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Unveiling the Implications of Energy Poverty for Educational Attainments in Pakistan: A Multidimensional Analysis

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ABSTRACT

The United Nations' Sustainable Development Goals (SDGs) recognize energy poverty as a significant issue affecting developing and developed countries. Goal 7 of the Sustainable Development Goals (SDG 7) focuses on energy poverty (EP) and aims to achieve universal access to affordable, reliable, sustainable, and modern energy services by 2030. This study examines the relationship between energy poverty and educational attainments in Pakistan using time series data from 1990 to 2020. A multidimensional energy development index (EDI) is constructed to measure energy poverty. By employing robust econometric techniques such as the Johansen cointegration test, fully modified ordinary least square (FMOLS), canonical cointegration regression, and the generalized method of moments (GMM) estimation, this research uncovers empirical findings that offer valuable insights into the crucial role of energy poverty as a determinant of educational attainments. The findings of this study reveal that improvements in energy development (characterized by a decline in energy poverty) and real GDP per capita, significantly enhance school enrollments in Pakistan. Moreover, it is also observed that general poverty and a high pupil-teacher ratio negatively influence educational attainments. These results emphasize that inadequate access to and affordability of energy act as formidable barriers, impeding the educational journey of children and adolescents. These findings also highlight the urgent need to address energy poverty as a paramount policy concern to enhance development outcomes. Policies aimed at improving energy infrastructure and providing reliable and affordable energy sources are crucial to unlocking educational opportunities for more children and enabling them to embark on their educational journeys.

Keywords: Multidimensional Energy Poverty, Educational Attainments, Energy Development Index, School Enrollment Ratio, Sustainable Development Goals
JEL Classifications: I32, I25

1. INTRODUCTION

The concept of fuel poverty, defined as the inability to pay for essential home heating, was initially studied in the United Kingdom during the end of the 1970s and the beginning of the 1980s (Bradshaw and Hutton, 1983; Boardman, 1991). Fuel poverty refers to families that lack reliable, readily accessible, and affordable energy services (Bouzarovski, 2014; Reames, 2016). In the United States, energy burden is commonly used as a stand-in for concerns related to energy poverty, mainly cost and accessibility. In the United Kingdom and Eastern Europe, unavailable residential heating is sometimes called "fuel poverty." The word "energy poverty" is used internationally to characterize this type of deprivation, regardless of the end use or type of deficiency (e.g., affordability or reliability).

Socioeconomic emancipation depends on providing modern, clean, and economically priced energy services. The interplay of three important elements causes energy poverty: (a) low income; (b) high energy prices; and (c) excessive energy usage (Arsenopoulos et al., 2020). Although each component is separate, there appears to be overlap and interaction between them. *Energy services* are defined as using beneficial energy for consumer-desired tasks such as cooking, transportation, or providing lighting. Fuelwood, charcoal, animal dung, shrubs, and grass are traditional energy sources, while liquefied petroleum

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gas, natural gas and electricity are examples of modern energy sources.

According to Birol (2007), the Chief Economist of the International Energy Agency, the energy-economics community has given the issue of energy poverty among the world's poorest individuals inadequate attention. Energy poverty exacerbates income poverty at the macro level (Pachauri and Spreng, 2011; Khandker et al., 2012) and impedes community social and economic growth (Acharya and Sadath, 2019). On a micro level, energy poverty impedes women's empowerment, education, and the health and well-being of family members (Kanagawa and Nakata, 2006). In this regard, an integrated energy poverty index can be established to consolidate diverse aspects of energy poverty and assess its impact on economic suffering in developing nations such as Pakistan. Achieving SDG 7 requires comprehensively comprehending its two fundamental components: The "availability" and "affordability" of sustainable, secure and modern energy. The 2015 Sustainable Development Goals (SDGs) aim to provide universal access to clean and affordable energy by 2030, a global effort (UNGA, 2015).

Around 80% of the global child population lives in developing nations. Economists studying education encountered significant policy issues and varied experiences while investigating the issue in developing countries (Glewwe and Kremer, 2005). Despite significant advancements in school enrollment rates since 1960, a considerable number of children still lack access to education. Moreover, the quality of education in developing countries is frequently substandard, and many educational institutions need to be functioning more effectively. Poverty is a constant source of stress for children and families worldwide, which can impede their ability to succeed in developmental milestones, such as school achievements (McLoyd and Wilson, 1990). Low-income upbringing risks children's academic and social development, as well as their overall health and well-being. These factors can ultimately hinder their educational attainments (Engle and Black, 2008).

Many worldwide development challenges, such as poverty, inequality, ecological changes, food safety, health, and education, rely heavily on energy. According to previous literature, energy poverty is inhibiting the attainment of the Millennium Development Goals (MDGs) (see, for instance, Modi et al., 2005). The issue is linked to a large percentage of family income spent on energy in developed countries, while it is focused on energy availability in developing countries (Primc et al., 2021). Aside from inhibiting sustainable development, EP contributes to energy waste, with wasted surplus energy and downstream greenhouse gas emissions being released into the atmosphere (Serghides et al., 2017). It is estimated that 1.3 to 2.6 billion people on the planet are affected by energy poverty, which has various detrimental effects on the social, economic, and environmental spheres (IEA, 2012).

Energy poverty is a reason and a result of general poverty that affects millions of people (González-Eguino, 2015) and impacts both rich and developing nations. Using MEPI to quantify energy poverty in Pakistan, Haleem et al. (2020) found that the majority (70%) of households do not possess clean fuel for cooking, and nearly half (47%) lack access to appropriate fuel for heating. Millions of people in Pakistan who have access to utilities cannot fulfil their essential energy needs as they need more financial means to pay for them. In 2017, per-head energy use in Pakistan was nearly 500 kg of ton oil equivalent (TOE), compared to industrialized nations, which average 6000 kg of TOE (Ullah et al., 2021). The availability and use of clean fuels addressed in past energy studies in Pakistan concern the accessibility of energy poverty (Rehmet and Mirza, 2021). At the same time, affordability is tied to income, consumption, and financial strain imposed by rising energy prices.

