Study to Investigate the Potential of Coalbed Methane (CBM) in Nigeria

Ibrahim Modibbo Ahmed* and **Saleem Qadir Tunio**, Cyprus International University, Nicosia, North Cyprus

Abstract

The increasing global demand for energy has led to a heightened interest in unconventional hydrocarbons, including coalbed methane (CBM), a type of natural gas found in coal deposits. This research explores the viability of utilizing CBM in Nigeria, focusing on four key basins, including Okpara, Onyeama, Okaba, and Owukpa basin. Key coal quality parameters, such as coal rank, depth, moisture content, ash content, and volatile matter, were analyzed and compared to data from prominent coal basins in the United States, Indonesia, China, India, Australia, and Canada.

The findings indicate that Nigerian coal is predominantly sub-bituminous, with an average moisture content of 10.95% by weight and is located at relatively shallow depths. These characteristics suggest that Nigeria has significant potential for CBM production, positioning it as a promising alternative energy source for the country.

Introduction

As conventional oil and natural gas supplies continue to decline globally, the need to explore unconventional energy sources has become increasingly urgent. Innovations in the petroleum industry have necessitated the development of new methods to exploit "unconventional" oil and gas reservoirs, which were previously untapped. According to the International Energy Agency's 2011 World Energy Outlook, unconventional hydrocarbons are those that cannot be extracted in their natural state from a conventional production well without the use of heating or dilution (Wolfson 2023). These resources include coalbed methane (CBM), shale gas, shale oil, tight gas, tight oil, coal seams, tar sands, and gas hydrates, all of which require advanced energy and technology to extract.

Geologically, unconventional hydrocarbons are solid, liquid, or gaseous hydrocarbons that originated from organic compounds in source rocks over geological time and may have undergone changes, especially in the case of solid particles and extra-heavy liquids (Chew 2013). Coalbed methane (CBM) is a type of natural gas primarily composed of methane, found within coal seams.

Many countries possess CBM reserves, but the United States, Canada, Australia, China, and India are the primary producers. According to the U.S. Energy Information Administration (Energy Information Administration 2023), the United States has approximately 11,878 billion cubic feet of proven CBM reserves, leading the global market. The profitability of CBM projects in the U.S. is influenced by various factors such as seam thickness, gas content, methane content, coal rank, and permeability (Green et al. 2019).

Nigeria, with over 2 billion metric tons of coal reserves, including 650 million tons of proven reserves (Bureau of Public Enterprises 2006), has significant CBM potential. Despite this, Nigeria's CBM resources remain largely undeveloped due to insufficient research into CBM's potential and the lack of development techniques to optimize its production. Nigeria's electricity sector also faces challenges; the country generates between 2,687 and 4,200 megawatts of power, far below the peak demand of 12,800 megawatts. 86% of Nigeria's electricity is currently generated from fossil fuels, particularly natural gas (Barka and Nur 2023). The

Improved Oil and Gas Recovery

DOI: 10.14800/IOGR.1286

Received May 17, 2024; revised July 1, 2024; accepted August 14, 2024.

*Corresponding author: modibbo.edu@gmail.com

decline in crude oil and natural gas production threatens the country's natural gas supply, which is crucial for power generation. CBM, as a clean source of natural gas, offers a viable alternative to replace natural gas as an energy source.

This research aims to evaluate the potential of coalbed methane (CBM) development in Nigeria by analyzing the physical properties of coal. The study is divided into two parts: the first part investigates the potential of CBM in Nigeria by examining coal quality parameters such as ash content, moisture content, and volatile matter. The second part compares the quality of Nigeria's coal with that of other CBM-producing countries, including the United States, China, India, and Indonesia.

Literature Review

Coal Characterization. Coal characteristics are determined through various methodologies and analytical tools that identify both the physical and chemical properties of coal. The two primary methods used for determining coal quality are proximate analysis and ultimate analysis.

Proximate Analysis: This method estimates key parameters such as calorific value, volatile matter, fixed carbon, and moisture content in coal (Ozbayoglu 2018).

Ultimate Analysis: This method independently identifies the elemental composition of coal, including carbon, hydrogen, nitrogen, sulfur, and oxygen. The results are often presented as percentages (SGS Corp 2022).

Coal is categorized into four distinct ranks based on its characteristics: anthracite, sub-bituminous, bituminous, and lignite, with lignite being the lowest grade, as shown in **Table 1**. The ranking of coal is primarily determined by two factors: the amount of thermal energy it can provide and the types and concentrations of carbon it contains. The quality of a coal deposit is influenced by the amount of pressure and heat it has been subjected to over time (Energy Information Administration 2022).

Table 1—Coal rank system (Adapted from Greb et al. 2017).

