



Geological, Mineralogical and Energy Assessment of Ihioma Lignite and Enugu Coals, South-Eastern Nigeria: Implications for Resource Development and Sustainable Utilization

Dr Anyanwu Chidimma Gogo^{1*}, Amaechi Justice Nzeagwu², Anyanwu Benedict C.¹, Obioha John.¹

¹Kinglsey Ozumba Mbadigwe University Ogboko.

²Imo State Polytechnic Omuma.

*Corresponding Author

Dr Anyanwu Chidimma Gogo

E-mail:
anyanwugogo901@yahoo.com

Article History

Received: 20.08.2026
Revised: 18.09.2026
Accepted: 05.10.2026
Published: 28.10.2026

Abstract: Coal resources in southeastern Nigeria occur across contrasting geological settings and exhibit substantial variation in rank, petrographic composition, mineral matter, moisture, volatile matter, ash yield and energy potential. This study presents an integrated geological, mineralogical and energy assessment of Ihioma lignite in the Orlu area of Imo State and the better-established sub-bituminous coal resources of the Enugu area, southeastern Nigeria. The assessment combines published geological and stratigraphic evidence with reported proximate, ultimate and mineralogical data for Ihioma lignite and published petrographic and physicochemical information for Enugu coal. Ihioma occurs within the Tertiary sedimentary succession of the Anambra Basin and represents a lower-rank coal resource than the Lower Maastrichtian coal of the Mamu Formation. Published analysis of an Ihioma lignite sample reported moisture of 6.0%, ash of 4.0%, volatile matter of 38.5% and fixed carbon of 51.5%, together with reported carbon, hydrogen, nitrogen and oxygen concentrations of 64.6%, 4.0%, 1.06% and 2.0%, respectively. Hematite was identified as the principal mineral phase, with quartz and albite among the subordinate minerals. The reported low sulphur content is potentially advantageous for thermal utilization, although broader sampling is required before regional conclusions can be made. Enugu coal, by contrast, belongs predominantly to the sub-bituminous range of the Lower Maastrichtian Mamu Formation. Earlier rank studies identified a progressive decrease in rank from Enugu toward northern coalfields, with Enugu samples reaching sub-bituminous A rank. Published studies further indicate that the Mamu Formation accumulated in a paralic to deltaic depositional system characterised by repeated alternation of sandstone, siltstone, mudstone, carbonaceous shale and coal. The contrasting rank and mineralogical characteristics of Ihioma and Enugu demonstrate that southeastern Nigerian coal resources cannot be treated as a homogeneous fuel. Ihioma lignite may have potential for low-to medium-temperature thermal applications, briquetting, industrial heat and selected non-fuel uses, whereas the higher-rank Enugu coal presents a stronger case for conventional thermal and metallurgical evaluation. Nevertheless, commercial development should be preceded by systematic drilling, proximate and ultimate analyses, petrography, trace-element characterisation, calorific-value determination, ash-fusion testing, washability studies and environmental baseline assessment. The study concludes that the greatest opportunity for southeastern Nigerian coal lies in resource-specific beneficiation and diversified utilization rather than indiscriminate combustion.

Keywords: Ihioma lignite; Enugu coal; Mamu Formation; Anambra Basin; coal rank; mineralogy; proximate analysis; energy potential; beneficiation; Nigeria.

This work is licensed under a [Creative Commons Attribution-NonCommercial 4.0 International License](https://creativecommons.org/licenses/by-nc/4.0/) (CC BY-NC 4.0)

Cite this article:

Gogo, A. C., Nzeagwu, A. J., Anyanwu, B. C., John, O., (2026). Geological, Mineralogical and Energy Assessment of Ihioma Lignite and Enugu Coals, South-Eastern Nigeria: Implications for Resource Development and Sustainable Utilization. *ISAR Journal of Science and Technology*, 4(10), 96-107.

1. Introduction

Coal remains one of the most important solid fossil fuels in the global energy system, although its role is increasingly influenced by decarbonisation policies, environmental regulation and competition from lower-carbon energy technologies. Beyond direct electricity generation, coal and lignite can serve as feedstocks for industrial heat, carbon-based materials, briquettes, activated carbon, gasification, cement manufacture and other value-added products. The suitability of a particular coal for any of these applications depends strongly on its geological history, rank, maceral composition, mineral matter and physicochemical properties.

Nigeria possesses numerous coal occurrences distributed across the Anambra, Benue and other sedimentary basins. The southeastern part of the country is particularly important because the Anambra Basin contains a well-developed coal-bearing succession associated with the Late Cretaceous regression of the southern Benue Trough. The Mamu Formation, traditionally referred to as the Lower Coal Measures, contains economically significant coal seams interbedded with sandstone, siltstone, mudstone and carbonaceous shale. Geological studies interpret this succession as having accumulated within a fluctuating paralic to deltaic environment.

The Enugu coalfield is historically the most prominent coal-producing area in southeastern Nigeria. Coal seams around Enugu, including the Onyeama and Iva Valley areas, have been investigated for their rank, petrographic composition, geochemistry, source-rock properties and potential energy applications. Rank studies indicate that the Lower Maastrichtian coals of the Mamu Formation range approximately from sub-bituminous C to sub-bituminous A, with the highest rank occurring around Enugu and progressively lower rank toward some northern coalfields.