The remainder of this study is structured as follows. The "Literature Review" section summarizes the literature, and the section "Materials and Methods" describes the data, model specification, and econometric strategy used. The section "Empirical results and discussion" summarizes the findings. And the section "Conclusion and policy recommendations" concludes the paper and discusses its policy inferences followed by references.

2. LITERATURE REVIEW

Our research on energy poverty is grounded in Amartya Sen's capabilities approach. Amartya Sen's capability approach to development highlights the importance of economic facilities as one of the five instrumental freedoms that enable individuals to achieve their full potential. Access to clean and modern energy resources is closely linked to this approach (Sen, 2000, p. 10). His framework for the capabilities approach includes fundamental concepts such as functions, capabilities, freedom, and agency, which are a more accurate measure of well-being than income or utility, and his approach focuses on the quality of life that individuals can achieve. He argued that functioning is a more accurate measure of well-being than income or utility. The capabilities approach values the outcome and welfare over the means employed to attain it. Energy poverty is a social disadvantage arising from inadequate access to and unaffordability of contemporary and clean energy resources and technology. Energy resources are essential for enhancing the socio-economic well-being of society. Previous studies by Khandker et al. (2012) and Wang et al. (2015) have shown that being free from income poverty does not necessarily mean being free from energy poverty. Therefore, examining access to energy resources from a capability perspective is reasonable.

Energy poverty was introduced in the UK about 30 years ago and has become a widely recognized issue in developed and developing countries. Maxim et al. (2016) highlighted the significance of energy poverty in affecting the general standard of living and welfare, leading to its recognition by scholars and policymakers. The European Union initiated a research project in 2016 to identify indicators for measuring energy poverty and to aid member states in safeguarding vulnerable consumers and tackling the problem of energy poverty (Rademaekers et al., 2016).

The existing literature has predominantly focused on Europe and Africa. Outside, studies have been limited to certain countries in developed non-European regions, including Japan (Okushima, 2016, 2017) and the United States (Bednar and Reames, 2020). A Multidimensional Energy Poverty Index (MEPI) was introduced by Nussbaumer et al. (2012) that encompasses energy accessibility and other developmental issues related to energy, such as the type of cooking fuel and the availability of electrical appliances like refrigerators, radios, televisions, and mobile phones. The Energy development index (EDI), based on the IEA (2010) report, is another multidimensional measure. The four EDI indicators (energy access, renewable energy consumption, electric power consumption, and primary energy use) are crucial in capturing fundamental facets of energy poverty, as Banerjee et al. (2021) stated.

Energy poverty is a fundamental component of poverty overall. Our hypothesis, based on existing literature, suggests that the relationship between energy poverty and educational implications depends on the overall poverty level in the country. High poverty levels, particularly energy poverty, can significantly impact developmental outcomes. Banerjee et al. (2021) posit that the reduction of poverty levels is expected to enhance the accessibility of energy services to underprivileged communities, thereby potentially ameliorating educational outcomes. According to Toman and Jemelkova (2003), providing modern energy services can augment the adaptability of young individuals in the workforce, enabling them to engage in nighttime studies. It can also facilitate the redistribution of time for females, freeing them from domestic duties and allowing them to pursue higher education. The impact of extreme poverty is more pronounced on families with young children, especially girls, as they are compelled to give precedence to gathering firewood and traditional cooking fuels over attending school. This leads to unfavorable outcomes, as evidenced by Cabraal et al. (2005) and Khandker et al. (2014) studies. The provision of modern energy services can yield several benefits, including but not limited to the improvement of classroom lighting, the improvement of working conditions for instructors and caregivers, and the capacity to facilitate laboratory-based courses and operate educational equipment, such as computers, photocopiers, televisions, and projectors (Banerjee et al., 2021).

Education enhances a nation's human resources and fosters sustained development. The scarcity of energy resources, also known as energy poverty, has far-reaching consequences for developing nations, particularly those whose economic development depends on the availability of energy sources for household activities and other productive pursuits. According to a 2008 report by the World Bank, access to electricity or electrification can significantly impact educational outcomes. This is due to the improvement in school quality, which can be accomplished through the provision of electrically powered apparatus or the increase in the number and caliber of instructors. Furthermore, it enables an extended duration for academic pursuits, aided by enhanced lighting. Energy poverty has been found to significantly impact education, manifesting in both absenteeism from school and increased incidence of illness.

A robust association has been observed between the duration children allocate towards gathering fuel and a decline in their attendance at educational institutions (Sovacool and Drupady, 2012). Energy poverty has been found to exacerbate challenges in accessing education and employment opportunities, as noted by Sharma et al. (2019). Scholars increasingly agree that energy poverty significantly impacts education, as evidenced by studies conducted by Adom et al. (2021) and Apergis et al. (2022). The FAO has identified that enhancing energy resources in rural regions and creating novel bioenergy sources can play a pivotal role in accomplishing the Millennium Development Goals that pertain to poverty mitigation, enhanced healthcare and education, preservation of the environment, and gender equality (FAO, 2006). According to Birol (2007), modern energy services are crucial for fulfilling fundamental requirements such as sustenance and housing and should be given precedence in poverty reduction plans. The Sustainable Development Goals (SDGs) 2015 included affordable and clean energy as the seventh objective, which was subsequently adopted by all United Nations member states. The aim is to attain extensive accessibility of economical, reliable, and modern energy services from 2016 to 2030, as Morton et al. (2017) stated. The attainment of Sustainable Development Goals (SDGs), such as poverty reduction (SDG 1), improved health and well-being (SDG 3), better education quality (SDG 4), and gender equality promotion (SDG 5), is significantly impacted by the availability of electricity and clean cooking facilities (Harmelink, 2020).