U.S. Rank (ASTM)			Calorific Value (dmmf) (Btu/lb.)	Volatile Matter (dmmf) (%)	Fixed Carbon (dmmf) (%)	Vitrinite reflectance in oil (%Ro)	Moisture Content (af) (%)	International Rank (ISO)		
High rank	Anthracitic	Meta-anthracite				~8.0		A	High rank	Anthracite
				2	98	~6.0				
High rank	Anthracitic	Anthracite				4.0, 3.0		B	High rank	Anthracite
				8	92	2.5				
High rank	Anthracitic	Semi-anthracite				2.0		C	High rank	Anthracite
				14	86	1.9				
Medium rank	Bituminous	low volatile						A	Medium rank	Bituminous
				22	78	1.5				
Medium rank	Bituminous	medium volatile				1.4		B	Medium rank	Bituminous
				31	69	1.1				
Medium rank	Bituminous	high volatile A				1.0		C	Medium rank	Bituminous
			14,000			0.8				
Medium rank	Bituminous	high volatile B						C	Medium rank	Bituminous
			13,000			~0.66				
Medium rank	Bituminous	high volatile C				0.6		D	Medium rank	Bituminous
			11,500							
Low rank	Sub-bituminous	A				0.5		D	Medium rank	Bituminous
			10,500			~0.49				
Low rank	Sub-bituminous	B						A	Low rank	Sub-bituminous
			9,500			~0.42				
Low rank	Sub-bituminous	C				0.4		A	Low rank	Sub-bituminous
			8,300			~0.37				
Low rank	Lignite	A					35	B	Low rank	Lignite
			6,300							
Low rank	Lignite	B						C	Low rank	Lignite
			5,000	> 60	25	~0.25	75			
Peat								Peat		

Global Coalbed Methane Reserves. As technology advances, the global demand for energy resources, particularly crude oil, continues to rise. Over the past decade, coalbed methane (CBM), an unconventional resource, has emerged as a viable alternative to meet the increasing energy needs within the global energy mix.

This growth in demand is driven by the expanding global economy and population, which require a consistent and reliable energy supply (Ritchie et al. 2020). The largest CBM reserves are located in countries such as Russia, the United States, China, Canada, Australia, Indonesia, Poland, Germany, and France (Mastalerz 2014). Specifically, the United States, Canada, China, Australia, and Russia hold the most significant CBM reserves (Liu et al. 2023).

The estimated global CBM reserves exceed 229 trillion cubic meters, presenting promising development prospects for this unconventional natural gas resource (Zhang et al. 2021). Australia has been actively involved in CBM extraction and is well-known for having significant reserves of CBM, which are expected to be between 8.3 to 14.3 trillion cubic meters (Liu et al. 2023). The nation's emphasis on using CBM as a fuel source is consistent with its dedication to more environmentally friendly energy options (Martin et al. 2021). Furthermore, Canada has been acknowledged for its involvement in the production of CBM, which adds to the country's energy portfolio (Cho et al. 2016).

CBM extraction in China saw its initial investigation in the 1980s (Yang 1987) and the country's first commercial production from a CBM well did not begin until 2003 (Qin 2006). China has made notable strides in improving CBM production techniques. Drilling cost reductions and enhanced single-well output have resulted from innovations in completion technology, reservoir reconstruction, and drilling techniques (Lu et al. 2021). More than 90% of China's CBM production comes from high-rank coal, making it an essential component of the country's CBM production (Liu et al. 2023). Due to its substantial CBM reserves, the nation plays a significant role in the worldwide CBM industry (Xia et al. 2019).

Globally, coal remains the primary source of electricity generation on almost every continent, providing a reliable and secure supply of electricity to both industrialized and developing countries (World Coal Association 2012). The properties of coal, such as ash content, moisture, fixed carbon percentage, sulfur content, tar and light oil percentage, etc., must be considered to optimize energy production efficiency.

Coal Reserve in Nigeria. In Nigeria, significant coal deposits are found across the country, particularly from the southern to the northeastern regions, where there are primarily four coal mines. The coal characteristics in each of these basins may vary, influencing their suitability for different energy production methods.

Nigeria is estimated to have 2.5 gigatons (Gt) of proven coal reserves. Approximately 90% of these deposits are composed of sub-bituminous and bituminous coals, with the remaining 10% being lignite. These coal deposits are located in the Lower, Middle, and Upper Benue Troughs. Lignite and sub-bituminous coals are predominant in the Lower and Upper Troughs, while high-volatile bituminous coals are more common in the Middle Trough. Significant coal sites include Lafia-Obi in the Middle Trough, and the Onyeama and Okaba mines in the Lower Trough (Oboirien et al. 2018).

Nigeria is home to over 23 coal mines (Oboirien et al. 2018). According to the Nigerian Coal Corporation, four underground mines—Okpara and Onyeama in Enugu State, Okaba in Kogi State, and Owukpa in Benue State—are currently producing coal. Additionally, there are 13 untapped coal reserves. Nigeria's primary coal reserves are found in the cretaceous Anambra basin to Benue basin of Bakina and Okigwe city of Imo state. The coal in this area is mostly found at the lower to upper grade of coal type (Adedosu et al. 2007).

The Enugu Coalfield, particularly the Okpara and Onyeama underground mines, is abundant in coal. These basins are part of the eastern extension of the Cretaceous Sedimentary Basin (Synclinorium). The Onyeama seam, for instance, is located where the Asata River cuts through the Enugu escarpment (Adedosu et al. 2010).