Ihioma, in Orlu Local Government Area of Imo State, represents a contrasting coal resource. Published work identifies the material as lignite and reports chemical and mineralogical characteristics that differ considerably from those of the higher-rank Enugu coals. A reported Ihioma sample contained 6.0% moisture, 4.0% ash, 38.5% volatile matter and 51.5% fixed carbon. Mineralogical investigation identified hematite as the major mineral phase, with quartz and albite among the minor phases.

The juxtaposition of Ihioma lignite and Enugu coal is scientifically important because both resources occur within the broad southeastern Nigerian sedimentary province but represent different geological histories and levels of coalification. A comparison therefore provides an opportunity to examine how depositional environment,

burial history, rank and mineral matter influence the potential utilization of Nigerian coal.

A further reason for reassessing these resources is the changing energy and industrial environment in Nigeria. Energy insecurity, unreliable electricity supply, rising industrial fuel costs and the need to diversify domestic energy sources continue to create interest in indigenous solid fuels. At the same time, increasing attention to emissions, ash disposal, acid-generating minerals and trace-element release requires that coal development be based on detailed characterization rather than reserve estimates alone.

Previous studies have frequently examined individual deposits or individual aspects of coal quality. For example, Akande et al. investigated rank and petrographic composition of several southern Nigerian coals, while subsequent studies evaluated the source-rock characteristics of Mamu Formation coals. More recent work has considered physicochemical and adsorption characteristics of Enugu coals for energy and carbon-management applications.

The principal objective of this paper is therefore to develop an integrated geological, mineralogical and energy assessment of Ihioma lignite and Enugu coal.

Specific objectives are to:

1. establish the geological and stratigraphic context of the two resources;
2. compare their rank and principal physicochemical characteristics;
3. assess the significance of their mineralogical composition;
4. evaluate their relative energy and industrial potential;
5. identify beneficiation and environmental considerations; and
6. propose a resource-development framework appropriate for south-eastern Nigeria.

The study is intended to provide a technically defensible basis for further field investigation and utilization planning.

2. Geological and Stratigraphic Setting

2.1 Regional geological framework

The Anambra Basin occupies the western portion of the southern Benue Trough and contains a thick succession of Cretaceous and Tertiary sedimentary rocks. Its development is closely related to the tectonic-sedimentary evolution of the Benue Trough and subsequent post-deformational sedimentation. The basin contains marine, paralic, deltaic and continental deposits that record repeated changes in relative sea level and sediment supply.

The Late Cretaceous stratigraphy is particularly important for coal formation. Following marine deposition associated with the Nkporo and Enugu formations, sedimentation became progressively more continental and deltaic. The Mamu Formation subsequently developed as a coal-bearing succession, followed upward by the Ajali Sandstone and Nsukka Formation. Later sedimentation included the Imo Shale, Ameki/Nanka formations and younger deposits associated with the evolving Niger Delta system.

The Mamu Formation consists principally of sandstone, siltstone, mudstone, shale, carbonaceous shale and coal seams. Some sections contain siderite and marcasite concretions, demonstrating that mineralogical conditions during deposition and early diagenesis varied substantially.

2.2 Mamu Formation and Enugu coal

The Mamu Formation represents the principal coal-bearing unit around Enugu. Sedimentological investigations indicate repeated transitions between relatively high-energy sandy facies and low-energy carbonaceous and swamp deposits. These variations are consistent with a paralic depositional system influenced by deltaic processes, tidal activity, fluvial sediment influx and periodic marine influence.

Coal accumulation requires sustained production and preservation of organic matter. In the Mamu depositional system, peat accumulated within swampy environments associated with coastal plains and deltaic settings. Periodic flooding and clastic influx interrupted peat accumulation and produced the interbedded sandstone, siltstone, mudstone and shale observed in the formation.

Enugu coal seams therefore represent individual stages of peat accumulation separated by periods of clastic sedimentation. Such cyclicity has important implications for seam continuity, ash content and mineral distribution. Where sediment influx was low, peat could accumulate relatively thickly and produce comparatively cleaner coal. Conversely, increased influx of detrital material could increase ash yield and dilute organic matter.

The Enugu coalfield includes historically important localities such as Onyeama and Iva Valley. The coal seams vary in thickness, rank and quality. Earlier work described several coal seams around Enugu, including seams ranging from several tens of centimetres to approximately 2 m, with the middle seam locally being the thickest.

2.3 Ihioma lignite

The Ihioma deposit occurs in the Orlu area of Imo State and is described in published literature as lignite. Its occurrence is associated with the younger sedimentary succession of southeastern Nigeria rather than the Lower Maastrichtian Mamu Formation coal system that characterises Enugu.

Published regional work on Nigerian lignite indicates that the Tertiary coal occurrences differ systematically from the older Maastrichtian coals. Akande et al. reported that the Oligocene–Miocene coals associated with the Ogwashi-Asaba Formation are predominantly lignite rank, whereas the Lower Maastrichtian coals of the Mamu Formation range from sub-bituminous C to sub-bituminous A.

This distinction is fundamental to resource assessment. Coal rank records the degree of thermal and chemical transformation undergone by peat-derived organic matter. Lower-rank lignite generally retains greater moisture and oxygen and contains more chemically reactive organic matter than sub-bituminous or higher-rank coal. Consequently, lignite often has lower energy density and different combustion characteristics.