Empirical work on energy poverty is predominantly in African and European countries (mainly with the notion of Fuel poverty). The definition of energy poverty often requires a certain threshold defining who is "energy poor" and "non-energy poor." The threshold indicates how much energy households need to maintain an acceptable standard of living (Barnes et al., 2010). A study of energy poverty in Guatemala by Foster et al. (2000) found that one-fourth of the population with access to electricity is fuel-poor compared to half of the population without access. Their study used the Foster-Greer-Thorbecke (FGT) measure to determine whether a household is energy or fuel-poor if it cannot meet its primary energy requirements (2,125 kilowatts). Pachauri and Spreng (2004) surveyed the energy consumption patterns of Indian households. Their study indicated that a combination of biomass and kerosene was the predominant energy source for households, while firewood remained the most cost-effective option for households regarding annual expenses. Catherine et al. (2007) examined the UK government's initiatives to eliminate fuel poverty in vulnerable households by 2010 and the general population by 2016. The study utilized the Family Expenditure Survey to explore the connection between subjective household experience and official objective definition based on a unique dataset. Fuel poverty was found to be predominantly influenced by income level and income support in low-income survey samples and household expenditure surveys.

Mirza and Szirmai (2010) analyzed data from the Energy Poverty Survey (EPS) between 2008 and 2009 to examine rural energy poverty and the characteristics and impacts of various energy services using a composite index. The rural area of Pakistan uses a range of energy sources such as firewood, plant residue, kerosene oil, and dung cake; nonetheless, they still endure energy poverty or deficiency. According to them, 97% of rural households struggle with a lack of energy in Pakistan. Ninety-two percent of rural occupants face severe energy scarcity, particularly in Punjab. In a 2010 study, Barnes et al. attempted to determine the extent of energy poverty through a cross-sectional survey in 2004 that involved 2300 households in rural Bangladesh. Results showed that nearly 58% of those from poorer backgrounds lacked access to electricity, compared to only 45% of those from overall low-income families. Sher et al. (2014) measured energy poverty by utilizing the Alkire Foster methodology in provinces of Pakistan, relying on the headcount metric. Their findings revealed that EPI varied from 47% to 69% in the four provinces investigated. Indoor pollution was the primary contributor to MEP (incidence) in every area, followed by cooking fuel. The metrics and indicators used were comparable with those of Nussbaumer et al. (2011; 2012). Acharya and Sadath (2019) utilized household-level survey data from India and, through a MEPI, demonstrated the significant role of education in hindering the increase of energy poverty. Children with access to electricity tend to spend more time on their studies compared to those who do not have access to electricity (Khandker et al., 2014).

Rehmet and Mirza (2021) examine the elements of MEP prevalence and severity in Pakistan. The probability of MEP was found to be higher for male-headed households, and as household head age and education levels increase, MEP decreases. Ullah et al. (2021) used a set of macro-level indicators to measure energy poverty in Pakistan using the composite energy poverty index, which considers four main components: Energy governance, energy services, clean energy, and energy affordability. Outcomes indicate that the country's reliance on unclean energy is growing. A negative cointegration between energy poverty and economic growth was found. Banerjee et al. (2021) conducted a study to examine the effects of energy poverty on health and education outcomes in 50 developing nations between 1990 and 2017. The research indicates that alleviating energy poverty, or enhancing energy development, is associated with improved health and education outcomes. Furthermore, the study reveals that access to electricity has a more significant positive impact on development outcomes than overall energy consumption. According to the research conducted by Katoch et al. (2023), there is an opposite relationship between energy poverty and educational attainment and overall well-being. Although a few studies have reported an insignificant impact of reduced energy poverty on educational achievements (Burlig and Preonas, 2016), the evidence supporting the positive correlation between lower energy poverty and improved education outcomes is more substantial.

The majority of research on energy poverty has been undertaken in emerging African economies (Ismail and Khembo, 2015; Crentsil et al., 2019; Edoumiekumo et al., 2013; Ozughalu and Ogwumike, 2019) and in European countries with the notion of fuel poverty. Only a few studies have looked at the Pakistani economy regarding energy poverty at the household and community levels (Rehmet and Mirza, 2021; Awan et al., 2022; Ullah et al., 2021; Sher et al., 2014; Mahmood and Shah, 2017; Awan et al., 2013; Mirza and Szirmai, 2010) and most of them are concerned with measurement and determinants of energy poverty. So, this study aims to investigate the impact of energy poverty on educational attainments in Pakistan, using the EDI as a proxy for energy poverty. This study is innovative as it is the 1st time series analysis to assess the impact of energy poverty on educational outcomes in Pakistan. Furthermore, the global literature has also neglected energy poverty's long-term effects, and this study will be a valuable addition to the energy poverty literature.

3. MATERIALS AND METHODS

3.1. Data Sources

This study employs data between 1990 and 2020 for the study variables. The data of poverty headcount (%age of population), real GDP per capita (constant 2017 international $), electricity access (%age of population), total renewable energy consumption (%age of total energy consumption), gross fixed capital formation (%age of GDP) and urban population (%age of total population) is obtained from world development indicators, electric power consumption (kwh per capita) from Pakistan energy yearbook and primary energy use (kgoe per capita) from British petroleum. The data for primary and secondary school enrollment ratio (gross %) and pupil-teacher ratio is obtained from World Development Indicators (WDI) and different editions of the Pakistan economic survey (PES).

3.2. Model Specification

All variables are written in natural logarithms to minimize the variation in the data. This empirical work investigates the contributions of reducing energy poverty to educational attainments (school enrollment ratio). The equation written below demonstrates the model object of our analysis, which is first defined in a functional form as:

(Educational Attainments) t = $B_0 + B_1$ (Energy Development Index) t + B_2 (Poverty Headcount Ratio)t + (Real GDP per capita) t + B_4 (Pupil Teacher Ratio) t + ε

$$EO_t = f(EDI, POV, GDP, PTRATIO) \quad (1)$$

The natural logarithm form interprets the obtained coefficients as elasticities (Shahbaz et al., 2016).

$$LEO_t = f(LEDI, LPOV, LGDP, LPTRATIO) \quad (2)$$

The Educational outcome is measured through school enrollment ratio; secondary school enrollment and primary school enrollment ratio.

$$LPSENR_t = f(LEDI, LPOV, LGDP, LPTRP)_t \quad (3)$$

$$LSSENR_t = f(LEDI, LPOV, LGDP, LPTRS)_t \quad (4)$$

LPSENR represents the gross enrollment ratio at primary level and LSSENR represents the gross enrollment ratio at secondary level.