Orukpa and Okaba, both surface mines, are located in the north-central states of Benue and Kogi (Olaleye et al. 2009). The basic components of Okaba coal and shale are more abundant than global averages, although the trace amounts of heavy metals are well below coal quality standards. Okaba coal has an average moisture content of 12.51%, an ash content of 11.48%, and a volatile matter content of 47.49% (Fatoye et al. 2012).

Methodology

Study Area. This study primarily focuses on four of Nigeria's CBM basins: Okpara, Onyeama, Okaba, and Owukpa. All of these basins are located along or near the River Benue Channel. The Okpara and Onyeama basins, which show significant potential, are located in Enugu State in southeastern Nigeria, covering an area of over 667,000 acres. **Figure 1** provides a location map showing these basins, extending from the Bida Basin to the lower and upper Benue Trough Basin. The Okaba basin is situated in Kogi, near Lokoja, as marked on the Figure 1.

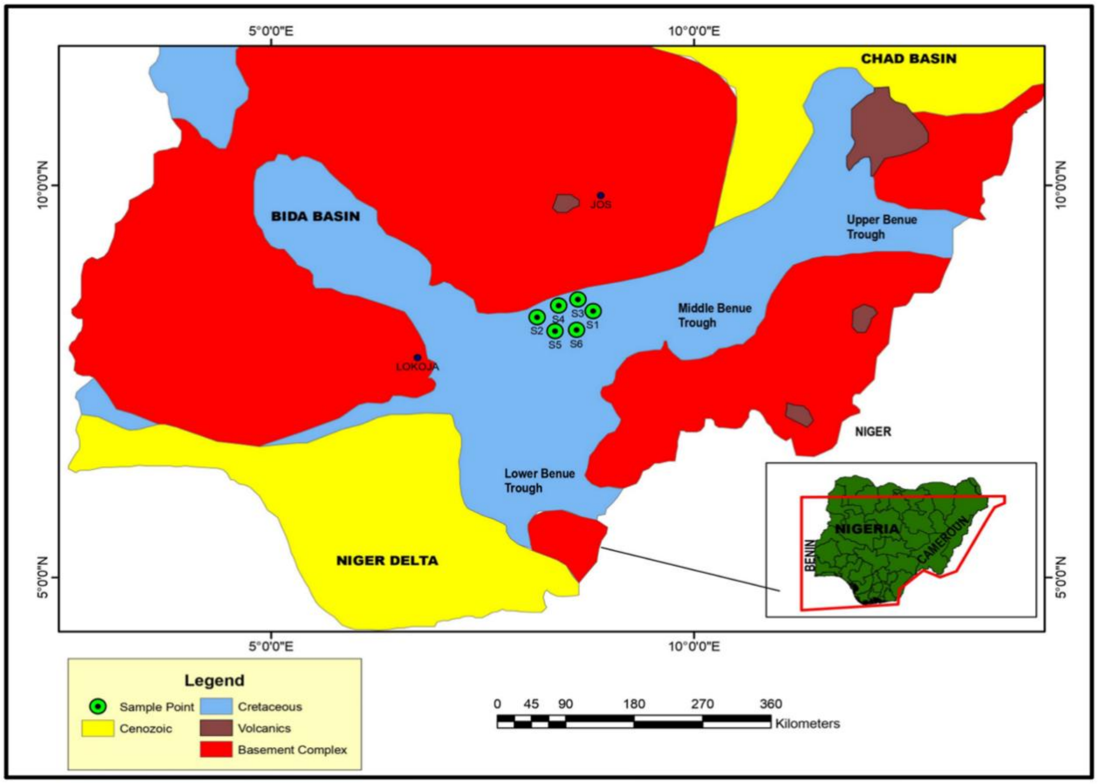

Figure 1—Coalbed methane producing fields in Nigeria (modified from Akinyemi et al. 2022).

Data Collection. Quantitative data on coal attributes and quality have been sourced from the Nigerian Coal Corporation (NCC), which is responsible for coal exploration and quality testing throughout the country. According to NCC data, there are currently four active coal mines in Nigeria, as detailed in **Table 2**. For this study, the collected coal data encompasses coal rank, seam depth, recoverable reserves, moisture content, volatile matter, ash content, and gas content.

Table 2—List of four CBM Basins in Nigeria.

No.	Basins	Location(state)	Status
1	Okpara	Enugu	Mining by excavating
2	Onyeama	Enugu	Mining
3	Okaba	Kogi	Operating coal mine
4	Owukpa	Benue	Mining

Data Analysis. The proximate analysis method was employed to assess the ash content, moisture content, calorific value, and volatile matter of the coal samples. For this analysis, 1 gram of each coal sample, passed through a 212 µm sieve, was used. Moisture content was determined using a LABCON air oven in accordance with the South African National Standards (SANS) 5925:2007. Volatile matter was analyzed using a volatile furnace based on ISO 562:1998. Ash content was evaluated with a LENTON programmable furnace, following ISO 1171:1997 guidelines (Taylor et al. 1998). Fixed carbon content in the coal was calculated using the appropriate formula as **Eq. 1**,

Fixed carbon (%) =100 – Moisture (%) – Ash (%) - Volatile Matter (%)...(1)

Porosity is determined through core analysis. Initially, the bulk and grain densities are measured, and porosity is then calculated by dividing the pore volume by the bulk volume.

