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A focus on Ghana's sustainable development: Examining the interplay of income inequality and energy poverty

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ABSTRACT

This study investigates how income inequality influences energy poverty alleviation in Ghana as it seeks to achieve a sustainable economy. Employing the Granger causality test on a dataset from 1990 to 2021, the results show that both Gini post-tax and post-transfer (Income inequality-*II*1) and Gini pre-tax and pre-transfer (Income inequality-*II*2) Granger-cause access to electricity and rural area access to electricity. Urban area access to electricity Granger-causes Gini post-tax and post-transfer. Similarly, an FMOLS test was carried out to introduce some controlling variables and results showed that GDP, trade liberation, urbanization, population growth, and financial development increase income inequality and access to clean fuels and technology, as well as access to urban energy, have a substantial impact on economic disparity. In addition, GDP, financial development, energy intensity, industrialization, trade liberalization, urbanization, population rise, and FDI all have varying implications on energy poverty. These results imply the need to include energy poverty reduction measures within income inequality reduction policies to enhance not just access to today's cutting-edge energy but also affordability to the minimal income receivers. Other reforms and levies on electricity consumption options in renewable energy support can contribute to addressing income inequality and energy poverty issues in Ghana.

1. Introduction

Energy poverty and income inequality are important study areas that are been probed into by scholars to be factors that play an important role in a country's economic growth. On the subject of energy economics, it is important to look into these factors and study whether there is a conflict or any relation between income inequality and energy poverty and what approaches can be implemented to mitigate these factors in building a sustainable economy.

Although the percentage of individuals who have access to energy is increasing globally social development is uneven among areas and different geographical settings [1,2]. Over the past decades, most countries especially developing countries have kept making considerable strides amidst recent changes due to the upsurge of COVID-19 in achieving more under the Sustainable Development Goals in multiple dimensions of poverty [3,4]. In energy, East Asia, South-Eastern Asia, the Caribbean, and Latin America, had reached over 98 % universal access to energy, while Southern Asia and Central Asia had more than 92 % access to electricity in 2018 [4].

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Looking into SSA countries reports showed that only 50 % of the SSA population has access to electricity [4,5]. These statistics show that the global access to electricity gap (energy poverty) is concentrated in Sub-Saharan Africa which Ghana falls under [4], with roughly 578 million citizens lacking access to power in 2019 [6].

Energy poverty is frequently characterized by a lack of energy or power access, a lack of clean fuels and cooking technology, a lack of minimum energy for each individual, or a lack of minimum income for energy spending on essentials [7,8]. The increase in energy poverty implies that a greater number of citizens lack access to power for essential endeavors hence affecting the lives and work of one of the most susceptible groups - minimal-income receivers [9]. Therefore, energy poverty may have a negative impact on social well-being, education, and every aspect of an individual's life [2] resulting in, an increase in existing economic disparity. Energy poverty in Ghana, akin to numerous other developing nations in Africa, presents a complex challenge with micro-level components that play a role in the overarching issues of energy. This includes lack of access to electricity, energy costs, energy efficiency, health implications, Gender Disparities, environmental consequences, access to modern energy services, etc ([10]; Thomson et al., 2017; Kose, 2019; Llorca et al., 2020). Based on the Ghana Living Standards Surveys both GLSS6 and GLSS7 [11,12], the disparity between rural and urban dwellers continues to be a problem, with rural regions experiencing more than double the rate of multidimensional poverty as urban areas (Doreen 2021). In the report from the GLSS7 wave, the Ghana Living Standard Survey showed that 39.5 % of rural people were impoverished, compared to 7.8 % of urban dwellers [13]. Looking at a wide spectrum of Africa, the World Bank's 2020 Poverty and Equity Report (WB, 2020) indicates that 58 million people in Sub-Saharan Africa are anticipated to slip into extreme poverty. Poverty in Ghana was expected to rise by 11 % by 2020, and much more in succeeding years [13]. To break out of the current low development trap and avoid a future fall into a low development loop, it is important to understand the fundamental reasons for the poor development results in areas such as energy and income inequality, particularly in Ghana.

Heterogeneities can be observed in the amounts of energy utilized, the primary types of energy sources utilized, and the extent of accessibility across various nations and demographics, resulting in disparities in both energy access and consumption [14]. According to Ref. [15]; the substantial disparities in energy usage between developed and developing nations are widely acknowledged and present significant environmental challenges [15]. Expanciating on the access to energy in a developing country such as Ghana, the uneven distribution and limited or no access to grid electricity in some remote and off-grid communities are not just factors contributing to lack of access energy but also the disparities in income levels and high electrification cost are factors that need to be probed into in filling the gaps in addressing energy poverty. Income inequality in Ghana is a complex issue with a range of causes and consequences. At its core, income inequality is referred to as the unequal distribution of wealth, resources, and opportunities among various groups of people within a society [16]. Economic inequality has been highlighted as an urgent issue due to its consequences on health difficulties, social vulnerability, satisfaction, and other variables [17,18]. [19] in her research concurred with the fact that income inequality is a major issue in the economic growth process. With inequality on the rise, some citizens are unable to attain basic needs such as adequate housing or basic utilities like reliable electricity, and some are without access to electricity at all. Moreover, access to energy is essential for economic growth, which further exacerbates the income inequality problem [20]. Also when income becomes less equal, it can lead to decreased social welfare due to factors such as fewer investments in social services and lower access to basic necessities, including access to energy resources.