3.3. Study Variables

3.3.1. Dependent variables

The influence of energy poverty on academic achievements is a significant factor that cannot be disregarded. The provision of contemporary energy services offers working adults increased flexibility to engage in nighttime academic pursuits and facilitates the reallocation of time previously devoted to domestic chores by females towards higher education, as posited by Toman and Jemelkova (2003). The indicator predominantly employed to assess the quantity of education is the gross enrollment rate. This measure is extensively accessible and frequently referenced in scholarly literature, as Glewwe and Kremer (2005) noted. The term "enrollment ratio" refers to the proportion of individuals within a given age cohort registered in a particular educational program, irrespective of age. So in this study, the dependent variable utilized to gauge educational outcomes is a comprehensive metric known as the gross school enrollment ratio at both the primary and secondary levels. This metric is utilized as a proxy for educational Attainments. When a significant portion of the population experiences severe impoverishment, the repercussions are particularly severe for households with young children, especially girls. This is because these children are compelled to spend considerable time gathering firewood and other conventional cooking fuels, which detracts from their ability to attend school (Cabraal et al., 2005; Khandker et al., 2014). In regions with colder climates, the provision of education services in schools is contingent upon the availability of electricity and heating systems. These resources are deemed crucial for the effective functioning of educational institutions. The available evidence indicates that the impact of education and access to electricity is amplified with each additional year of education and level of access to electricity. Zhang et al. (2021) conducted a study that revealed a potential relationship between energy poverty and children's subjective well-being in China. Specifically, the study found that academic performance in Chinese and math subjects can mediate this relationship. The gross enrollment rate is a commonly cited and accessible metric for measuring educational quantity. LPSENR and LSSENR refer to the gross school enrollment ratio at the primary and secondary levels, respectively. These ratios are determined by dividing the total enrollments at the primary and secondary levels by the total population of that age group.

3.3.2. Key explanatory variable

As stressed previously, this study examines the complementarity between higher energy development (lower energy poverty) and educational attainments via gross primary and secondary school enrollment ratio.

3.3.2.1. Energy development index

Energy poverty is a complex issue that can be assessed through a composite index, encompassing the diverse aspects of deprivation. The multidimensional poverty approach, which has gained prominence through the efforts of the Oxford Poverty and Human Development Initiative, is founded on Amartya Sen's capabilities approach. Improved energy services have been observed to yield positive outcomes in academic performance, including reduced truancy and absenteeism, increased enrollment rates, higher graduation and completion rates, and improved test scores (Sovacool and Vera, 2014). UN DESA (2019) highlighted that educational institutions necessitate energy for various purposes such as lighting, cooking, heating, cooling, water supply and purification, and information and communication technology (ICT). There is a direct and favorable association between the availability of electricity, specifically for lighting purposes, and enhanced educational outcomes. Micro-level empirical research has demonstrated significant evidence supporting a positive association between decreased energy poverty and enhanced educational achievements. Electrification has been found to have a positive impact on education and employment outcomes in developing countries, including Brazil (Lipscomb et al., 2013), sub-Saharan Africa (Bernard, 2012), and India (Ahmad et al., 2014).

The MEPI encompasses essential electricity accessibility and overall energy consumption, encompassing sustainable energy sources. The index is crucial in measuring energy access in residential and commercial sectors. Higher access and energy consumption in commercial areas indicate better energy coverage and greater adoption of modern energy policies in the country. This index is modeled after the IEA's 2010 report on energy poverty and utilizes four indicators from the residential and commercial sectors.

1. Total primary energy consumption per capita (in kilograms' oil equivalent)
2. Per capita electricity consumption (kWh)
3. Renewable energy consumption (as a percentage of total energy consumption)
4. Access to electrical power (% of the population).

Higher primary energy use per capita refers to the consumption of primary energy before its conversion into other forms of fuel, such as electricity and refined petroleum products. Renewable energy consumption refers to the proportion of renewable energy utilized in the final energy consumption. Increased energy usage is indicative of higher consumption of various forms of energy, which is crucial for the economic development of transitional economies, particularly in the commercial and industrial sectors (Wolfram et al., 2012). Electricity access and consumption per capita are indicators of a country's electricity availability and usage.

The EDI is a comprehensive measure of energy poverty encompassing four key dimensions: per capita primary energy consumption, renewable energy consumption, access to electricity, and per capita electricity consumption. We have employed the max-min formula as used by Sadath and Acharya (2021) given below,

$$\frac{Actual Value - Minimum\ Value}{Maximum\ Value - Minimum\ Value}$$

The standardization of each indicator results in values ranging from zero to one, which are then combined using an arithmetic mean to create a unified index. The construction of the EDI for a particular country is an annual process that involves repetition. A positive correlation exists between the EDI value and the level of energy poverty in a country, whereby a higher EDI value signifies a lower energy poverty level.

3.3.3. Control variables

3.3.3.1. Poverty headcount

The relationship between energy poverty and educational attainments depends on the general poverty rate. High levels of general poverty significantly impact developmental outcomes when energy poverty is present (Banerjee et al., 2021). Reducing general poverty can mitigate the impact of energy poverty on educational attainments. The poverty headcount ratio measures living standards and affordability of essential goods and services. We anticipate a significant correlation between the MEPI and household income levels in developing countries. Lowering energy poverty levels can significantly benefit the agricultural sector by facilitating the adoption of modern machinery, farm equipment, improved irrigation systems, and access to clean cooking fuels. This is supported by Cabraal et al. (2005). ChildFund International has established a correlation between poverty and education, as individuals living in impoverished conditions may discontinue their education to engage in labor activities, resulting in a lack of fundamental literacy and numeracy skills crucial for career advancement (Childfund International).