With all necessary data collected and assumptions established, a comparative data analysis technique was used in this study. This approach involved examining CBM data from Nigeria and comparing it with data from CBM-producing countries such as the U.S., China, Indonesia, India, Australia, and Canada. The gas-proven results were calculated by multiplying the gas reserves (in million tons) by the gas content (cubic feet per ton).

Gas content (cubic feet)=Proven reserve (tons) * Gas content (cubic feet/ton)...(2)

Results and Discussions

The coal deposits in Nigeria are characterized by shallow depths, sub-bituminous rank, low ash content, and high volatile matter. As summarized in **Table 3**, coal from the four basins analyzed is classified as sub-bituminous coal, which is a low-rank coal type, according to the United States Geological Survey (U.S. Geological Survey 2017). Sub-bituminous coal, often gray-black or dark brown, represents an intermediate stage between lignite and higher-quality bituminous coal. It is widely used in power plants for steam generation and can also be liquefied to produce petroleum and natural gas (Energy Education 2008).

Table 3—Coal quality of four Nigeria`s basins.

Quality Parameter	Locations				
	Okapara	Onyeama	Okaba	Owukpa	Average
Proven Reserve(mt)	24	40	73	57	-
Coal Rank	Sub-bituminous	Sub-bituminous	Sub-bituminous	Sub-bituminous	Sub-bituminous
Depth (m)	180	100.2	100	100	120.05
Moisture (%)	7.5	12.61	15.4	8.3	10.95
Ash (%)	8.4	3.67	7.3	8.6	6.99
Volatile Matter	38.26	36.64	36.4	38.6	37.48
Gas Content (scf/ton)	312.14	312.14	312.14	312.14	312.14

The coal seams in Nigeria generally lie at shallow depths, around 100 meters, except for the Okapara basin in Enugu, where the formation reaches a depth of 180 meters. The average moisture content is 10.95%, while ash content varies from 3.67% to 8.6% in the Owukpa basin, with an overall average of 6.99%. The gas content of these CBM basins suggests significant potential for coal-bed methane production.

Mature coals, which are deeper and older, typically have higher carbon content and lower moisture and volatile materials. This results in increased carbon dioxide (CO_2) production during combustion or gasification, with fewer volatile gases such as methane and hydrogen. High ash content can lead to increased slagging and fouling in gasifiers, reducing gas production efficiency and increasing maintenance requirements. Additionally, inorganic chemicals in ash may react with gas-forming compounds, potentially altering the gas composition. High moisture content in gas can produce water vapor, which may dilute the desired gas products.

Nigeria's coal shows considerable potential for combustion processes which involve the burning of coal to release thermal energy which can be used to generate electricity, heat, or other industrial process, as it contains a high concentration of volatile matter, which facilitates gas generation, including flammable gases like methane, hydrogen, and carbon monoxide. The specific gas products can vary based on the volatile matter composition and the conditions of gasification or combustion. For example, methane tends to be the primary gas at lower temperatures, while higher temperatures may favor the production of carbon monoxide and hydrogen.

Table 4 provides a summary of the reservoir characteristics. The reservoir's porosity of 1.9% is considered low for a coal-bed methane (CBM) reservoir. Typically, a porosity greater than 5-10% is preferred, as it enhances the storage capacity for methane. However, it is worth noting that even reservoirs with lower porosity can still be productive, as several CBM reservoirs with similar characteristics have successfully generated gas.

Permeability of 45 millidarcies is considered moderate to good for coal beds. While methane flow through coal seams is generally more efficient at higher permeability levels, significant gas production can still occur at lower permeability values. The coal seam thickness of 1.7 meters, though not very substantial, can be viable for extraction if the porosity and permeability are adequate. Thicker coal seams typically offer more storage capacity for gas, which can lead to higher production rates.

Table 4—Average reservoir data.

Coal Thickness (m)	1.7
Porosity (%)	1.9
Permeability (mD)	45
Density (g/m^3)	1.4
Specific Gravity	1.33

Coalbed Methane (CBM) Reserve. The CBM reserves across these four basins have been evaluated based on an average gas content of 312.14 standard cubic feet per ton of coal. **Figure 2** provides a graphical representation of the gas reserves in each of these basins.