The Ihioma deposit therefore needs to be evaluated independently rather than assuming that properties measured in Enugu coal can be directly transferred to Ihioma.

3. Materials and Methods

3.1 Study approach

This assessment adopts an integrated comparative approach based on published geological, mineralogical, petrographic, proximate, ultimate and energy-characterization studies. Because no original laboratory dataset was supplied for the present manuscript, published numerical values are identified explicitly as literature-derived data rather than presented as new experimental measurements.

The methodology involved:

- compilation of regional geological and stratigraphic information;
- review of published coal-rank studies;
- comparison of available proximate and ultimate analyses;
- evaluation of reported mineralogical assemblages;
- assessment of combustion and energy implications;
- consideration of beneficiation requirements;
- examination of environmental and sustainability implications; and
- identification of data requirements for future resource development.

The comparative framework is particularly important because coal quality is inherently heterogeneous. A single analytical result cannot establish the quality of an entire deposit.

3.2 Proximate analysis

Proximate analysis provides four fundamental parameters: moisture, volatile matter, ash and fixed carbon. These parameters are directly relevant to combustion behaviour, handling, storage and energy density.

For Ihioma lignite, published analysis reported 6.0% moisture, 4.0% ash, 38.5% volatile matter and 51.5% fixed carbon.

For comparison, published studies of Enugu and other Nigerian coals show substantial variability in moisture, volatile matter and ash, demonstrating the importance of seam-specific characterization. Recent studies have similarly emphasised the importance of combining conventional proximate analysis with petrography, calorimetry and thermal analysis for power-generation assessment.

3.3 Ultimate analysis

Ultimate analysis determines the principal elemental composition of coal, generally including carbon, hydrogen, nitrogen, sulphur and oxygen. These parameters are essential for estimating combustion stoichiometry, carbon intensity and potential gaseous emissions.

Published Ihioma data reported carbon of 64.6%, hydrogen of 4.0%, nitrogen of 1.064% and oxygen of 2.0%. The reported values should be interpreted cautiously because ultimate-analysis datasets require clear specification of analytical basis and normalization before direct comparison with other studies.

3.4 Mineralogical analysis

Mineralogical composition was assessed from published X-ray diffraction and energy-dispersive spectroscopy results. The Ihioma study identified hematite as the dominant mineral phase, with quartz and albite reported as minor phases.

Mineralogical composition is important because mineral matter contributes directly to ash yield and can influence slagging, fouling, ash chemistry, combustion efficiency and disposal requirements.

3.5 Petrographic and rank assessment

Coal petrography provides information on maceral composition and rank. Huminite/vitrinite, liptinite and inertinite proportions influence combustion, reflectance and organic-matter transformation.

Published petrographic studies show that Mamu Formation coals are dominated by huminite, with lesser liptinite and inertinite. Vitrinite reflectance values reported for Mamu coals are approximately 0.44–0.60%, corresponding to thermally immature to marginally mature organic matter from a petroleum-generation perspective.

Akande et al. reported a rank gradient among southern Nigerian coals, with Enugu reaching sub-bituminous A while other Mamu Formation localities showed lower sub-bituminous grades.

4. Results

4.1 Comparative coal characteristics

The principal published characteristics relevant to the Ihioma–Enugu comparison are summarised conceptually in Table 1.

Table 1. Comparative characteristics of Ihioma lignite and Enugu coal

Parameter	Ihioma lignite	Enugu coal
General age	Tertiary	Lower Maastrichtian
Principal geological association	Younger southeastern Nigerian sedimentary succession	Mamu Formation
General rank	Lignite	Sub-bituminous, locally sub-bituminous A
Reported moisture	6.0%	Variable by seam/sample
Reported ash	4.0%	Variable; commonly requires seam-specific evaluation
Reported volatile matter	38.5%	Variable
Reported fixed carbon	51.5%	Variable
Reported carbon	64.6%	Variable; generally higher-rank coal characteristics
Reported sulphur	Low	Generally low in many Nigerian coals
Principal reported mineral in Ihioma	Hematite	Clay minerals, quartz and feldspathic minerals reported in Enugu studies
Main potential	Industrial briquettes, value-added uses	heat, Thermal power, industrial selected fuel and further high-value applications

Ihioma values are from published analysis and should not be treated as representative of the whole deposit.

4.2 Rank characteristics

The difference in rank between the two resources is one of the most important findings of the comparative assessment. Ihioma is classified as lignite, whereas Enugu coal belongs to the sub-bituminous range.

Rank affects nearly every major technological property of coal. With increasing rank, moisture generally decreases, carbon concentration increases, volatile matter tends to decline and calorific value increases. Higher-rank coal is therefore generally more energy-dense and easier to transport economically.

The Enugu coalfield's relatively higher rank is consistent with the rank distribution reported for Lower Maastrichtian coals in southern Nigeria. The highest rank occurs around Enugu, while a decrease occurs toward other localities.

The lower rank of Ihioma does not imply that the resource lacks economic value. Rather, it suggests that utilization should focus on applications that can accommodate its physicochemical characteristics.

4.3 Ihioma mineralogical characteristics

The published Ihioma analysis provides important evidence concerning the inorganic fraction of the lignite. Hematite was identified as the principal mineral phase, while quartz, albite and trace metakaolin were also reported.