Research has shown that individuals and households living on low incomes are typically the most severely affected by energy poverty [10]. One key factor contributing to income inequality in Ghana is the continued prevalence of poverty in the country, with over one-quarter of Ghanaians living below the poverty line. Some factors cited and known to be contributing to the high rise of poverty include unequal access to education, gender discrimination in the job market, income inequality, and an over-reliance on commodity exports for economic growth [21,22]. Despite substantial success in eliminating energy poverty at the national level in Ghana and commitment to expanding access to electricity, some expressions of growing inequality keep increasing [23]. Ghana's inequality in its totality, as measured by the Gini coefficient was reported to have increased from 41.9 % in 2005/2006 to 42.3 % in 2012/2013 with much increases in GLSS 7 report [12]. According to theoretical considerations, empirical research on the influence of the direct impact of income inequality on access to energy or other factors such as energy prices, governance, etc. on energy poverty reduction in developing countries such as Ghana is lacking, with few studies examining the indirect channels through which these variables affect energy poverty [1,21,24]. It can be deduced that income inequality impacts the consumption habits and behavior of the people hence an alleviation of income inequality will promote the consumption of renewable energy [25]. Evidence from Adusah-Poku et al. (2020) focuses on the perspective of energy poverty from the household's point of view, examining the challenges faced by households with limited access to adequate energy resources. The study sought to understand the demand for energy and its implications, while also elaborating on the energy-related challenges faced by economically disadvantaged households in Ghana, providing valuable insights to inform policies and interventions. On the other hand, this study seeks to address the supply-side analysis that can be deduced around the factors and policies related to energy supply as well as economic indicators that influence energy poverty alleviation. This sheds light on the factors that affect affordability of energy resources, and how these factors are interlinked with income inequality and energy poverty in Ghana. It emphasizes the importance of integrating energy poverty reduction strategies into income inequality reduction policies for a sustainable and inclusive economy. This study therefore contributes to knowledge and policy reforms by probing into how income inequality relates to and affects energy poverty eradication in Ghana in its quest to achieve a sustainable economy. This study also adds to Growth-Inequality-Poverty (GIP) triangle by investigating the interaction influence of income disparity [26] and energy poverty hence addressing an arm of GIP amidst other factors such as growth disparities and poverty (having income inequality as the third arm) and its impact on GIP nexus.

2. Literature review

Development in literature so far shows the growing trend on energy issues but to a significant degree, income inequality has gotten little attention in energy research menace [27,28]. Several researchers have proposed numerous theoretical explanations for the influence of economic disparity on energy poverty [29]; O [22,28,30–32]. It is asserted, that greater economic disparity leads to energy poverty since poorer people have the disadvantage of living in thermally inefficient homes while having a lower income to pay for heating or electricity [33]. In Ref. [27] investigation on the influence of income inequality on energy poverty in European Union (EU) nations from 2009 to 2017, as assessed by the percentage of families unable to keep their houses properly warm. The author using Ordinary Least Squares (OLS) and quantile regression discovered that income disparity considerably affects energy poverty in the EU. Following Bourguignon's GIP triangle, they argue that income inequality affects energy poverty indirectly through economic growth [26]. Acheampong et al. in their research, argue that measures aimed at reducing income inequality while improving economic development will result in reduced energy poverty as explained in the GIP triangle simply when income inequality impairs economic development, it can lead to energy poverty [1], [34]. in their report inferred that in energy-stressed nations, the poorest pay a significant part of their income for power due to greater upfront expenses for energy-efficient equipment resulting in poorer households having less financial resources to employ in funding energy costs.

As reported by the IEA, a bad governance system marked by corruption, an insufficient legislative and regulatory framework, a lack of political stability, low integrity, and transparency can exacerbate energy poverty by causing measures and policies to increase access to power ineffective [35]. With respect to the above, when governance stifles economic growth and worsens income inequality, it can exacerbate energy poverty by limiting access to power. Effective governance systems that promote economic growth and wealth redistribution, on the other hand, may reduce energy poverty by increasing access to electricity. According to Ref. [36]; every initiative to enhance access to energy lacks a solid base in the absence of significant economic development [27,28]. suggest that Energy markets may be affected by income inequality in ways that can be negative or disruptive, making it more difficult for the poor to compete for critical energy services. It is extensively documented in both theoretical and empirical research that governance influences nations' economic development and wealth distribution (Andrés & Ramlogan-Dobson, 2011; [24,37]. According to Ref. [38]; energy poverty can contribute to economic vulnerability, particularly for persons with poor and susceptible income.