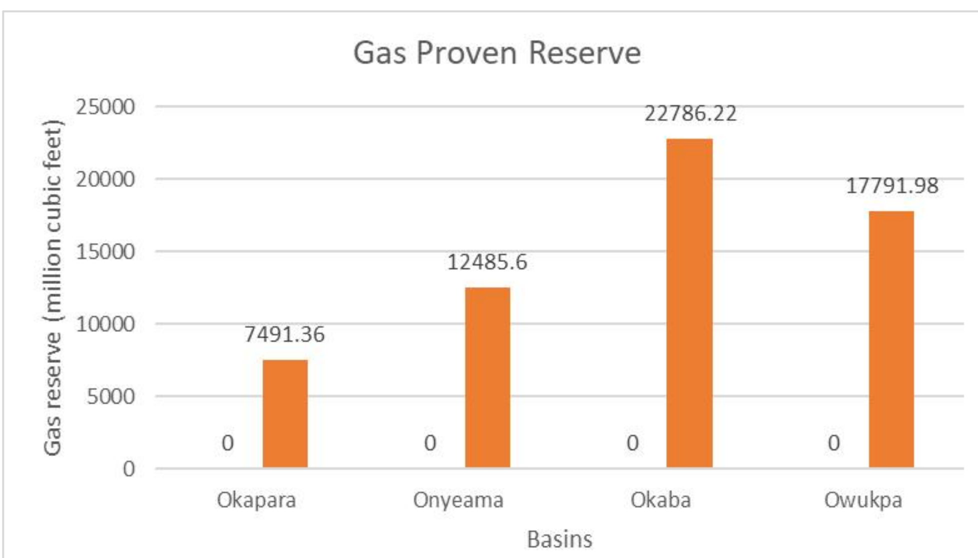

Figure 2—Estimated gas proven reserve.

Depths of the Seams. The coal seams in the Owukpa, Okaba, and Onyeama fields are approximately 100 meters deep, close to the surface, while the Okpara basin features coal seams at a depth of 180 meters. Compared to other CBM basins globally, the shallow depth of Nigerian coal suggests that it can be readily extracted through pit mining. **Figure 3** shows a comparison of the seam depths of Nigeria's CBM basins with those of CBM basins worldwide.

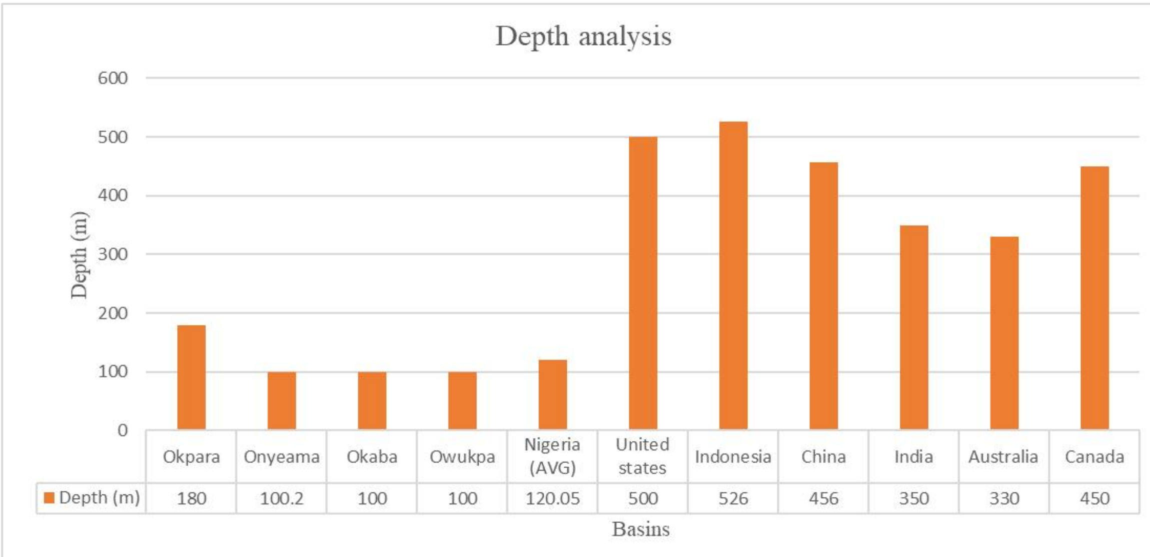

Figure 3—Comparison of seams depth.

Moisture Content Analysis. In comparison to the other four Nigerian basins, as illustrated in **Figure 4**, Okpara coal exhibits the lowest moisture content. The highest moisture content is observed in coal from the United States, whereas coal from China has a relatively low moisture level of 1.02%. Nigerian coal averages 10.95% moisture, which is similar to that of Australian coal. This low moisture content enhances power plant efficiency and reduces coal transportation costs, indicating that Nigeria's coal holds significant potential for power generation.