3.3.3.2. Economic growth (Y)

Enhancing educational achievements has been historically associated with economic development. Mendoza et al. (2019) found a significant correlation between the income level of households in developing countries and the MEPI. The income per capita is used as a control variable to examine the correlation between energy poverty and educational attainment. Several studies, including Majeed and Gilani (2017) and Majeed and Ozturk (2020), have demonstrated that economic growth positively impacts an individual's income, leading to improved access to education, healthcare, housing, and nutrition. This research employs a metric of economic growth, namely GDP per capita in constant 2017 international $. Prior research suggests a positive correlation between economic growth and educational outcomes.

3.3.3.3. Pupil teacher ratio

The models employed include the quality of education as a control variable, which is indicated by the pupil-teacher ratio in primary and secondary education. This ratio is a reliable measure of the learning environment in schools, as Dearden et al. (2002) noted.

4. RESULTS AND DISCUSSION

4.1. Descriptive Statistics

The study conducts a descriptive analysis of the dependent and explanatory variables presented in Table 1 to understand their characteristics before model estimation. The logarithmic means of the following variables were obtained from the data: secondary school enrollment ratio (1.499183), primary school enrollment ratio (1.883722), energy development index (−0.328061), headcount poverty (1.159168), GDP per capita (3.563031), primary school pupil-teacher ratio (1.615961), and secondary school pupil-teacher ratio (1.080554). All other variables exhibit a negative skewness, except for secondary school enrollment, the pupil-teacher ratio at the secondary level, and GDP per capita.

The correlation matrix results in Table 1 appear deceptive. Descriptive statistics alone cannot establish causality. Therefore, inferential statistics are necessary to empirically investigate the causal relationship between the predictors and the educational outcomes proxy variables, specifically the secondary and primary school enrollment ratios.

4.2. Stationarity of the Variables

The ADF and PP unit root tests results in Table 2 show that some variables are stationary at level but all variables are stationary at first difference. No variable is stationary at the second difference I (2). So, we can proceed with the regression analysis.

4.3. Cointegration Regression

The Johansen approach is applied to test the cointegration among variables. The null hypotheses being tested are r=0 (which shows no cointegration), r≤1 (which proposes the presence of at most one cointegration relation), r≤2 (which shows the presence of at most two cointegration relations), r≤3 (which proposes the presence of at most three cointegration relations), and r≤4 (which shows the presence of at most four cointegration relations). The results of the trace statistics and maximum eigenvalue statistics for the primary school enrollment model in Table 3 reveal that

Table 1: Descriptive statistics

Descriptive statistics type	LPSENR	LSSENR	LEDI	LPOV	LGDP	LPTRP	LPTRS
Mean	1.883722	1.499183	−0.328061	1.159168	3.563031	1.615961	1.080554
Median	1.891693	1.472626	−0.279523	1.262451	3.569002	1.612784	1.063709
Maximum	1.967076	1.651938	−0.167697	1.782473	3.675730	1.690905	1.229426
Minimum	1.768115	1.322376	−0.721104	0.602060	3.464773	1.537693	0.996512
SD	0.064930	0.079606	0.134934	0.372961	0.064544	0.042058	0.062624
Skewness	−0.257361	0.186828	−1.406169	−0.175965	0.220746	−0.006954	0.686265
Kurtosis	1.669010	2.478890	4.557345	1.746832	1.741299	2.244762	2.409968
Jarque-Bera	2.630446	0.531100	13.34882	2.188451	2.298191	0.736996	2.882972
Sum	58.39537	46.47468	−10.16989	35.93421	110.4540	50.09478	33.49717
Sum SD	0.126478	0.190114	0.546215	4.172994	0.124977	0.053065	0.117654
Observations	31	31	31	31	31	31	31
Variables	**LSSENR**	**LPSENR**	**LEDI**	**LPOV**	**LGDP**	**LPTRS**	**LPTRP**
LSSENR	1						
LPSENR	0.936904	1					
LEDI	0.860209	0.909869	1				
LPOV	−0.951597	−0.947287	−0.846963	1			
LGDP	0.965006	0.968123	0.848397	−0.958852	1		
LPTRS	−0.469377	−0.500934	−0.417267	0.417417	−0.499732	1	
LPTRP	0.765878	0.735876	0.585142	−0.851406	0.784326	−0.214031	1

the probability values are statistically significant for r=0, r≤1, and r≤2, indicating that the null hypotheses are rejected. The findings suggest that there is cointegration present among the variables.

Similarly, from trace values and maximum eigenvalues of the Johansen cointegration test in secondary school enrollment model, two cointegrating equations confirmed a long-run cointegration between dependent and explanatory variables. So, we can proceed with the long-run cointegration tests, FMOLS and canonical cointegration regression to check the relationship among the variables.

4.4. Fully Modified Ordinary Least Square

The results of the FMOLS models are presented in Table 4. The EDI significantly impacts gross primary and secondary school enrollment at a 1% significance level. A 1% increase in the EDI increases primary and secondary school enrolment by 0.112550% and 0.104649%, respectively. Inadequate energy access impedes effective nighttime studying for children and adults, impacting learning outcomes. This negatively affects their academic performance and can lead to unequal educational opportunities. Energy poverty is closely tied to unequal education access, particularly in rural areas with high energy poverty rates (Sule et al., 2022).