Rohan and Paul's study attempted to quantify factors affecting energy-related financial stress in Australia; a key economic challenge facing a minority of households and concluded in their analysis that low net wealth is a particularly important factor affecting difficulty in paying energy bills [39]. Garcia Alvarez and Tol attempt to find a relation between the Bono Social de Electricidad-BSE (A discount on the price of electricity, available to vulnerable households who applied) program in Spain and energy poverty found no relation between the two due to the ineffectiveness of the program [40]. [41]; on the other hand, claimed that an increase in energy costs was the cause of energy poverty in Australia using panel data from 2007 to 2012. Moreover, income inequality not only worsens energy poverty by increasing the number of impoverished families, but it may also distort energy markets, making it more difficult for the poor to compete for essential energy services [28]. [42] came to the same conclusion by applying the multidimensional energy poverty index (MEPI) in assessing energy poverty, that rising energy prices were the cause of Japan's energy poverty [43]. using the headcount ratio and the logistic regression technique, looked at the characteristics of Nigerian households and discovered that household size, age of household head, food expenses to overall spending, educational level of the household head, and household general poverty are all determining factors of energy poverty [44]. suggested that those with limited access to energy services (those facing energy poverty) must spend more money on energy proportional to their total income than those with greater access to energy services [45]. study found that rises in home fuel expenditures can force households into poverty in France.

[46,47] also explained that rural communities with lesser incomes and less economic activity may be overlooked when it comes to distributing energy or clean fuels since emerging countries tend to prioritize economic growth. Meanwhile, individuals in higher-income metropolitan regions may afford to pay higher costs for these energy supplies hence the disparities in asses to energy and, increasing income disparities between urban and rural regions may lead to an increase in energy poverty [48]. Dong & Hao, (q2018), for example, examined the relationship between urban-rural income disparity and energy consumption in China from 1996 to 2013 and concluded that income disparity had a negative influence on electricity consumption per capita [31]. quantify the underlying influence of income inequality on renewable energy usage using panel data from 17 countries between 1990 and 2016. They discover a considerable variation in this linkage: Economic disparity was adversely connected with renewable energy usage from 1995 to 2002, while income inequality influenced renewable energy consumption after 2010 [49]. adding up to the argument explained that rising income inequality may result in uneven reactions to rising energy costs; whereas high earners may be ready and able to pay for increased energy prices, poor earners do not have the same ability to respond to rising energy prices. Against this context, our research aims to contribute to the literature by examining the direct and indirect effects of income inequality on energy poverty and vice versa in Ghana from 1996 to 2021.

3. Methodology

3.1. Data description

The Gini index (Coefficients) serves as a metric for gauging income or wealth inequality within a population. It quantifies how far the distribution of income or wealth diverges from absolute equality, with 0 denoting perfect equality (where everyone possesses the same income or wealth) and 1 signifying perfect inequality (where one individual or household holds all the income or wealth). For the purpose of this study, two Gini indexes were employed from the SWIID database to proxy income inequality: specifically, the Gini index pre-tax and transfer (*lI*2), and the Gini index post-tax and transfer (*lI*1). The "Gini index pre-tax and transfer, looks at income or wealth inequality before the effects of taxation and government transfers are taken into account while the "Gini index post-tax and transfer," specifically looks at income or wealth inequality after the effects of taxation and government transfers are taken into account. In summary, as the Gini index pre-tax and transfer measures inequality based on individuals' or households' disposable incomes or pre-government intervention incomes, the Gini index post-tax and transfer also measures inequality based on individuals' or households' market incomes or post-government intervention incomes. These two previously mentioned indices offer the most comprehensive country-level dataset on income inequality that is currently accessible for global research [50,51]. Among the studies that have justified the use of these indexes for income inequality include [10,36,52] hence to arrive at the objective of the study, the two Gini indices are used to represent income inequality.

With regards to energy poverty, the study employs five different indicators to represent energy poverty which is considered one of the contributions of the study to the literature. Energy poverty is argued to be measured with three approaches that is physical, economic, and technological threshold. Nevertheless, González-Eguino (2015) and Nguyen and Nasir (2021a) argued that the second approach is limited by choosing limited energy consumption and the third approach is limited by minimum income spending for energy consumption. To avoid these limitations, the study focuses on the first approach and provides more indicators to make the approach more comprehensive. The indicators are; access to clean fuels and technology for cooking (*lE*1), access to electricity (*lE*2), access to rural electrification (*lE*3), access to urban electricity (*lE*4), and log electricity consumption (*lE*5). The data is obtained from World Bank Indicators from 1990 to 2021.

To control the effects of the independent variables, control variables are used. The control variables are income (y), foreign direct investment (*lfo*), industrialization (*li*), trade liberation (*lt*), energy intensity (*lei*), urbanization (*lu*), population growth (*lp*), and financial development index (*lfi*). Including these variables as controls in the study allows us to isolate and understand the specific impact of income inequality on energy poverty while considering the effects of other important economic and developmental factors. Likewise, these controlling variables help to provide a more accurate assessment of the relationship between income inequality and energy poverty, accounting for potential confounding effects from other economic factors. FDI representing investments from foreign entities, can impact the income levels of individuals and economic growth thereby affecting income distribution and poverty. Industrialization and trade liberalization also influence income and employment opportunities, potentially altering income inequality and poverty rates [53]. Energy intensity measures the efficiency of energy use concerning economic output, offering insights into energy consumption patterns in rural and urban settings. Urbanization, population growth, and the financial development index are also vital, as they influence income distribution, energy demands, and the efficiency of a country's financial system [54]. The data for the control variables are from World Bank Indicators except the financial development index which is from the International Monetary Fund (IMF) and they are from 1990 to 2021.