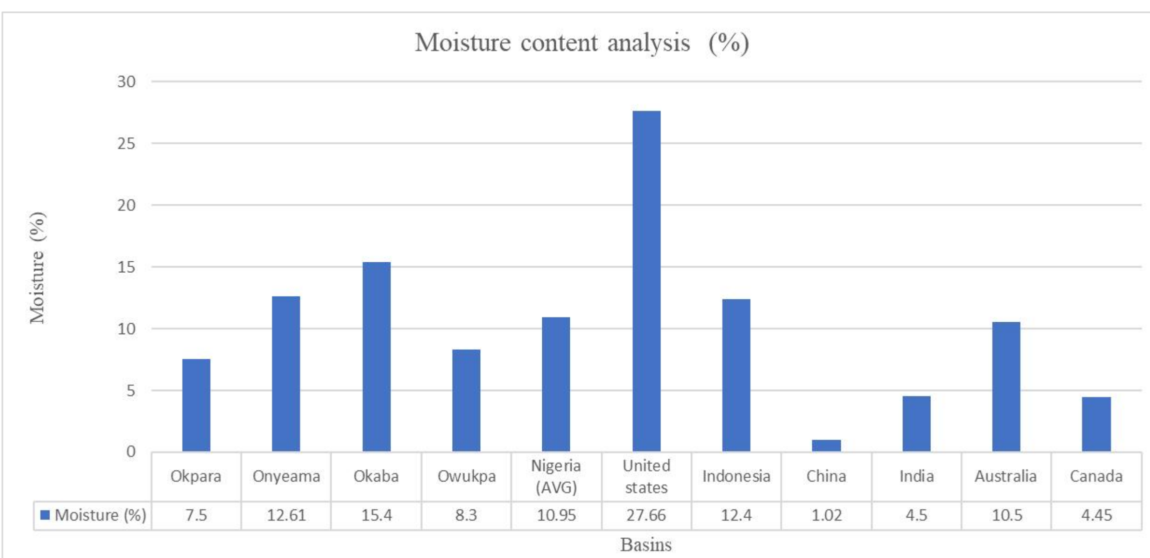

Figure 4—Comparison of moisture content.

Ash Content. Coal from the Onyeama field is noted for its low ash content compared to other analyzed basins, while coal from India shows a higher ash value. The average ash concentration in Nigerian coal is 6.99%, which is comparable to that of the Powder River Basin in the United States. These figures are considered favorable since coal with high ash content can lead to environmental pollution (air, water, and land) and reduce the efficiency of combustion boilers used for power generation. Indian coal, with its high ash content, poses environmental challenges and is less suitable for use in power sectors. As shown in **Figure 5**, coal from Nigeria and the United States is relatively pure in comparison.

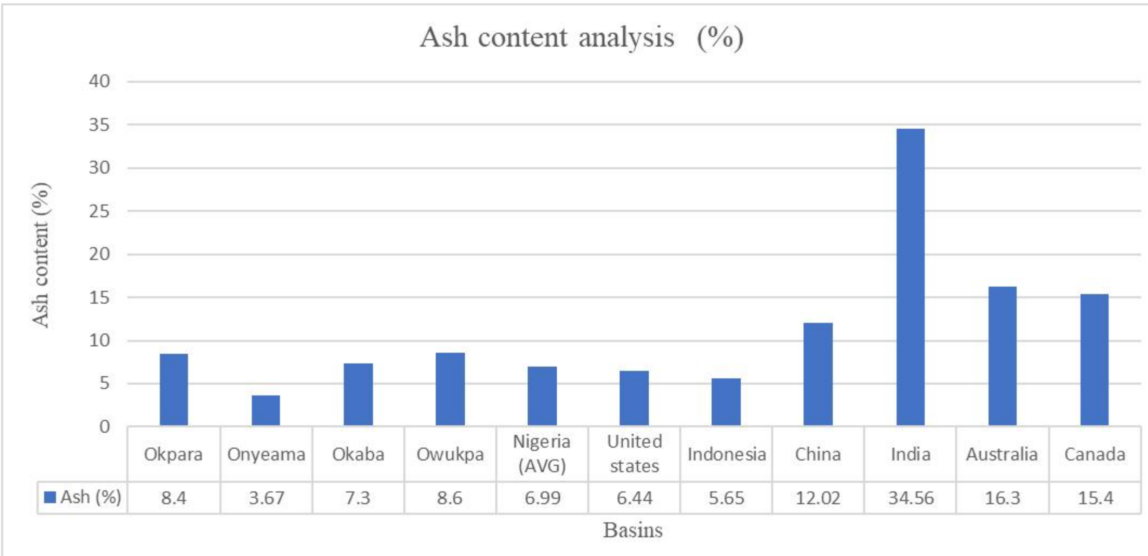

Figure 5—Result of ash content.

