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Socio-Economic Determinants of Energy Intensity: Comparative Evidence from Developed and Developing Countries

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Abstract
The study objective is to examine the determinants of energy intensity across developed and developing countries from 1990 to 2023. For this purpose, the study employs the system Generalized Method of Moments (GMM). Among the socioeconomic determinants of energy intensity, GDP, FDI, and education reduce energy intensity in developed and developing countries. The education variable appeared to be most influential in reducing energy intensity, particularly in developed countries, followed by FDI and GDP growth. These variables reduce energy intensity, which is driven by the shift towards less energy-intensive sectors and enhancement in energy efficiency. The factors that increase energy intensity include population growth, urbanization, financial development, and currency exchange rate. The strongest driver of energy intensity is urbanization, observed in the panel of developed countries. Energy intensity increases due to more demand for goods and services induced by higher population and urbanization, besides the improvement of the financial sector which facilitates purchases of energy-intensive goods. Therefore, it is desirable to implement energy-efficient policies to achieve the economic growth target with energy sustainability. However, the variables of access to electricity, trade openness, and capital-to-labor diverge in their impact across the panel of developed and developing countries. Understanding the determinants of energy intensity is crucial because it directly influences how effectively economies utilize energy resources. By identifying and addressing the socio-economic factors that drive energy intensity, policymakers can design targeted strategies to optimize energy use, reduce environmental impacts, and align with global energy sustainability goals. This knowledge is vital for balancing economic growth with environmental preservation, ensuring a sustainable energy future.

Keywords: *Socio-economic, Energy Intensity, Education, Financial Development*

JEL Classification: *G15, I23, Q40, Q56*

1. Introduction
Energy intensity is the quantity of energy required during the production process to generate one unit of output. A greater energy intensity point out that more use of energy to produce one unit of economic output (Lin and Xu, 2019) and lesser energy intensity specifies that lesser use of energy for the production in order to produce one unit of economic output. Meanwhile, inefficient production methods are frequently linked with high energy intensity, which leads to energy waste and environmental pollution. Moreover, energy intensity describes the energy input to economic output ratio. However, energy conservation can be achieved through reductions in energy intensity. The degree of energy intensity can be affected through the push and pull effect of openness of trade (Adom, 2015). In case of pull effect, host countries have an opportunity to learn from the outsiders under the greater amount of trade openness. However, push effects posit that a sound-integrated economy generates an economic environment that affects the indigenous firms through the adoption of energy-saving technologies and familiarize them with intense global market rivalry.

There are several aspects that determine energy intensity such as economic development, technical progress, industrial structure, urbanization, energy price, education, population, and international trade (Yu et al., 2022). Energy consumption decreases due to technical progress, however coal-based energy structure also raises the intensity of energy. Consumption of renewable energy is one more influential factor of energy intensity. Technological and industrial supply networks associated with renewable energy are more effective in technologically advanced countries than the less advanced countries. A huge volume of capital is invested in advanced countries due to the renewable energy development. It stimulates cost efficiency and development of renewable energy at domestic level. Hence, economic output increases with identical level of energy inputs through the higher renewable energy level as a result, it lowers the energy intensity. Conversely, the lower the level of development in renewable energy occurs due to lack of technology ultimately, the cost of renewable energy would become higher. This contributes toward the higher output loss and consumption of energy which in turn increases the energy intensity (Yu et al., 2022). It is important to highlight that research and development and is the main factor that brings economic, energy, and environmental awareness. Energy sources can be used efficiently through more knowledge on energy conservation.

In the beginning of 1970s, there was an oil price shock across the globe. The consequences of the 1970s oil price shocks were devastating and amplified due to urbanization, industrialization, population, and environmental crunch. Meanwhile, the demand for energy and natural resources (Voigt et al., 2014) become higher due to population that leads to higher energy intensity. In many developing countries, subsequently 1970s shocks of oil price that increased the energy intensity over the extractive nature of industries which are too much energy intensive. A substantial quantity of energy is utilized in the manufacturing industry. However, the spread of technologies that are energy-efficient is altering the manufacturing sector's technical specifications. It banned the energy inefficient technologies and energy-efficient imports are possible through trade reforms which reduce the energy intensity (Adom and Kwakwa, 2014).