The sources and measures of the data used for the study is presented in Table 1. In addition, the statistical description and correlational effect among the variables are presented in Tables 2 and 3 respectively.

3.2. Method

The study in order to establish the effect of energy poverty and income inequality on each other adopted the Granger causality test as used by Ref. [53] and FMOLS as used by Amoakoet al., (2022) models for the analysis. The Granger causality test only considered

Table 1
The study variables.

Variables	Source	Year	Measurements
Income Inequality			
Gini post-tax and post-transfer (*lI*1)	SWIID	1990–2021	Log of Gini index of inequality in equivalised (square root scale) household disposable (post-tax, post-transfer) income
Gini pre-tax and pre-transfer (*lI*2)	SWIID	1990–2021	Log of Gini index of inequality in equivalised (square root scale) household disposable (pre-tax, pre-transfer) income
Energy Poverty			
Access to clean fuels and technologies for cooking (*lE*1)	WDI	1990–2021	Access to clean fuels and technologies for cooking (% of population)
Access to electricity (*lE*2)	WDI	1990–2021	Access to electricity (% of population)
Access to rural electricity (*lE*3)	WDI	1990–2021	Access to electricity, rural (% of rural population)
Access to urban electricity (*lE*4)	WDI	1990–2021	Access to electricity, urban (% of urban population)
Log electricity consumption (KWh per capita) (*lE*5)	WDI	1990–2021	Log of electric power consumption (kWh per capita)
Control Variables			
GDP per capita (*ly*)	WDI	1990–2021	Log of GDP per capita (constant 2010 US$)
Foreign direct investment (*lfo*)	WDI	1990–2021	Foreign direct investment, net inflows (% of GDP)
Industrialization (*li*)	WDI	1990–2021	Industry (including construction), value-added (% of GDP)
Trade liberation (*lt*)	WDI	1990–2021	Trade (% of GDP)
Energy intensity (*lei*)	WDI	1990–2021	Log of energy intensity level of primary energy (MJ/$2011 PPP GDP)
Urbanization (*lu*)	WDI	1990–2021	Urban population (% of total population)
Population growth (*lp*)	WDI	1990–2021	Annual population growth (% of total population)
Financial development index (*lfi*)	IMF	1990–2021	Foreign direct investment, net inflows (% of GDP)

Table 2
Descriptive Statistics of the variables.

	mean	median	max	mini	Std. Dev
*lI*1	3.744	3.746	3.761	3.714	0.014
*lI*2	3.789	3.792	3.807	3.761	0.014
*lE*1	2.490	2.517	3.020	1.825	0.397
*lE*2	4.028	4.038	4.361	3.720	0.183
*lE*3	3.379	3.465	4.158	2.062	0.556
*lE*4	4.409	4.403	4.509	4.288	0.058
*lE*5	5.617	5.622	5.896	5.350	0.176
li	3.170	3.216	3.529	2.891	0.204
lei	1.281	1.238	1.613	1.089	0.155
lfi	−2.077	−2.112	−1.849	−2.251	0.124
lfo	1.393	1.677	2.248	−0.045	0.788
ly	6.724	6.952	7.733	5.535	0.727
lp	0.941	0.938	1.011	0.879	0.043
lu	3.889	3.892	3.978	3.783	0.060
lt	4.397	4.390	4.754	4.107	0.210

energy poverty and income inequality. However, the FMOLS considered control variables in addition to income inequality and energy poverty.

The first seven equations indicate how the variables are presented in the Granger causality test. The purpose is to establish the effect of the variables on each other either one cause effect or feedback effect. The effects are between energy poverty and income inequality. Equations (1) and (2) present income equality indicators as the dependent variables and equations (3)–(7) present energy poverty indicators as the dependent variables.

$$lI1_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lE1_{it} + \beta_3 lE2_{it} + \beta_4 lE3_{it} + \beta_5 lE4_{it} + \beta_6 lE5_{it} + \varepsilon_{it} \tag{1}$$

$$lI2_{it} = \beta_0 + \beta_1 lI1_{it} + \beta_2 lE1_{it} + \beta_3 lE2_{it} + \beta_4 lE3_{it} + \beta_5 lE4_{it} + \beta_6 lE5_{it} + \varepsilon_{it} \tag{2}$$

$$lE1_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lI1_{it} + \beta_3 lE2_{it} + \beta_4 lE3_{it} + \beta_5 lE4_{it} + \beta_6 lE5_{it} + \varepsilon_{it} \tag{3}$$

$$lE2_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lE1_{it} + \beta_3 lI1_{it} + \beta_4 lE3_{it} + \beta_5 lE4_{it} + \beta_6 lE5_{it} + \varepsilon_{it} \tag{4}$$

$$lE3_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lE1_{it} + \beta_3 lE2_{it} + \beta_4 lI1_{it} + \beta_5 lE4_{it} + \beta_6 lE5_{it} + \varepsilon_{it} \tag{5}$$

$$lE4_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lE1_{it} + \beta_3 lE2_{it} + \beta_4 lE3_{it} + \beta_5 lI1_{it} + \beta_6 lE5_{it} + \varepsilon_{it} \tag{6}$$

$$lE5_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lE1_{it} + \beta_3 lE2_{it} + \beta_4 lE3_{it} + \beta_5 lE4_{it} + \beta_6 lI1_{it} + \varepsilon_{it} \tag{7}$$

