methanol, ammonia) rather than power-only applications [26].

8.2. Post-combustion Control and Carbon Capture, Utilization, and Storage (CCUS)

Emission Control Systems: Flue Gas Desulfurization

(FGD), Selective Catalytic Reduction (SCR) for NO_x, and electrostatic precipitators or bag houses for particulate matter must be standard. The CCUS Question: For large point sources like gasification plants or power stations, incorporating carbon capture is a necessary component of deep decarbonization scenarios for hard-to-abate industrial sectors. However, its role in power generation is contingent on natural gas prices, carbon pricing mechanisms, and competition from renewables plus storage. Captured CO₂ could be utilized for Enhanced Oil Recovery (EOR) in mature basins such as the Permian (US) or Alberta (Canada), where CO₂ pipeline infrastructure exists. However, EOR should be viewed as an interim utilization pathway; long-term climate benefits require dedicated geological storage in saline aquifers or depleted reservoirs. To offset cost barriers, project developers should align with Article 6.4 of the Paris Agreement (carbon crediting) and national incentives such as the US 45Q tax credit (\$85/tCO₂ for geological storage) or the UK CCS Infrastructure Fund. Notably, 'CCUS-readiness' has faced criticism for lacking enforcement; therefore, regulatory mandates (e.g., Canada's Clean Fuel Regulations) are likely more effective than voluntary planning [27].

9. Policy, Governance, and Investment Framework for Sustainable Development

A coherent, internationally aligned national strategy is the critical link required to transform Ethiopia's geological coal potential into commercially bankable projects.

9.1. Developing a Comprehensive Coal Policy

Drawing on the institutional failures observed in jurisdictions such as South Africa's Integrated Resource Plan disputes and India's coal allocation controversies, a legally binding National Coal Policy should mandate: (a) strategic reserves allocation, (b) binding emissions intensity targets, and (c) third-party audited licensing mechanisms demonstrably correlated with reduced rent-seeking.

9.2. Resource Mapping and Data Transparency

Experience from Peru's Geocatmin database and Tanzania's online mineral cadaster indicates that public geological data reduces information asymmetry but must be paired with fiscal stability agreements to materially de-risk investment [28].

9.3. Innovative Financing and Public-private Partnerships

In the context of Ethiopia's current economic landscape, the development of the domestic coal sector primarily centered in regions necessitates a shift toward Innovative Financing and

Public-Private Partnerships (PPPs) to mitigate high entry risks and capital demands. Under this framework, the Ethiopian government would likely act as an enabler by providing essential infrastructure, such as road networks and power connectivity, while securing long-term off-take agreements through state-driven sectors like the Ethiopian Sugar Industry Group and the massive domestic cement industry to replace expensive coal imports. Meanwhile, private partners would contribute specialized mining technology and private equity to optimize extraction and processing efficiencies. Leveraging the Ethiopian Investment Holdings (EIH) or seeking support from development finance institutions could provide the necessary de-risking mechanisms to transform Ethiopia's coal reserves into a viable feedstock for industrial industrialization, thereby reducing the nation's heavy reliance on foreign currency for energy inputs [29].

9.4. Regional Integration and Export Potential

A sequenced strategy is required: Phase 1 prioritizes import substitution to establish domestic refining capacity and fiscal capture; Phase 2 leverages overcapacity and by-product streams (e.g., ammonium nitrate from urea synthesis) for regional export. This trajectory mirrors Indonesia's post-2014 down streaming policy [30].

10. Conclusion

Ethiopian coal deposits represent a substantial, yet developing and misunderstood national resource. Their historical neglect is rooted in a confluence of geological challenge, infrastructural deficit, policy ambivalence, and the global zeitgeist against fossil fuels. However, this review has argued that a binary choice between renewables only and dirty coal is a false dichotomy for a nation at Ethiopia's stage of development.

The responsible development of coal is not about replicating the 19th-century industrial model. It is about leveraging 21st-century technology to extract maximum value from a domestic asset while minimizing its environmental footprint. By leapfrogging directly to advanced applications as a feedstock for industry and chemical synthesis, coupled with CCT and a roadmap for CCUS Ethiopia could potentially write a new chapter in resource governance. This path could provide affordable, dispatchable energy and raw materials to fuel industrialization, create skilled jobs, and reduce crippling import bills. The capital and stability generated by such industries could, in turn, accelerate the very transition to a renewable future by funding grid expansion, research, and development.

Ultimately, the future prospects of Ethiopian coal hinge on a bold, evidence-based, and transparent national conversation. It requires moving beyond dogma to a pragmatic assessment of tools available to build a secure and prosperous economy. With visionary policy, rigorous environmental stewardship, and strategic technological adoption, Ethiopia's coal deposits could paradoxically serve as a bridge to a more sustainable

and industrialized future, rather than an anchor to a polluting past. The window for such a deliberate, technology-led approach is narrow, but the potential rewards for national energy sovereignty and economic transformation are substantial.

Abbreviations

DRI	Direct Reduced Iron
CTL	Coal-to-Liquids
CFB	Circulating Fluidized Bed
IGCC	Integrated Gasification Combined Cycle
FGD	Flue Gas Desulfurization
SCR	Selective Catalytic Reduction
ESIAs	Environmental and Social Impact Assessments
PPPs	Public-Private Partnerships

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Author Contributions

Wakjira Tesfaye: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Data Availability Statement

No new data were generated or analyzed in support of this review article.

Conflicts of Interest

The author declares no conflicts of interest.

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