The energy intensity is also dependent on the comparative weight of energy used by exports and saved through imports. Energy saved over the imports compensates the utilization of energy by exports which leads to the decrease in energy intensity (Cole, 2006). Trade openness promotes energy efficiency (Sbia et al., 2014) while the studies of Su and Zhen (2010) show that international trade would lead towards higher energy intensity. Energy intensity could be positively or negatively associated with trade openness according to Fisher et al. (2004). Industrial and economic structure is also linked with energy use. Energy intensity would increase by the higher level of industrial activities. This shows that the growing industries are more energy intensive.

Energy intensity is highly correlated to income. Poorer income countries are using more energy than the countries that have greater incomes. Energy intensity is also influenced by urbanization and industrialization. But it is challenging to anticipate the influence of urbanization on energy intensity. On one hand, urbanization upsurges economic activities through the greater consideration of production and consumption. However, urbanization leads in the direction of economies of scale that provide the chance to upsurge energy efficiency. Urbanization affects energy use through the different channels (Madlener and Sunak, 2011; and Parikh and Shukla, 1995). Therefore, these channels are production, transportation, private consumption patterns, and infrastructure which increase energy use. In the case of industrialization, positive link between energy intensity and industrialization is reported by various studies. For instance, higher industrial activities are supported by the introduction of new equipment and techniques which require higher energy use (Sadorsky, 2013; Xu & Lin, 2015).The increase in population growth and urbanization increases the demand for energy which consequently increases environmental degradation(Qingquan et al., 2020).

Some other socio-economic variables such as wage, age, share of capital owned by private sector and capital intensity in manufacturing sector also determine energy intensity. The reason behind the increases in energy intensity due to wage and age is that higher salary earners in the manufacturing industry are more probable to use products and services which are energy-intensive, like bigger homes, more appliances, and more frequent travel. As a result, there may be a rise in energy intensity. Higher wages may also encourage manufacturers to use more energy-intensive production techniques and technologies, it may cause the energy intensity to increase. Productivity and efficiency in the manufacturing industry tend to diminish as the workforce ages, which might result in increased energy intensity. This is due to the possibility that older workers are less skilled in order to utilizing modern technology and may necessitate more frequent equipment maintenance and repairs, which might result in an increase in energy intensity.

Existing studies on energy intensity often overlook critical aspects, such as the unique socio-economic dynamics of developing countries. They also fail to explore collective effects between key factors like urbanization and education or financial development and trade openness. Many rely on static models, missing the dynamic nature of energy intensity determinants, and exclude essential policy-relevant variables like trade openness. Addressing these gaps, this study aims to provide a more detailed and robust analysis to guide effective policies for sustainable energy use. Energy price is often excluded from analyses of the socio-economic determinants of energy intensity in existing literature due to several challenges. Reliable and consistent data on energy prices across countries and time periods are difficult to obtain, particularly in developing nations where energy markets are less transparent or heavily regulated. Additionally, energy prices are highly volatile and influenced by government policies, subsidies, and international market dynamics, making it challenging to isolate their direct impact on energy intensity.

Limited determinants of energy intensity are modeled in the existing literature, however, there are various other social and economic factors which drive energy intensity but overlooked in the existing studies. Hence, this study extends the frontier of determinants of energy intensity by including social and economic variables in the analysis. This study deviates from the prior literature in many aspects. Firstly, this study segregates social and economic variables in order to determine energy intensity. Second, it provides empirical evidence and the theoretical channel that how each of the variables is influencing energy intensity. Further a large sample of developed and developing countries are taken which not only provides a comparison between these two region but also provide results in the combined panel. Thirdly, the current study provides the policy implications with respect to developed and developing countries as the influence of the variables diverges in these regions due to difference in the structure of the economies. Moreover, the fresh evidence is covering a period of during 1990 to 2023.