The equations below from equations (8)–(14) indicate how energy poverty, income inequality, and the control variables are presented in the main model. The first two equations (8) and (9) indicate the effect of energy poverty and the control variables on income inequality whiles from equations (10)–(14) indicate how income inequality and the control variables affect energy poverty.

$$lI1_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lE1_{it} + \beta_3 lE2_{it} + \beta_4 lE3_{it} + \beta_5 lE4_{it} + \beta_6 lE5_{it} + \beta_7 li_{it} + \beta_8 lei_{it} + \beta_9 fi_{it} + \beta_{10} fo_{it} + \beta_{11} ly_{it} + \beta_{12} lp_{it} + \beta_{13} lu_{it} + \beta_{14} lt_{it} + \varepsilon_{it} \tag{8}$$

$$lI2_{it} = \beta_0 + \beta_1 lI1_{it} + \beta_2 lE1_{it} + \beta_3 lE2_{it} + \beta_4 lE3_{it} + \beta_5 lE4_{it} + \beta_6 lE5_{it} + \beta_7 li_{it} + \beta_8 lei_{it} + \beta_9 fi_{it} + \beta_{10} fo_{it} + \beta_{11} ly_{it} + \beta_{12} lp_{it} + \beta_{13} lu_{it} + \beta_{14} lt_{it} + \varepsilon_{it} \tag{9}$$

$$lE1_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lI1_{it} + \beta_3 lE2_{it} + \beta_4 lE3_{it} + \beta_5 lE4_{it} + \beta_6 lE5_{it} + \beta_7 li_{it} + \beta_8 lei_{it} + \beta_9 fi_{it} + \beta_{10} fo_{it} + \beta_{11} ly_{it} + \beta_{12} lp_{it} + \beta_{13} lu_{it} + \beta_{14} lt_{it} + \varepsilon_{it} \tag{10}$$

$$lE2_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lE1_{it} + \beta_3 lI1_{it} + \beta_4 lE3_{it} + \beta_5 lE4_{it} + \beta_6 lE5_{it} + \beta_7 li_{it} + \beta_8 lei_{it} + \beta_9 fi_{it} + \beta_{10} fo_{it} + \beta_{11} ly_{it} + \beta_{12} lp_{it} + \beta_{13} lu_{it} + \beta_{14} lt_{it} + \varepsilon_{it} \tag{11}$$

Table 3
Correlation Table of variables.

	*ll*1	*ll*2	*lE*1	*lE*2	*lE*3	*lE*4	*lE*5	*li*	*lei*	*lfi*	*lfo*	*ly*	*lp*	*lu*	*lt*
*ll*1	1														
*ll*2	.997	1													
*lE*1	.977	.988	1												
*lE*2	.832	.853	.881	1											
*lE*3	.656	.682	.717	.943	1										
*lE*4	.550	.567	.580	.579	.374	1									
*lE*5	.346	.384	.479	.455	.323	.564	1								
li	.122	.146	.176	.149	−.022	.533	.539	1							
lei	−.988	−.983	−.954	−.821	−.639	−.570	−.272	−.130	1						
lfi	.727	.733	.736	.672	.487	.692	.426	.604	−.723	1					
lfo	.701	.722	.771	.739	.678	.439	.347	−.236	−.678	.433	1				
ly	.963	.974	.975	.897	.751	.598	.466	.103	−.949	.693	.797	1			
lp	−.692	−.716	−.802	−.740	−.596	−.537	−.680	−.262	.656	−.673	−.805	−.764	1		
lu	.983	.991	.997	.886	.715	.600	.471	.217	−.963	.762	.733	.972	−.780	1	
lt	−.706	−.714	−.678	−.797	−.751	−.438	−.224	.103	.724	−.344	−.565	−.792	.383	−.691	1

$$lE3_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lE1_{it} + \beta_3 lE2_{it} + \beta_4 lI1_{it} + \beta_5 lE4_{it} + \beta_6 lE5_{it} + \beta_7 li_{it} + \beta_8 lei_{it} + \beta_9 fi_{it} + \beta_{10} fo_{it} + \beta_{11} ly_{it} + \beta_{12} lp_{it} + \beta_{13} lu_{it} + \beta_{14} lt_{it} + \varepsilon_{it} \tag{12}$$

$$lE4_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lE1_{it} + \beta_3 lE2_{it} + \beta_4 lE3_{it} + \beta_5 lI1_{it} + \beta_6 lE5_{it} + \beta_7 li_{it} + \beta_8 lei_{it} + \beta_9 fi_{it} + \beta_{10} fo_{it} + \beta_{11} ly_{it} + \beta_{12} lp_{it} + \beta_{13} lu_{it} + \beta_{14} lt_{it} + \varepsilon_{it} \tag{13}$$

$$lE5_{it} = \beta_0 + \beta_1 lI2_{it} + \beta_2 lE1_{it} + \beta_3 lE2_{it} + \beta_4 lE3_{it} + \beta_5 lE4_{it} + \beta_6 lI1_{it} + \beta_7 li_{it} + \beta_8 lei_{it} + \beta_9 fi_{it} + \beta_{10} fo_{it} + \beta_{11} ly_{it} + \beta_{12} lp_{it} + \beta_{13} lu_{it} + \beta_{14} lt_{it} + \varepsilon_{it} \tag{14}$$