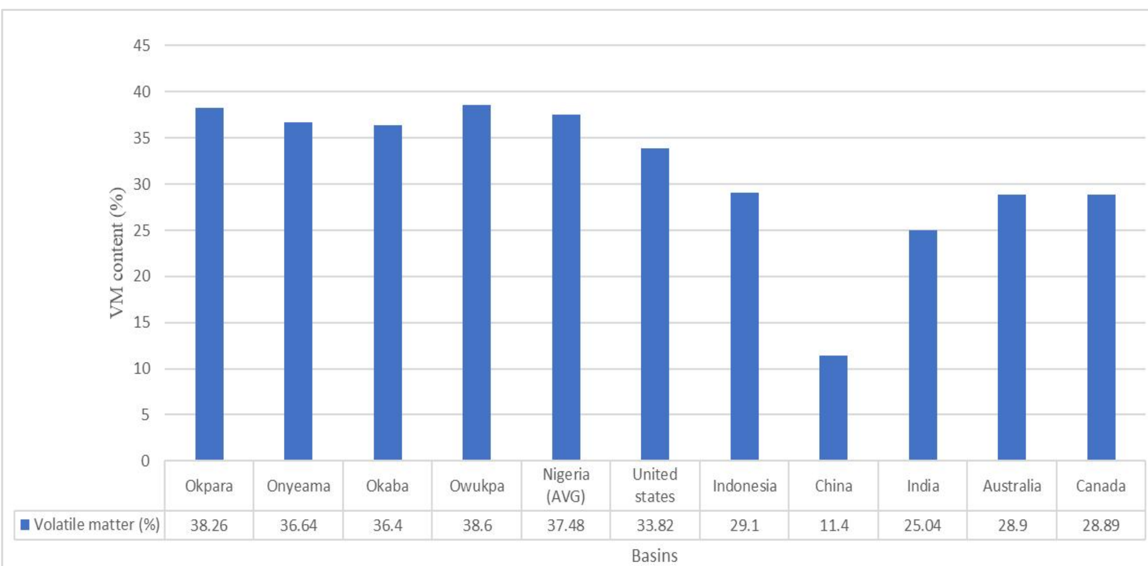

Figure 6—Volatile matter comparison analysis.

Volatile Matter. The four Nigerian basins exhibit high concentrations of volatile matter (VM), averaging 33.82%, surpassing those of all other basins except the Powder River Basin in the United States. Chinese coal, in contrast, has the lowest volatile matter concentration. The elevated volatile matter content in Nigerian coal requires moderate temperatures for effective combustion of the coal dust. **Figure 6** illustrates the volatile matter levels in the Nigerian basins and compares them with those in other CBM-producing countries. Additionally, the high volatile matter content suggests that Nigeria's coal rank is low and of average grade, as lower volatile matter typically indicates higher coal rank.

Conclusions

The study estimates the proven Coalbed methane (CBM) reserves in the four Nigerian basins at 194 million tons of coal, which translates to approximately 60 trillion cubic feet (TCF) of CBM, given a gas content of 312.14 scf/ton. The coal in these basins is classified as sub-bituminous, indicating a lower grade. The average moisture content across these basins is 10.95%, which is comparable to that of Australian coal. Among the analyzed basins, the Onyeama coal field is noted for its low ash content, whereas coal from India shows higher ash values. The Nigerian coals are identified as sub-bituminous, with shallow deposits and relatively low ash and moisture contents, making them well-suited for open-pit mining and combustion. These attributes underscore Nigeria's significant potential as a CBM producer. However, despite the promising characteristics, the moderate permeability and lower porosity of the CBM reservoirs suggest that the efficiency of methane extraction will be influenced by various factors, including geological conditions, drilling and completion methods, and advancements in extraction technology.

Conflicting Interests

The author(s) declare that they have no conflicting interests.

References

Adedosu, T. A., Sonibare, O. O., Ekundayo, O., et al. 2010. Hydrocarbon-Generative Potential of Coal and Interbedded Shale of Mamu Formation, Benue Trough, Nigeria. *Petroleum Science and Technology* **28**(4):412-427.

Adedosu, T.A., Adedosu, H.O., and Adebiyi, F.M., 2007. Geochemical and Mineralogical Significance of Trace Metals in Benue Trough Coals, Nigeria. *Journal of Applied Sciences* **7**(20): 3101-3105.

Akinyemi, S.A., Hower, J.C., Madukwe, H.Y., et al. 2022. Geochemical, Mineralogical, and Petrological Characteristics of the Cretaceous Coal from the Middle Benue Trough Basin, Nigeria: Implication for Coal Depositional Environments. *Energy Geoscience* **3**(3): 300-313.

Annual Energy Outlook. 2023. Energy Information Administration. http://www.eia.gov/forecasts/aeo/er/index.cfm (accessed July 24 2023).

Barka, J. and Nur, A. 2023. Geothermal Prospective Areas in The Northern Sector of Bida Basin and Environs, North-Central Nigeria. *Science World Journal* **18**(3): 509-518.

Chew, K. J. 2013. The Future of Oil: Unconventional Fossil Fuels. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* **372**(2006):1-12.

Cho, D., Song, H., Yoon, K. H., et al. 2016. Treatment of Simulated Coalbed Methane Produced Water Using Direct Contact Membrane Distillation. *Water* **8**(5): 194.

Coal and Electricity Generation. 2012. World Coal Association. http://www.worldcoal.org/resources/wca-publications (accessed 24 December 2022).

Coal. 2022. Energy Information Administration. https://www.eia.gov/energyexplained/coal/ (accessed December 24 2022).

Fatoye, F. B., Omada, A. J. I., and Olatunji, J. A. 2012. Quality Assessments and Industrial Usages of Cretaceous Okaba Coal, Anambra Basin, Nigeria. *Journal of Mining and Geology* **48**(1): 81-87.

Greb, S. F., Eble, C. F., and Hower, J. C. 2017. Coal. *Encyclopedia of Earth Sciences Series* **15**(3):1-16.