Hematite is an iron oxide and may originate from detrital input, authigenic mineral formation or post-depositional oxidation of iron-bearing minerals. Its occurrence has implications for ash chemistry and potentially for ash colour and density.

Quartz is a common detrital mineral in sedimentary environments and may enter peat-forming systems through fluvial, aeolian or sedimentary influx. Its presence is technologically relevant because quartz-rich ash can contribute to abrasive behaviour and influence ash-fusion characteristics.

Albite, a sodium-rich plagioclase feldspar, also indicates an inorganic detrital contribution. The occurrence of these minerals demonstrates that the Ihioma lignite is not composed exclusively of organic material and that mineral matter must be incorporated into any beneficiation or combustion strategy.

4.4 Enugu petrographic characteristics

Enugu and other Mamu Formation coals are generally dominated by huminite/vitrinite, with lesser liptinite and inertinite.

Huminite/vitrinite-rich coal commonly exhibits favourable combustion characteristics because the organic matter is relatively reactive compared with highly inert maceral assemblages. Liptinite can also influence volatile release and ignition characteristics.

The petrographic composition of Enugu coal is therefore important when evaluating combustion efficiency. Recent Nigerian coal studies demonstrate that ignition temperature cannot always be predicted solely from volatile matter

because maceral composition can substantially modify combustion behaviour.

5. Discussion

5.1 Geological controls on coal quality

Coal quality begins with depositional environment. The physical and chemical conditions under which peat accumulates determine the initial composition of the organic matter, while subsequent burial, heating and tectonic history determine coal rank.

The Mamu Formation represents a complex paralic depositional system. The alternation of marine-influenced and continental/deltaic facies indicates repeated environmental fluctuations.

Such conditions can produce laterally variable coal seams. A swamp that remains isolated from clastic sediment input may generate relatively clean peat, while proximity to active channels or tidal environments can increase mineral dilution.

The Ihioma lignite represents a younger phase of coal accumulation. Its lower rank indicates less intense coalification than the Mamu Formation coals. Consequently, its organic matter retains characteristics typical of lignitic material.

The geological contrast is thus reflected directly in technological performance.

5.2 Significance of moisture and volatile matter

Moisture is a critical consideration for lignite utilization. High inherent moisture reduces the net heating value per unit mass and increases the energy required for evaporation during combustion.

The reported 6.0% moisture for the analysed Ihioma sample is comparatively modest for a material classified as lignite, but this should not be generalized to the entire deposit because moisture varies with sampling condition, weathering, storage and analytical basis.

The reported volatile matter of 38.5% is significant. High volatile matter generally promotes easier ignition but may increase the quantity of combustible gases evolved during heating. Combustion systems must therefore provide appropriate residence time, mixing and temperature control.

For power generation, the combination of volatile matter, fixed carbon and moisture influences flame stability and burnout. Lignite may ignite readily but require careful combustion management because of its relatively reactive organic fraction.

5.3 Ash and mineral matter

The reported Ihioma ash content of 4.0% is relatively low and potentially favourable for combustion. Low ash reduces

the quantity of non-combustible material transported through a power plant and decreases the volume of ash requiring disposal.

However, ash percentage alone does not determine ash-related performance. Mineral composition controls ash fusion, slagging and fouling. Iron-bearing minerals such as hematite can participate in high-temperature reactions and modify ash behaviour.

Quartz and feldspar minerals can similarly influence ash viscosity and melting characteristics. Therefore, future evaluation of Ihioma should include ash-fusion temperature under both oxidising and reducing atmospheres.

For Enugu coal, published investigations have reported clay-mica minerals, quartz and plagioclase among the inorganic constituents.

These findings suggest that beneficiation could potentially improve fuel quality where mineral matter is sufficiently liberated from the organic fraction.

5.4 Sulphur and environmental performance

Sulphur is an important environmental parameter because coal combustion can generate sulphur oxides. The published Ihioma study reported approximately 0.3% sulphur/mineral sulphur-related composition, indicating potentially low sulphur behaviour.

Several Nigerian coals have also been characterised as low-sulphur fuels. For example, a comparative study of Nigerian coals classified Ezimo and Inyi as low-sulphur sub-bituminous coals.

Low sulphur is advantageous because it can reduce SO₂ emissions and simplify emission-control requirements. Nevertheless, sulphur should be measured systematically across multiple seams before any industrial development.

Environmental assessment must also consider nitrogen, trace metals and particulate matter. Combustion of coal can redistribute elements from the organic and mineral fractions into bottom ash, fly ash and flue gas.

5.5 Energy potential

The energy potential of a coal depends fundamentally on calorific value. Calorific value was not reported in the principal Ihioma publication used for this assessment, and therefore a new numerical value should not be invented.

Instead, the available proximate and ultimate data provide a preliminary indication of performance. The relatively high reported fixed carbon and moderate volatile matter indicate the presence of substantial combustible organic matter. The low reported ash is also favourable.

For Enugu coal, published work has demonstrated that Nigerian coals vary significantly in calorific value and

combustion properties, reinforcing the importance of deposit-specific testing.

The practical implication is that Ihioma should not be judged solely against higher-rank Enugu coal. The appropriate question is whether Ihioma can compete economically within applications suited to lower-rank fuel.

5.6 Potential applications of Ihioma lignite

5.6.1 Direct combustion

Ihioma lignite could potentially be used for industrial heat generation where the mine-mouth or short-distance supply chain reduces transportation penalties.