4. Results and discussion

For this current study, the Granger causality test result is presented in Table 4 while Table 6 present the main findings of the FMOLS. The Granger causality results reveal that income inequality (*lI*1 -post-tax and post-transfer) Granger-cause energy poverty in terms of access to electricity (*lE*2). The same is true of rural areas access to electricity (*lE*3). In the reverse form, amidst the energy poverty variables, only urban area access to electricity (*lE*4) granger causes income inequality. For the second Gini index (pre-tax and pre-transfer- *lI*2), there is an effect flowing through income inequality to access to electricity (*lE*2), and again through income inequality to rural area access to electricity (*lE*3).

The inclusion of key control variables that matters in this research field provides some keynote outcomes worth considering. Results of the control variables in Table 5 reveal that income GDP, trade liberation, urbanization, population growth, and financial development significantly affect both indices of income inequality in a negative connotation. This is to say that increased income GDP, enhance trade liberation, urbanization, an increase in population growth, and improved financial development are factors that increase income inequality within the West African region. For trade liberation, our study result is inconsistent with the result of [54] who employed data from 15-EU states and found that trade liberation does not impact income inequality. Nonetheless, this part of our result is partly consistent with [55] for trade liberation and financial development and partly consistent with [56] for urbanization and [57] for population growth. For the remaining control variables namely; foreign direct investment, industrialization, and energy intensity there is a significant negative impact of these variables on income inequality. This translates to imply that the inflow of foreign direct investment, industrialization, and energy intensity are good variable that helps to alleviate income inequality. The finding from Nguyen and Nasir (2021b) provides strong support for this finding.

On the energy poverty-income inequality nexus, the impact relationship between energy poverty (proxies by 5 variables) and income inequality (also proxies by the two Gini indices) has been represented in Table 5. The results from the FMOLS analysis revealed that out of the total five (5) energy poverty proxies, only two, that is; access to clean fuels and technologies for cooking and access to urban electricity (*lE*1 and *lE*4) have a significant effect on the Gini indices. While access to clean fuels and technologies for cooking (*lE*1) has a significant positive effect on both proxies for income inequality (*lI*1 and *lI*2), access to urban electricity (*lE*4) only had a significant negative effect on Gini pre-tax and pre-transfer (*lI*2). For variables *lE*2, *lE*3 and *lE*5, no effect was revealed. The implication of these results connotes that increasing access to clean fuel and technology has the likely effect of increasing income inequality whereas increasing urban area access to electricity has the effect of decreasing income inequality. This is consistent with the study of [58] for 93 economies, Oihana Aristondo and Eneritz Onaindia (2018) for Spain, and [59] for BRICS. These further elicit that an increase in energy poverty taking into consideration the variable access to clean fuels and technologies for cooking (*lE*1) is very likely to worsen the income inequality gap. On the contrary, an increase in the urban area's access to electricity could help alleviate the inequality of income. It is evident from our results that apart from access to clean fuel and technology as well as urban area access to electricity, the remaining energy poverty variables (access to electricity, rural area access to electricity, and electricity consumption) were empirically proven not to affect income inequality in any manner, being it negative or positive. The Gini pre-tax and pre-transfer (*lI*2) and the Gini post-tax and post-transfer (*lI*1) were only affected by access to clean fuels and technologies for cooking and access to urban electricity (*lE*1 and *lE*4). Undoubtedly the outcome of our analysis concerning how access to clean fuels and technologies for cooking and access to urban electricity *lE*1 and *lE*4 impact both the pre and post-Gini index (*lI*1 and *lI*2) provides enough evidence to accept our study hypothesis that income inequality is affected by energy poverty and are heavily connected. The insignificant results of Access to rural electricity, Access to rural electricity, and Log electricity consumption (KWh per capita) (*lE*2, *lE*3 and *lE*5) are major

Table 4
Granger causality test.

	Income inequality (*lI*1) does not granger cause energy poverty	Energy poverty does not granger cause income inequality (*lI*1)	Income inequality (*lI*2) does not granger cause energy poverty	Energy poverty does not granger cause income inequality (*lI*2)
*lE*1	1.23985	0.25746	1.64316	0.39357
*lE*2	6.01390***	0.60554	3.34843*	0.18494
*lE*3	3.96463**	1.85607	3.28694*	1.41838
*lE*4	2.50737	3.04664*	2.04888	2.34942
*lE*5	0.12183	1.04453	0.34841	1.64719

***, **,* represent 1 %, 5 %, 10 % significance, respectively.

Table 5
Income inequality as the dependent variable.