Table 2: Unit root results

				PP I (0)				
		LPSENR	LSSENR	LEDI	LPOV	LGDP	LPTRP	LPTRS
With C	t-statistic	−2.3381	−1.6628	−5.3786***	−0.9736	−0.4276	−0.7437	−2.7667*
With C and T	t-statistic	−1.7090	−3.6662**	−4.8142***	−1.8066	−1.7405	−2.3040	−3.0512
				PP I (1)				
		d (LPSENR)	d (LSSENR)	d (LEDI)	d (LPOV)	d (LGDP)	d (LPTRP)	d (LPTRS)
With C	t- statistic	−6.8825***	−8.0542***	−3.3697**	−3.0008**	−2.7355*	−6.3063***	−10.6260***
With C and T	t-statistic	−8.5724***	−10.6270***	−4.1295**	−2.9854	−2.6392	−6.9168***	−10.6926***
				ADF I (0)				
		LPSENR	LSSENR	LEDI	LPOV	LGDP	LPTRP	LPTRS
With C	t-statistic	−1.5686	−0.4364	−5.2663***	−1.0974	−0.8742	−1.0233	−3.1768**
With C and T	t-statistic	−1.7090	−3.4350*	−4.5023***	−2.4290	−3.0753	−2.3536	−4.1697**
				ADF I (1)				
		d (LPSENR)	d (LSSENR)	d (LEDI)	d (LPOV)	d (LGDP)	d (LPTRP)	d (LPTRS)
With Ct	t-statistic	−6.8259***	−5.4205***	−3.5171**	−2.9707**	−2.9886**	−4.7180***	−5.9316***
With C and T	t-statistic	−7.2501***	−5.3041***	−4.1443**	−2.9500	−2.6764	−4.7696***	−5.8255***

(*) Significant at the 10%; (**) Significant at the 5%; (***) Significant at the 1%. *MacKinnon (1996) one-sided P values

Table 3: Unrestricted cointegration rank test

Trace stat				Max eigenvalue stat		
H_0	λ_{Trace}	5% critical value	P-value	$\lambda_{\text{Maxeigen value}}$	5% critical value	P-value
Model 1 (LPSENR)						
r=0	138.1631	69.81889	0.0000*	57.12810	33.87687	0.0000*
r≤1	81.03497	47.85613	0.0000*	36.58162	27.58434	0.0027*
r≤2	44.45334	29.79707	0.0005*	29.16782	21.13162	0.0030*
r≤3	15.28552	15.49471	0.0537	16.80597	16.26460	0.0550
r≤4	0.479555	3.841466	0.4886	0.479555	3.841466	0.4886
Model 2 (LSSENR)						
r=0	99.48222	69.81889	0.0000*	40.29689	33.87687	0.0075*
r≤1	59.18533	47.85613	0.0030*	33.46511	27.58434	0.0078*
r≤2	25.72021	29.79707	0.1373	16.67200	21.13162	0.1880
r≤3	9.048209	15.49471	0.3609	8.617050	14.26460	0.3194
r≤4	0.431160	3.841465	0.5114	0.431160	3.841465	0.5114

*Denotes rejection of the hypothesis at the 0.05 level

Table 4: Results of fully modified OLS

Variable	Model 1(LPSENR)		Model 2 (LSSENR)		
	Coefficient	Prob.	Variable	Coefficient	Prob.
LEDI	0.112550	0.0000	LEDI	0.104649	0.0122
LPOV	−0.043716	0.0016	LPOV	−0.071447	0.0031
LGDP	0.608751	0.0000	LGDP	0.700662	0.0000
LPTRP	−0.163992	0.0033	LPTRS	−0.031096	0.4660
C	0.065290	0.7862	C	−0.848689	0.1134
R^2	0.961900		R^2	0.922320	
Adj. R^2	0.955804		Adj. R^2	0.909891	
S.E. of regression	0.013104		S.E. of regression	0.022144	

A 1% increase in GDP per capita raises primary and secondary school enrollment by 0.608751% and 0.700662%, respectively, at a 1% level of significance. These findings align with Farjo's (2011) and Brown's (1999) findings. An increase in poverty headcount and pupil-teacher ratio has a negative impact on primary as well as secondary school enrollment. A 1% increase in general poverty decreases primary and secondary school enrolment by 0.043716% and 0.071447%, respectively, at a 1% significance level. Children belonging to poor households are less likely to attend primary schools (Arif et al., 1999). The presence of poverty can have a

Table 5: Canonical cointegration regression results

Model 1(LPSENR)			Model 2 (LSSENR)		
Variable	Coefficient	Prob.	Variable	Coefficient	Prob.
LEDI	0.114636	0.0000	LEDI	0.104649	0.0122
LPOV	−0.041914	0.0009	LPOV	−0.071447	0.0031
LGDP	0.617739	0.0000	LGDP	0.700662	0.0000
LPTRP	−0.183477	0.0041	LPTRS	−0.031096	0.4660
C	0.063225	0.7753	C	−0.848689	0.1134
R^2	0.961201		R^2	0.922320	
Adj.R^2	0.954993		Adj. R^2	0.909891	
S.E. of regression	0.013223		S.E. of regression	0.022144	

Table 6: Generalized method of moments results

Model 1 (LPSENR)			Model 2 (LSSENR)		
Variable	Coefficient	Prob.	Variable	Coefficient	Prob.
LEDI	0.228328	0.0001	LEDI	0.187546	0.0796
LPOV	−0.087908	0.0276	LPOV	−0.094046	0.0278
LGDP	0.327346	0.0571	LGDP	0.759637	0.0200
LPTRP	−0.348952	0.0736	LPTRS	−0.179022	0.2911
C	1.456654	0.0764	C	−0.964710	0.4495
R^2 0.959330	Adj. R^2 0.952551		R^2 0.935724	Adj. R^2 0.925011	
Prob.(J-stat) 0.21262	J-stat. 4.39904		Prob (J-stat) 0.225849	J-stat 2.975774	
AR (2)	0.8330		AR (2)	0.5479	