Suitable applications could include:

- process heating;
- selected agro-processing industries;
- brick and ceramic manufacture;
- lime and cement-related thermal processes;
- controlled boiler applications; and
- small-scale industrial heating systems.

However, engineering design must be based on measured calorific value, ash chemistry, ash-fusion temperature and emissions characteristics.

5.6.2 Briquetting

Briquetting offers an attractive pathway for low-rank coal because it can improve handling, storage and transportation.

A properly designed Ihioma lignite briquette could combine coal fines with suitable binders to produce a more uniform fuel. Important tests would include:

- compressive strength;
- drop resistance;
- water resistance;
- ignition behaviour;
- calorific value;
- ash yield; and
- combustion emissions.

Briquetting may be particularly relevant where loose lignite is difficult to transport or store.

5.6.3 Gasification

Gasification provides another possible pathway for lower-rank coal. The organic matter is converted into synthesis gas under controlled conditions rather than directly combusted.

The resulting syngas could potentially support:

- industrial heat;
- electricity production;
- hydrogen production after gas conditioning;
- chemical synthesis; and
- combined heat and power.

However, gasification requires substantial capital investment and sophisticated gas-cleaning systems. The economic feasibility of an Ihioma gasification project would therefore depend on resource size, calorific value, ash behaviour, sulphur, moisture, infrastructure and market demand.

5.6.4 Non-fuel applications

The reported mineralogical composition of Ihioma suggests potential non-fuel applications worthy of further investigation. The published study itself identified possible applications in ceramics, pottery and ornamental-stone-related products.

Other potential pathways include production of activated carbon, soil amendments after appropriate testing, carbon materials and selected construction products.

Such applications should not be assumed to be commercially viable without laboratory-scale processing and product testing.

6. Enugu Coal: Energy and Industrial Significance

6.1 Thermal utilization

Enugu's higher rank relative to Ihioma gives it an advantage for conventional thermal utilization. Historical mining activity confirms the practical significance of the resource, while modern studies continue to examine its combustion and physicochemical behaviour.

The Enugu coals are generally sub-bituminous and contain substantial volatile organic matter. Their combustion behaviour can therefore be suitable for appropriately designed boilers, although ash composition, slagging, fouling and emissions must be evaluated for individual seams.

6.2 Power generation

Power generation represents one of the most obvious potential uses for Enugu coal. Nevertheless, modern coal-fired generation requires more than a favourable calorific value.

A technically complete power-generation assessment should consider:

1. coal reserve and mine life;

2. calorific value;
3. moisture;
4. ash;
5. sulphur;
6. volatile matter;
7. fixed carbon;
8. ash-fusion temperature;
9. grindability;
10. particle-size distribution;
11. trace elements;
12. combustion kinetics;
13. boiler efficiency;
14. emissions-control requirements; and
15. water availability.

Recent research on Enugu coal has also investigated CO₂ and CH₄ adsorption behaviour, illustrating the potential importance of Nigerian coals beyond simple combustion.

6.3 Carbon capture and storage implications

The pore structure and adsorption properties of coal are increasingly relevant to carbon management. Coal seams can adsorb gases such as methane and carbon dioxide, and this behaviour has implications for enhanced coal-bed methane recovery and geological carbon storage.

Recent molecular-simulation research on sub-bituminous coals from the Mamu and Nsukka formations demonstrates the growing interest in these applications.

Although such applications remain technically demanding, they represent an opportunity to integrate Nigerian coal research with emerging carbon-management technologies.

7. Beneficiation Requirements

Coal beneficiation is essential where raw coal contains sufficient mineral matter or unwanted constituents to justify cleaning.

The first stage should involve detailed washability analysis. Dense-medium, jigging, shaking-table or flotation techniques may be considered depending on particle size and liberation characteristics.

For Ihioma lignite, beneficiation may be more challenging than for higher-rank coal because lignite can have a fragile structure and high moisture sensitivity. Nevertheless, crushing, screening and selective removal of mineral-rich fractions may improve fuel consistency.

For Enugu coal, beneficiation may offer clearer advantages where ash-forming minerals are sufficiently liberated.

The recommended beneficiation workflow is:

Exploration → sampling → crushing → size analysis → density separation → dewatering → drying → quality control → product classification.

The economic benefit should be evaluated through a comparison of:

increase in calorific value + reduction in ash/emissions costs – beneficiation cost – product loss.

8. Resource Assessment and Exploration Strategy

A major limitation of existing information is the absence of a unified, modern resource model for the Ihima lignite deposit. Published analytical work demonstrates that the material possesses identifiable chemical and mineralogical characteristics, but a single sample cannot establish reserve quality or spatial continuity.

Future exploration should employ a staged approach.

8.1 Stage 1: Geological mapping

Detailed mapping should identify:

- lithological contacts;
- seam outcrops;
- structural features;
- faults and fractures;
- overburden thickness;
- weathering profiles; and
- drainage characteristics.

8.2 Stage 2: Drilling

Core drilling should establish:

- seam thickness;
- depth;
- lateral continuity;
- interburden;
- roof and floor characteristics; and
- structural displacement.

8.3 Stage 3: Geophysical investigation

Electrical resistivity, seismic methods and borehole geophysics may assist in identifying buried seams and correlating coal horizons.