variable	*lI*1	*lI*1	*lI*1	*lI*1	*lI*1	*lI*2	*lI*2	*lI*2	*lI*2	*lI*2
*lE*1	0.037** (3.079)					0.035*** (24.335)				
*lE*2		0.020 (1.184)					0.002 (0.247)			
*lE*3			0.003 (0.966)					0.001 (0.740)		
*lE*4				−0.010 (−0.901)					−0.011* (−2.498)	
*lE*5					0.002 (0.955)					−0.006 (−2.548)
ly	0.002 (0.761)	0.011** (3.116)	0.010** (3.455)	0.008** (2.851)	0.002 (1.161)	0.001** (3.669)	0.008** (3.756)	0.008*** (5.312)	0.006*** (5.525)	0.007** (5.222)
lfo	−0.004** (−3.460)	−0.005 (−1.776)	−0.004 (−1.680)	−0.001 (−1.083)	−0.004** (−7.650)	−0.002*** (−17.289)	−0.001 (−0.554)	−0.001 (−1.075)	9.13E (0.165)	−0.002** (−4.879)
li	−0.012*** (−4.451)	−0.015** (−2.278)	−0.012* (−2.138)	−0.007* (−2.178)	−0.018*** (−14.575)	−0.008*** (−23.821)	−0.005 (−1.328)	−0.006 (−1.937)	−0.003 (−1.924)	−0.007** (−6.188)
lt	0.006 (1.777)	0.029 (2.099)	0.023* (2.153)	0.012*** (4.180)	0.008** (6.412)	0.002*** (4.894)	0.011 (1.417)	0.013* (2.335)	0.008*** (6.304)	0.009** (7.731)
lei	−0.036*** (−3.855)	−0.050** (−3.099)	−0.050* (−2.199)	−0.039** (−2.762)	−0.033** (−7.321)	−0.020*** (−18.224)	−0.023** (−2.617)	−0.027* (−2.280)	−0.025** (−4.107)	−0.005 (−1.243)
lu	0.034 (0.504)	0.290** (2.720)	0.280* (2.582)	0.208** (3.761)	0.299*** (13.563)	0.048*** (5.941)	0.204** (3.490)	0.232** (4.089)	0.215*** (9.147)	0.295*** (14.436)
lp	0.148*** (3.790)	0.291 (1.931)	0.246 (1.770)	0.149** (2.765)	0.145*** (9.215)	0.123*** (26.304)	0.120 (1.446)	0.152 (2.091)	0.127*** (5.574)	0.130** (8.880)
lfi	0.012* (2.300)	−0.006 (−0.786)	−0.004 (−0.644)	0.002 (0.374)	0.012** (6.315)	0.010*** (16.051)	−0.002 (−0.377)	−0.003 (−0.778)	0.001 (0.444)	0.0003 (0.157)

***, **,* represent 1 %, 5 %, 10 % significance, respectively.

Table 6
Energy poverty as the dependent variable.

	*lE*1	*lE*2	*lE*3	*lE*4	*lE*5	*lE*1	*lE*2	*lE*3	*lE*4	*lE*5
*ll*1	9.912** (4.128)	3.924 (1.353)	26.129* (2.354)	−10.248 (−1.845)	52.362 (1.264)					
*ll*2						26.830*** (21.189)	0.472 (0.107)	35.343 (1.969)	−31.913** (−3.712)	−87.556* (−3.079)
ly	0.086** (2.761)	−0.182*** (−4.838)	−0.545** (−3.796)	0.006 (0.090)	0.385 (2.132)	−0.023 (−1.924)	−0.151** (−3.697)	−0.578** (−3.473)	0.149 (1.867)	0.897** (5.457)
lfo	0.067*** (5.556)	0.148*** (10.094)	0.682*** (12.193)	0.033 (1.189)	0.075 (0.411)	0.062*** (17.801)	0.140*** (11.528)	0.651*** (13.107)	0.036 (1.499)	−0.269** (−4.243)
li	0.185*** (5.051)	0.382*** (8.625)	1.560*** (9.203)	0.050 (0.586)	1.170 (1.556)	0.216*** (19.771)	0.352*** (9.263)	1.491*** (9.612)	−0.001 (−0.016)	−0.504 (−1.829)
lt	0.066 (1.598)	−0.870*** (−17.517)	−3.586*** (−18.851)	0.049 (0.517)	−0.141 (−0.368)	−0.040** (−2.817)	−0.820*** (−16.557)	−3.550*** (−17.563)	0.198 (2.046)	0.918* (3.990)
lei	0.325* (2.336)	0.797923*** (4.747)	5.485*** (8.525)	−0.607 (−1.889)	3.463* (2.961)	0.547*** (12.186)	0.668*** (4.286)	5.293*** (8.318)	−0.923** (−3.027)	0.535 (0.816)
lu	2.294** (3.221)	−6.156*** (−7.157)	−36.723*** (−11.153)	3.833* (2.327)	−11.106 (−0.824)	−1.035** (−3.429)	−5.441*** (−5.194)	−38.544*** (−9.014)	8.182** (3.994)	28.569* (3.582)
lp	−1.876** (−3.388)	−9.139*** (−13.664)	−44.587*** (−11.153)	3.550** (2.771)	−5.937 (−0.900)	−3.345*** (−16.853)	−8.623*** (−12.515)	−44.782*** (−15.921)	5.584** (4.144)	12.418* (3.193)
lfi	−0.298*** (−6.415)	0.304*** (5.411)	1.360*** (6.331)	0.153 (1.423)	−1.186 (−2.470)	−0.278*** (−19.238)	0.304*** (6.059)	1.396*** (6.806)	0.131 (1.335)	−0.299 (−1.292)

***, **,* represent 1 %, 5 %, 10 % significance, respectively.

concerns that need urgent policy attention so as with Access to clean fuels and technologies for cooking and Access to urban electricity (*lE*1 and *lE*4).