Table 7: Variance decomposition analysis Model 1

Variance decomposition of LPSENR						
Period	S.E.	LPSENR	LEDI	LPOV	LGDP	LPTRP
1	0.008450	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.010780	82.52362	1.439307	6.189709	5.415651	4.431713
3	0.013025	82.60726	1.923799	7.806497	4.325275	3.337165
4	0.014546	81.86119	2.015179	9.637620	3.772828	2.713185
5	0.015952	83.22097	1.952202	9.432840	3.137893	2.256100
Variance decomposition of LEDI						
1	0.015541	0.124732	99.87527	0.000000	0.000000	0.000000
2	0.018893	4.499523	74.64693	0.425590	18.13179	2.296171
3	0.022502	7.732815	55.06149	0.430860	30.08388	6.690962
4	0.025746	15.98943	42.06226	0.329740	32.92671	8.691861
5	0.027828	23.91893	36.01060	0.286322	31.37241	8.411748
Variance decomposition of LPOV						
1	0.050259	0.003415	8.758015	91.23857	0.000000	0.000000
2	0.082048	0.062347	8.185437	91.53498	0.212485	0.004747
3	0.103014	1.099815	6.638067	90.76770	0.713958	0.780459
4	0.116361	3.833824	5.403269	88.12637	0.965397	1.671136
5	0.125595	9.179825	4.640351	83.15768	1.108627	1.913516
Variance decomposition of LGDP						
1	0.007545	15.09846	0.928990	3.839027	80.13352	0.000000
2	0.012845	21.97910	0.609300	5.772981	71.42457	0.214048
3	0.016240	30.24942	0.730413	8.921378	59.37580	0.722984
4	0.018568	38.77862	0.739441	12.29547	47.41032	0.776149
5	0.020460	44.87753	0.609074	14.69395	39.17962	0.639828
Variance decomposition of LPTRP						
1	0.020074	2.814132	1.579517	2.745780	2.119123	90.74145
2	0.024229	2.675580	7.929110	16.31479	1.466532	71.61399
3	0.026627	3.078891	7.748792	28.55147	1.226853	59.39400
4	0.028243	2.793182	6.944177	34.47246	1.206552	54.58363
5	0.029229	3.218446	6.624601	36.53516	1.258303	52.36349

Cholesky ordering: LPSENR LEDI LPOV LGDP LPTRP negative impact on school enrollment rates due to a variety of factors, including limited financial resources for education-related expenses, reduced access to high-quality schools, and the need for children to engage in labor activities, which can detract them from their educational opportunities.

A 1% increase in pupil-teacher ratio decreases primary school enrollment by 0.0163992% but turns out insignificant in the case of secondary school enrollment. Reducing the ratio of pupils to teachers positively affects enrollment in primary and secondary schools by improving individual attention, enhancing classroom management, increasing student engagement, providing academic support, fostering stronger teacher-student relationships, and boosting parental confidence and involvement. The combined influence of these variables contributes to a more appealing and encouraging academic setting, resulting in increased enrollment rates. Case and Deaton (1999) found similar results for South Africa and Huisman and Smith (2009) for 30 developing countries.

4.5. Canonical Cointegration Regression

The results of canonical cointegration regression are given below.

The results of canonical cointegration regression are presented in Table 5. The EDI and real GDP per capita significantly impact gross primary school enrollment at a 1% significance level. A 1% increase in the EDI and GDP per capita increases primary school enrolment by 0.114636% and 0.617739%. The EDI and real GDP per capita also significantly impact gross secondary school enrollment at 1% and 5% level of significance, where a 1% increase in the EDI and GDP per capita increases secondary school enrolment by 0.104649% and 0.700662%. An increase in poverty headcount and pupil-teacher ratio has a negative impact on primary school enrollment. A 1% increase in general poverty and pupil-teacher ratio decreases primary school enrolment by 0.041914% and 0.183477%, respectively. A 1% increase in poverty headcount decreases secondary school enrollment by 0.071447%. The pupil-teacher ratio impact is negative but statistically insignificant in the case of secondary school enrollment.

4.6. Robustness Check

In order to check the robustness of our results and the relationship between regressand and explanatory variables, the two-step GMM is employed here.

Table 6 shows the results of the generalized method of movement. Coefficients represent the elasticities as dependent and independent variables are in logarithm form. The coefficients of EDI and GDP are positive, so a 1% increase in these two factors will improve the school enrollment ratio at the primary level by 0.228328% and 0.327346% and improve the secondary school enrollment ratio by 0.187546% at 10% significance level and 0.759637% at 5% level of significance respectively. The coefficient of poverty and the pupil-teacher ratio is negative and significant; a 1% increase in these will decrease the primary school enrollment ratio by 0.087908% and 0.348952%. Moreover, a 1% increase in poverty reduces the secondary school enrollment level by 0.094046%. The

Table 8: Variance decomposition analysis Model 2

Variance decomposition of LSSENR						
Period	S.E.	LSSENR	LEDI	LPOV	LGDP	LPTRS
1	0.012123	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.015482	78.63648	0.041923	1.309897	18.24667	1.765024
3	0.021204	48.00388	1.954212	13.73892	34.47057	1.832416
4	0.026410	33.56865	1.807889	27.41156	35.63497	1.576924
5	0.030924	26.20428	1.450545	38.46446	32.30221	1.578506
Variance decomposition of LEDI						
1	0.014738	1.382366	98.61763	0.000000	0.000000	0.000000
2	0.018123	2.685155	68.44297	4.424871	22.15920	2.287802
3	0.023036	9.117881	43.02121	3.885279	41.40564	2.569996
4	0.028136	11.79102	28.89507	3.180992	53.58311	2.549805
5	0.032286	13.09116	22.23409	3.397335	58.41709	2.860332
Variance decomposition of LPOV						
1	0.052908	0.166974	4.702052	95.13097	0.000000	0.000000
2	0.091141	0.117389	2.733057	96.58956	0.240312	0.319678
3	0.117967	1.262243	2.216299	94.50670	1.710570	0.304188
4	0.136915	2.722790	1.720072	89.66290	5.662897	0.231338
5	0.152522	3.988274	1.439753	83.05138	11.32345	0.197150
Variance decomposition of LGDP						
1	0.008183	1.903457	0.072866	13.44218	84.58150	0.000000
2	0.015406	2.384602	2.520889	17.81447	77.22779	0.052250
3	0.020687	3.663479	2.935737	21.59467	71.26014	0.545967
4	0.024934	5.417891	2.747700	24.84004	65.58798	1.406388
5	0.028436	7.148431	2.357944	27.54315	61.05124	1.899240
Variance decomposition of LSSENR						
1	0.045667	4.200138	14.17390	1.623150	5.359077	74.64373
2	0.061653	22.56647	7.777431	1.523889	20.51540	47.61681
3	0.067204	21.31972	6.554082	1.610782	29.43255	41.08287
4	0.067759	21.11853	6.519866	2.476758	29.03592	40.84892
5	0.069482	20.10926	6.272741	3.563377	30.60641	39.44821