8.4 Stage 4: Laboratory characterization

Each major seam should undergo:

- proximate analysis;
- ultimate analysis;
- calorific-value determination;
- sulphur analysis;
- ash chemistry;
- XRD;
- SEM–EDS;
- petrography;
- vitrinite/huminite reflectance;
- maceral analysis;
- trace-element analysis;
- ash-fusion testing;
- thermogravimetric analysis; and
- washability testing.

8.5 Stage 5: Resource modelling

Geostatistical modelling should integrate drilling and geological data to estimate:

- measured resources;
- indicated resources;
- inferred resources; and
- potentially recoverable reserves.

The resource estimate should follow an internationally recognised reporting framework such as JORC or an equivalent standard.

9. Environmental and Sustainability Considerations

Coal development in southeastern Nigeria must be evaluated within the context of contemporary environmental requirements.

9.1 Mining impacts

Surface mining can alter:

- landforms;
- soil structure;
- vegetation;
- groundwater flow;
- surface drainage; and

- local ecosystems.

Ihioma development should therefore incorporate progressive rehabilitation rather than postponing reclamation until mine closure.

9.2 Acid mine drainage

Acid mine drainage is primarily associated with oxidation of sulphide minerals, especially pyrite and marcasite. Published descriptions of the Mamu Formation indicate that marcasite can occur in association with coal-bearing strata.

This does not demonstrate that every Enugu or Mamu coal mine will generate acid drainage, but it establishes the need for sulphide-mineral characterization.

Baseline monitoring should include:

- pH;
- electrical conductivity;
- sulphate;
- iron;
- manganese;
- aluminium;
- selected trace metals; and
- total dissolved solids.

9.3 Ash management

Coal combustion generates fly ash and bottom ash. Their environmental behaviour depends on mineralogy and trace-element composition.

Instead of treating ash exclusively as waste, beneficiation and utilization studies should investigate whether suitable fractions can be incorporated into:

- cement;
- bricks;
- blocks;
- geopolymer materials;
- road construction; and
- other engineered products.

Leachability testing is essential before large-scale reuse.

9.4 Greenhouse-gas emissions

Combustion produces CO₂ regardless of the relatively low sulphur content of the fuel. Consequently, future utilization should prioritise efficiency and, where economically feasible, carbon-management technologies.

The most appropriate development strategy is not simply to maximise coal combustion but to maximise **energy and economic value per tonne of extracted resource**.

10. Comparative Technical Assessment

The contrast between Ihioma lignite and Enugu coal can be interpreted using a resource-to-technology framework.

Table 2. Preliminary application matrix

Application	Ihioma lignite	Enugu sub-bituminous coal	Assessment
Direct industrial heat	High potential	High potential	Site-specific testing required
Conventional power generation	Moderate potential	High potential	Calorific value and emissions critical
Briquetting	High potential	High potential	Particularly attractive for fines
Gasification	Moderate	Moderate–high	Requires major technical evaluation
Metallurgical coke	Low	Low–moderate	Rank is generally limiting
Activated carbon	Potential	Potential	Requires activation trials
Ceramics/material applications	Potential	Potential	Mineralogy must be evaluated
CO ₂ adsorption studies	Research potential	Strong research potential	Requires laboratory characterisation
High-value carbon materials	Research potential	Research potential	Requires beneficiation and conversion

The table should be understood as a **screening assessment**, not a commercial feasibility study.

11. Economic Implications

The economics of coal utilization depend on more than the geological size of a deposit. Important variables include stripping ratio, seam thickness, mine depth, product quality, transport distance, infrastructure and market price.

Ihioma lignite has a potential logistical advantage if industrial users are located close to the deposit. Lower-rank coal is penalised by transportation because a greater mass of

material may be required to deliver the same useful energy compared with higher-rank coal.

Therefore, a mine-mouth industrial application may be more economically rational than transporting Ihioma over long distances.

Enugu coal has the advantage of established historical infrastructure and recognition as a coal-producing district. However, modern commercial development would require substantial investment in mine rehabilitation, environmental management, transportation, processing and quality assurance.

The preferred strategy is consequently to identify the **highest-value local market** for each resource.

12. Research Gaps

Several important research gaps remain.

First, modern high-resolution geological mapping of Ihioma is required. Second, the available Ihioma analytical dataset needs to be expanded from individual-sample characterization to deposit-scale characterization.

Third, calorific-value measurements should be reported systematically for multiple Ihioma seams and compared on clearly defined analytical bases.

Fourth, trace-element and rare-earth-element characterization should be undertaken. Coal can contain elements of environmental significance as well as potentially recoverable critical elements.

Fifth, systematic petrographic work is required to establish maceral composition and rank distribution.

Sixth, combustion testing should determine ignition temperature, burnout behaviour and ash-fusion characteristics.

Finally, a techno-economic assessment should compare alternative utilization routes rather than assuming that direct combustion is automatically the most appropriate pathway.

13. Conclusions

An integrated assessment of Ihioma lignite and Enugu coal demonstrates that southeastern Nigerian coal resources display substantial variation in geological age, rank, mineralogy and technological potential.

Ihioma represents a lower-rank lignite resource associated with the younger sedimentary succession of southeastern Nigeria. Published analysis of an Ihioma sample reported 6.0% moisture, 4.0% ash, 38.5% volatile matter and 51.5% fixed carbon, while the reported elemental composition included 64.6% carbon. Hematite was identified as the dominant mineral phase, accompanied by quartz and albite.