Green, I. A., Ugoji, K. U., and Igbere, B. N. 2019. Economic Analysis of Natural Gas Reserves Addition from Coal Bed Methane in Nigeria. *European Journal of Engineering and Technology Research* **4**(4): 31-34.

Hamawand, I., Yusaf, T., and Hamawand, S. G. 2013. Coal Seam Gas and Associated Water: A Review Paper. *Renewable and Sustainable Energy Reviews* **22**: 550-560.

Liu, G., Li, B., Zhang, Z., et al. 2023. Effects of Liquid CO_2 Phase Transition Fracturing on Methane Adsorption of Coal. Energy and Fuels **37**(3):1949-1961.

Lu, Y., Zhang, H. D., Zhou, Z., et al. 2021. Current Status And Effective Suggestions for Efficient Exploitation of Coalbed Methane in China: a review. *Energy and Fuels* **35**(11):9102-9123.
Martin, A., Wahab, H., and Barbarosa, M. 2021) Coalbed Methane as a New Source of Energy in Indonesia and Some Developed Countries-A Review. *Journal of Ocean, Mechanical and Aerospace* **65**(2):40-60.
Mastalerz, M. 2014. Coalbed Methane: Reserves, Production and Future Outlook. In *Future Energy-Improved, Sustainable and Clean Options for Our Planet,* ed by Letcher, T.M., Chap 7, 145-158. Bloomington, IN, USA: Indiana University.
Nigerian Coal Corporation. 2006. Bureau of Public Enterprises. https://www.bpe.gov.ng/nigerian-coal-corporation/(accessed 20 April 2022).
Oboirien, B., North, B., Obayopo, S., et al. 2018. Analysis of Clean Coal Technology in Nigeria for Energy Generation. *Energy Strategy Reviews* **20**: 64-70.
Olaleye, B. M., Onyemaobi, O. O., and Akande, J. M. 2009. Permeability Characteristics and Classification of Coal Seams in Nigeria. *Advanced Materials Research* **62**:357-367.
Ozbayoglu, G. 2018. Energy Production From Coal. *Comprehensive Energy Systems* **20**(2): 788-821.
Proximate and Ultimate Analysis. 2022. SGS Corp. https:///en-us/services/proximate-and-ultimate-analysis (accessed 24 December 2022).
Qin, Y. 2006, Situation and Challenges of China's CBM Exploration (I): Current Stage of Development: *Natural Gas Industry* **26**(1): 4-7 (in Chinese).
Ritchie, H., Rosado, P., and Roser, M. 2020. Energy. https://ourworldindata.org/energy (accessed 10 November 2020).
Sub-bituminous Coal. 2008. Energy Education https://energyeducation.ca/encyclopedia/Sub-bituminous_coal (accessed 27 December 2023).
Taylor, G. H., Teichmüller, M., Davis, A., et al. 1998. *Organic Petrology: A New Handbook Incorporating Some Revised Parts of Stach's Textbook of Coal Petrology*. Gebrüder Borntraeger.
What Are the Types of Coal? 2017. U.S. Geological Survey. https://www.usgs.gov/faqs/what-are-types-coal (accessed 24 December 2022).
Wolfson, R. 2023. *Energy, Environment, and Climate*, 4th edition. New York, NY, U.S.A.: W.W. Norton Inc.
Xia, L., Yin, Y., Yu, X., et al. 2019. An Approach to Grading Coalbed Methane Resources in China for The Purpose of Implementing a Differential Production Subsidy. *Petroleum Science* **16**(2): 447-457.
Yang, L. 1987. National Coal Mine Gas Geological Map of China. *Xi'an, Shaanxi Science and Technology Press* **12**(3):248-257 (in Chinese).
Zhang, L., Kang, T., Kang, J., et al. 2021. Response of Molecular Structures and Methane Adsorption Behaviors in Coals Subjected to Cyclical Microwave Exposure. *ACS Omega* **6**(47): 31566-31577.

Ibrahim Modibbo Ahmed is a petroleum engineer who currently serves as a research assistant at Cyprus International University, North Cyprus. His research interests are coal bed methane (CBM), enhanced oil recovery (EOR), and biogas. He holds a BSc and MSc in Petroleum and Natural Gas Engineering from Cyprus International University and is currently pursuing a PhD in Energy Systems Engineering at Cyprus International University.

Dr. **Saleem Qadir Tunio** is an experienced academician and researcher in the field of petroleum engineering with PhD in Petroleum Engineering from the University of Technology PETONAS (UTP) Malaysia with Master's degree in Petroleum Engineering from the University of Adelaide, Australia, and Bachelor's in Petroleum and Natural Gas Engineering from Mehran University of Engineering and Technology Pakistan. His overall experience is related to teaching and research for more than 17 years in countries like (Pakistan, Malaysia and Cyprus) which includes teaching petroleum engineering courses both at undergraduate and postgraduate levels and supervising research projects/thesis. His research is related to unconventional hydrocarbons, formation evaluation and enhanced hydrocarbons recovery.