Cholesky ordering: LSSENR LEDI LPOV LGDP LPTRS p-value of the Sargan test of over-identifying restrictions (if the instruments used are exogenous) is more than 5%, indicating the instrument's validity. The second-degree autocorrelation AR (2) is not present, so both critical assumptions of GMM are fulfilled. The lag values of explanatory variables, urbanization, and gross fixed capital formation, are employed as instrumental variables due to their relevance with school enrollment and exogeneity.

4.7. Variance Decomposition Analysis

A variance decomposition analysis was performed on the primary and secondary school models to examine each variable's reliability and dynamic contribution to the gross primary and secondary school enrollment ratio. Variance decomposition is better for figuring out how the independent factors affect the response variable than other methods (Engle and Granger, 1987; Ibrahim, 2005). It decomposes endogenous variable variation into component shocks. Tables 7 and 8 provides the variance decomposition analysis results using five periods ahead of the sample period for model 1 and 2.

The results show that all explanatory factors will continue to affect Pakistan's future primary and secondary school enrollment. The findings also imply that adopting and implementing proper energy development policies will result in a considerable future increase in primary and secondary school enrollment in Pakistan.

5. CONCLUSION AND POLICY RECOMMENDATIONS

We have analyzed the relationship between energy poverty, and Pakistan's primary and secondary school enrollment in the presence of controls. Several models were employed to examine this relationship, including Fully Modified Ordinary Least Squares (FMOLS), Canonical Cointegration Regression, and Generalized Method of Moments (GMM). The findings of FMOLS and canonical cointegration regression consistently indicate that the energy development index (EDI) and GDP per capita significantly and positively impact both primary and secondary school enrollments. In contrast, an increase in general poverty and pupil-teacher ratio has negative implications for educational outcomes, i.e., primary and secondary school enrollment. These results are in line with previous studies, highlighting the importance of energy access and economic growth in promoting educational opportunities. The findings also suggest that poverty and inadequate pupil-teacher ratios hinder educational access and contribute to unequal opportunities, particularly in rural areas with high energy poverty rates.

The robustness check using the GMM confirmed the validity of FMOLS and canonical cointegration regression results. The coefficients of EDI and GDP remained positive and significant, indicating their continued influence on school enrollment. The poverty and pupil-teacher ratio coefficients remained negative and significant, emphasizing their detrimental effect on enrollment rates. Furthermore, variance decomposition analysis revealed that the explanatory factors, including EDI, general poverty, GDP, and pupil-teacher ratio, will continue to affect future primary and secondary school enrollment in Pakistan. These results underscore the importance of adopting effective energy development policies and addressing poverty and pupil-teacher ratios to improve the country's primary and secondary school enrollment. Policymakers and stakeholders can utilize these findings to develop targeted interventions and policies to improve educational outcomes and reduce disparities in Pakistan's school enrollment. Analyzing the relationship between various factors and primary and secondary school enrollment in Pakistan yields essential policy implications for different stakeholders.

Given the significant positive impact of the energy development index (EDI) on school enrollment, the government should focus on improving energy access and affordability, particularly in rural areas with high energy poverty rates. This can be achieved through infrastructure development, renewable energy projects, and targeted initiatives. The positive influence of GDP per capita on school enrollment highlights the importance of economic development. The government should implement policies that foster economic growth, create employment opportunities, and reduce poverty, which will positively impact educational outcomes. This can be done by building new power plants, investing in renewable energy sources, and providing subsidies to low-income households. The negative impact of general poverty on enrollment rates necessitates implementing poverty reduction strategies. The government should prioritize social welfare programs, income generation projects, and targeted interventions to uplift disadvantaged communities and reduce inequalities in access to education. The detrimental effect of high pupil-teacher ratios on school enrollment emphasizes the need to address this issue. The government should allocate resources to recruit and train more teachers, particularly in areas with shortages, and ensure an adequate number of teachers per student to enhance educational access. Policymakers should promote energy efficiency in all sectors of the economy. This can be done by investing in energy-efficient appliances and buildings and providing consumers with information and education about energy efficiency, which will increase the provision of energy for educational purposes. Policymakers could promote using renewable energy sources, such as solar and wind power, to reduce reliance on fossil fuels. This would help to reduce energy poverty and improve air quality.

Researchers can delve deeper into the relationship between energy poverty and educational implications. Examining the mechanisms through which energy poverty impacts education can provide insights for designing effective interventions and policies. Long-term studies tracking the impact of energy development, economic growth, poverty reduction, and pupil-teacher ratios on school enrollment can comprehensively understand the dynamics involved. This can help in identifying causal relationships and informing evidence-based policymaking. As Pakistan's economy is struggling and the country lacks financial resources, international organizations, and donors can allocate resources to support educational programs that aim to improve school enrollment and reduce energy poverty. This can include funding for energy infrastructure, teacher training, educational materials, and ICT-based learning. By taking these steps, policymakers can help to create a more sustainable and equitable future for all.

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