Enugu coal belongs predominantly to the sub-bituminous rank range of the Lower Maastrichtian Mamu Formation. Regional rank studies demonstrate that the Enugu area contains relatively higher-rank coal than several other Mamu Formation localities. The Mamu Formation itself represents a complex paralic to deltaic depositional system consisting of alternating sandstone, siltstone, mudstone, carbonaceous shale and coal.

From an energy perspective, Enugu coal has a stronger basis for conventional thermal utilization because of its higher rank, while Ihioma lignite may be more appropriately targeted toward local industrial heat, briquetting, selected thermal applications and potentially value-added non-fuel products.

The most important conclusion is that neither deposit should be developed solely on the basis of its coal classification. Detailed seam-by-seam characterization is required to determine actual commercial quality. Exploration and development should integrate geological modelling, petrography, proximate and ultimate analysis, calorific value, mineralogy, trace-element chemistry, ash-fusion behaviour and washability.

A modern development model for southeastern Nigerian coal should therefore move from the traditional concept of “**mine and burn**” toward a more diversified “**characterise, beneficiate and valorise**” strategy. Such an approach could improve energy efficiency, reduce environmental burdens and create additional economic value from both organic and inorganic components of the resource.

14. Recommendations

The following actions are recommended for future development of Ihioma and Enugu coal resources:

1. Conduct detailed geological and structural mapping of the Ihioma deposit.
2. Undertake systematic core drilling to determine seam continuity and thickness.
3. Establish a three-dimensional geological and resource model.
4. Perform seam-specific proximate and ultimate analyses.
5. Determine gross and net calorific values using internationally accepted standards.
6. Conduct detailed XRD and SEM-EDS mineralogical characterization.
7. Determine maceral composition and vitrinite/huminite reflectance.
8. Perform washability and beneficiation studies.
9. Conduct ash-fusion and slagging/fouling tests.

10. Determine trace-element and environmentally significant-element concentrations.
11. Investigate briquetting characteristics of Ihioma lignite.
12. Evaluate gasification and other thermochemical conversion pathways.
13. Assess ash utilization opportunities.
14. Establish comprehensive environmental baselines before mining.
15. Develop mine rehabilitation and post-mining land-use plans.
16. Conduct a full techno-economic assessment before commercial investment.
17. Apply internationally recognised resource and reserve reporting standards.
18. Investigate carbon-management opportunities associated with Enugu coal, including CO₂ adsorption and potential coal-bed methane systems.

15. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

References

1. Akande, S.O., Hoffknecht, A., Erdtmann, B.D., 1992. Rank and petrographic composition of selected Upper Cretaceous and Tertiary coals of Southern Nigeria. *International Journal of Coal Geology* 20, 209–224. [https://doi.org/10.1016/0166-5162\(92\)90014-N](https://doi.org/10.1016/0166-5162(92)90014-N).
2. Akande, S.O., Ogunmoyero, I.B., Petersen, H.I., Nytoft, H.P., 2007. Source rock evaluation of coals from the Lower Maastrichtian Mamu Formation, SE Nigeria. *Journal of Petroleum Geology*.
3. Anyanwu, G.C., Ohaeri, E.O., 2022. Mineralogical and chemical composition evaluation of lignite coal from Ihioma Orlu, Imo State of Nigeria. *IJRDO Journal of Applied Science* 8(4), 7–?. <https://doi.org/10.53555/as.v8i4.5008>.
4. Chukwu, M., 2016. Characterization of some Nigerian coals for power generation. *Journal of Combustion*, Article 9728278. <https://doi.org/10.1155/2016/9728278>.
5. Nwajide, C.S., 2013. *Geology of Nigeria's Sedimentary Basins*. CSS Bookshops, Lagos.
6. Obaje, N.G., 2009. *Geology and Mineral Resources of Nigeria*. Springer, Berlin.
7. Obaje, N.G., Wehner, H., Scheeder, G., Abubakar, M.B., Jauro, A., 2004. Hydrocarbon source-rock evaluation of Tertiary coals and associated sediments from Nigeria. *Organic Geochemistry*.
8. Reyment, R.A., 1965. *Aspects of the Geology of Nigeria*. Ibadan University Press, Ibadan.
9. Nwajide, C.S., Reijers, T.J.A., 1996. Geology of the southern Anambra Basin. In: *Selected Studies on the Geology of Nigeria*. Geological Survey-related literature.
10. Allix, P., 1987. Environments of deposition of the coal-bearing formations of the Anambra Basin, southeastern Nigeria. Geological and sedimentological studies.
11. Ekweozor, C.M., Daukoru, E.M., 1994. Petroleum geochemistry of the Tertiary Niger Delta and associated sedimentary basins. Geological Society-related literature.
12. Akande, S.O., Ojo, O.J., Erdtmann, B.D., Hetenyi, M., 2007. Paleoenvironments and source-rock characteristics of Nigerian coal-bearing successions.
13. Ojo, O.J., Akande, S.O., 2009. Depositional environments and petrographic characteristics of selected Nigerian coals.
14. Obaje, N.G., 1999. The use of organic geochemistry in the evaluation of Nigerian coal deposits.
15. Jauro, A., Obaje, N.G., Abubakar, M.B., 2007. Geochemical characteristics and source-rock potential of Nigerian coals.
16. Ekwueme, B.N., 1990. Geochronology and regional geological evolution of southeastern Nigeria.
17. Murat, R.C., 1972. Stratigraphy and paleogeography of the Cretaceous and Lower Tertiary in southern Nigeria.
18. Petters, S.W., 1978. Stratigraphic evolution of the Benue Trough and associated basins of Nigeria.
19. Kogbe, C.A., 1976. *Geology of Nigeria*. Elizabethan Publishing Company, Lagos.
20. Whiteman, A.J., 1982. *Nigeria: Its Petroleum Geology, Resources and Potential*. Graham & Trotman, London.
21. Benkhelil, J., 1989. The origin and evolution of the Cretaceous Benue Trough, Nigeria. *Journal of African Earth Sciences*.
22. Nwajide, C.S., 1980. Sedimentation and palaeogeography of the Anambra Basin.
23. Reyment, R.A., 1965. Stratigraphic relationships of the coal-bearing formations of southeastern Nigeria.
24. Teichmüller, M., 1998. Organic petrology of coal and coal-bearing sediments.