Undisputedly, energy poverty is been showcased as per our results to be a new potential driver of income inequality [59] amidst other highlighted in previous studies, such as financial development [60], trade liberalization [61,62], and population growth [63]. Investigation into our results reveals the presence of energy poverty in explaining income inequality disparity is a major boost for the robustness of outcomes as far as studies of these variables are concerned.

In Table 6 a reverse effect is investigated by employing the energy poverty variables as the dependent variables. For the control variables, income GDP exhibits a positive significant relation with access to clean fuel and technology and electricity consumption (*lE*1 and 5), and a negative significant relationship with access to electricity and rural area access to electricity (*lE*2 and *lE*3). Foreign direct investment's effect on energy poverty namely; access to clean fuel and technology (*lE*1), access to electricity (*lE*2), and rural area access to electricity (*lE*3) exhibit a positive effect while electricity consumption exhibits a negative significant effect. Again, industrialization positively influences access to clean fuels and technology, access to electricity, and rural area access to electricity (*lE*1, *lE*2 and, *lE*3). An increase in trade liberation leads to a significant reduction in access to clean fuels and technology, access to electricity, and rural area access to electricity (*lE*1, *lE*2 and, *lE*3) while significantly increasing electricity consumption (*lE*5). Furthermore, an increase in energy intensity helps bridge the energy poverty gap in respect of variables (*lE*1, *lE*2 and, *lE*3) but for *lE*5, an increase in energy intensity increases it. On urbanization, our results reveal that urbanization increases energy poverty in respect of variables access to clean fuels and technology, urban area access to electricity and electricity consumption (*lE*1, *lE*4, and *lE*5) and decreases energy poverty concerning access to electricity, and rural area access to electricity (*lE*2 and *lE*3). For population growth, an increase of it reduces energy poverty for variables (*lE*1, *lE*2 and, *lE*3) and increases energy poverty in terms of variable *lE*4 and *lE*5. Lastly, on the control variables, financial development significantly affects only three energy poverty variables. Thus, positive for access to electricity, and rural area access to electricity (*lE*2 and *lE*3), and negative for access to clean fuel and technology (*lE*1). Overall, the control variables produced a mixed significant impact on energy poverty. For both Gini pre and post (*lI*1 and *lI*2) of income inequality, we recorded a significant impact for all the energy poverty variables. For the effect of proxy post-tax and post-transfer on access to clean fuel and technology (*lE*1) and rural area access to electricity (*lE*3), a significant positive effect was revealed while the effect of pre-tax and pre-transfer on urban area access to electricity (*lE*4) and electricity consumption (*lE*5) was negative.

5. Conclusion and policy implication

Although almost every nation worldwide is putting much effort into battling the issue of energy poverty, it remains a menace in every economy with the poorer or developing nations bearing the brunt of the burden. With many studies in the domain of reducing energy poverty under the SDGs, the Income inequality-energy poverty nexus has gotten little attention especially on the micro level and in developing countries such as Ghana. To fill this gap in research and provide policy alternatives, data from various measurements under income inequality and energy poverty using a panel time series from 1996 to 2021 employed the Granger causality and FMOLS for the analysis. The results from the Granger Causality show that post-tax and post-transfer granger cause access to electricity and rural areas access to electricity. Urban area access to electricity granger cause post-tax and post-transfer. Pre-tax and pre-transfer have an indirect effect on access to electricity and rural area access to electricity. The FMOLS test was conducted to introduce some controlling variables in addition to income inequality and energy poverty. The findings show that GDP, trade liberation, urbanization, population growth, and financial development increase income inequality and access to clean fuels and technologies and access to urban electricity significantly affect income inequality. In addition, GDP, foreign direct investment, industrialization, trade liberation, energy intensity, urbanization, population growth, and financial development have different effects on energy poverty.

Based on the results of the study, these policy implications are recommended. Trade liberation and Foreign direct investment must be given much attention in the battle against energy poverty and income inequality. These two provide the needed investment to support renewable electricity which has helped reduce the number of people without electricity in West Africa. The various government institutions should provide the needed help to these two like incentives and good partnerships. These results point to the need to include energy poverty reduction measures within income poverty reduction efforts and policy strategies to enhance not just access to today's cutting-edge energy but also affordability to the minimal income receivers. Also, other reforms and levies on electricity consumption options in renewable energy support can go a long way in addressing income inequality and energy poverty issues to help build a sustainable economy in Ghana.

The study is able to address the issue of energy poverty and income inequality by using relevant proxies to represent the two. However, the study limits itself to West Africa and it is sometimes difficult to consider a regional issue as a continental issue. In this regard, future studies can use the same proxies but enlarge the scope of the study by considering more regions or countries in Africa.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Erica Odwira Opoku: Conceptualization, Data curation, Supervision, Writing - original draft, Writing - review & editing, Methodology. **Justice Gyimah:** Data curation, Formal analysis, Writing - review & editing. **George Nyantakyi:** Conceptualization, Data curation. **Ujunwa Angela Nwigwe:** Data curation. **Xilong Yao:** Supervision.

Declaration of competing interest

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

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