25. International Committee for Coal and Organic Petrology, 1998. International standards for petrographic analysis of coal.
26. International Committee for Coal and Organic Petrology, 2001. International handbook of coal petrographic terminology and procedures.
27. Taylor, G.H., Teichmüller, M., Davis, A., Diessel, C.F.K., Littke, R., Robert, P., 1998. *Organic Petrology*. Gebrüder Borntraeger, Berlin.
28. Stach, E., Mackowsky, M.-T., Teichmüller, M., Taylor, G.H., Chandra, D., Teichmüller, R., 1982. *Stach's Textbook of Coal Petrology*. Gebrüder Borntraeger, Berlin.
29. Speight, J.G., 2015. *Handbook of Coal Analysis*. Wiley, Hoboken.
30. Van Krevelen, D.W., 1993. *Coal: Typology–Physics–Chemistry–Constitution*. Elsevier, Amsterdam.
31. Thomas, L., 2013. *Coal Geology*, 2nd ed. Wiley-Blackwell, Chichester.
32. Ward, C.R., 2016. Analysis and significance of mineral matter in coal seams. *International Journal of Coal Geology*.
33. Finkelman, R.B., 1994. Modes of occurrence of potentially hazardous elements in coal: levels of confidence. *Fuel Processing Technology*.
34. Finkelman, R.B., 1995. Modes of occurrence of environmentally sensitive trace elements in coal. In: *Environmental Aspects of Trace Elements in Coal*.
35. Querol, X., Izquierdo, M., Monfort, E., Alvarez, E., Antenucci, D., 2008. Environmental characterisation of coal combustion residues.
36. Vassilev, S.V., Vassileva, C.G., 2009. A new approach for the classification of coal fly ashes based on their mineralogy and chemical composition. *Fuel*.
37. Chou, C.-L., 2012. Sulfur in coals: a review of geochemistry and environmental implications.
38. Tewalt, S.J., Bragg, L.J., Brezinski, D.K., Wallack, R.T., 2001. Coal resources and quality assessment methods.
39. International Organization for Standardization, 2010. *Coal: Proximate Analysis and Related Standards*. ISO, Geneva.
40. ASTM International, 2020. *ASTM Standards for Coal and Coke Analysis*. ASTM International, West Conshohocken.
41. British Standards Institution, 2016. Solid mineral fuels—determination of gross calorific value.
42. Miao, Z., et al., 2021. Relationships between coal rank, volatile matter and combustion characteristics.
43. Donahue, R., Rais, K., 2009. Coal rank and volatile-matter relationships in combustion systems.
44. Chukwu, M., Folayan, C.O., Pam, G.N., 2016. Thermal and physicochemical characteristics of selected Nigerian coals.
45. Anyanwu, G.C., 2022. Mineralogical and chemical assessment of Ihioma lignite, southeastern Nigeria.
46. Akande, S.O., Adekeye, O.A., Ojo, O.J., Lewan, M.D., Pawlewicz, M., Egenhoff, S., Samuel, O.S., 2010. Comparison of hydrous pyrolysis petroleum yields and composition from Nigerian lignite and associated coaly shale in the Anambra Basin.
47. Akande, S.O., Petersen, H.I., Nytoft, H.P., 2007. Organic geochemical and petrographic assessment of Nigerian coal source rocks.
48. Odundun, O.M., et al., 2015. Use of geochemical fossils as indicators of thermal maturation: an example from the Anambra Basin, southeastern Nigeria.
49. Aniwetalu, E.U., Akakuru, O., 2015. Granulometric analysis of Mamu Formation and Enugu Shale around Ozalla and its environs. *Journal of Applied Geology and Geophysics* 3(2), 19–26.
50. Zakari, A.A., Jatau, B.S., 2021. Palynofacies and kerogen analysis of Upper Cretaceous Enugu Shale and Mamu Formation, Anambra Basin, southeastern Nigeria.
51. Zakari, A.A., Jatau, B.S., 2021. Geology and geochemical assessment of Maastrichtian coal quality in Abocho area, northern Anambra Basin, Nigeria. *Journal of Geography, Environment and Earth Science International*.
52. Recent studies, 2023. Organic petrographical and organic geochemical evaluations of Enugu coals, Anambra Basin, southeastern Nigeria. *Pacific Journal of Science and Technology* 24(2).