This study's remaining sections are structured as follows: The pertinent literature is thoroughly reviewed in Section 2. The models and technique employed in the analysis are described in Section 3. In detail, the results are presented and discussed in Section 4. In Section 5, the conclusion and suggestions for policy are provided.

2. Literature Review

The elements that determine the energy intensity are being investigated in a lot of empirical research. Yet, there is no conclusive evidence on the determinant of those variables that may result from various models, economic systems, and sample populations examined in these studies. Energy intensity fall is primarily caused by three key aspects, namely the structural modifications of terminal demand, the improvement of efficiency in the use of energy, and the use of additional efficient fuels as an alternative (Bernardini and Galli, 1993).

Researcher outline numerous energy intensity important variables. It includes the variables of import-export structure of trade, FDI inflows, openness of trade, and the price of primary energy sources, the technology at economy level, the significance of the manufacturing sector in the nation, and structural effects. Bu et al. (2019), who endorse a substantial inverse relation between energy intensity and FDI, define FDI as a crucial driver of the economy's transformation to a more energy-efficient manufacturing model. Substantial investments in technology tend to reduce the gap between domestic and international firms in terms of the latter's improved capacity to adopt best practices.

Energy intensity declines because of economic instruments that raise the price of energy (Birol and Keppler, 2000). A study of twenty-eight transition nations found that increased in the prices of energy had the ability to save energy (Cornillie and Frankhanser, 2004). Similarly, Hang and Tu (2007) discover that energy intensity in China is negatively impacted by energy prices. Moreover, Adom (2015), Sun et al. (2022), and Lan et al. (2022) establish that price of energy is negatively connected with energy intensity. On the other hand, Samargandi (2019) found contradictory results regarding the energy intensity and energy price. He displays that energy intensity increases due to energy price. A standard energy-saving programs, market liberalization at local markets, an industrial growth strategy, technological catch-up, investment, and economic openness to trade are just a few of the successful Chinese initiatives that Rock (2012) advises the Indonesian government to follow. The findings imply that the government should concentrate on reducing subsidies that cause energy prices to increase, consequently it reduces the energy intensity and budget shortage.

The industrial sector often uses additional energy. Consequently, a larger industrial base cause the more need of energy and it ultimately raises the energy intensity. Addressing low- and middle-income economies, Poumanyvong and Kameko (2010) identified that industrial activity has a favorable effect on energy intensity. Manufacturing activity and energy intensity are positively and significantly correlated, according to Adom and Kwakwa (2014). The industrial structure changes may have energy-saving implications when industrialization is anticipated to increase energy needs. In South Africa energy efficiency trends between 1993 and 2006 are inspected by Inglesi-Lotz and Pouris (2012), who find that structural changes are to blame for the country's overall economic decline in energy intensity. According to research by Lin and Moubarak (2014), energy intensity in China is inversely correlated with changes in industrial structure.

Adom and Kwakwa (2014) concluded that changes after reforms within the manufacturing industry's structure (composition and technical) have lessened energy intensity in Ghana case. A structural shift to a sector that uses less energy, which increases energy productivity as demonstrated by Li and Lin (2014). Because industrial structure has a non-linear effect, it follows that large economic structural changes may have an unequal influence on the energy intensity. In 2020, Zhu and Lin look at Chinese energy intensity convergence characteristics. They suggest that the cities with higher marketization level, FDI proportion, and population density tend to converge to lower energy intensity.

The crucial role of advancing technology in reducing energy demand is emphasized by Garbaccio et al. (1999). They discover that the advancement of technology is an element that decreases the energy intensity. Ma and Stern (2008) demonstrate the strong influence of technical advancement on energy intensity by using the Logarithmic index of Mean Divisia. Moreover, Lin and Moubarak (2014) demonstrate that technology is negatively linked with energy intensity. Technology advancement led to improvements in energy intensity between 1995 and 2007, as demonstrated by Voigt et al. (2014). In addition, the role of domestic technological innovation is insignificant with reference to reduction of energy intensity (Samargandi, 2019). According to Hille and Lambernd (2020), trade openness, government spending on the environment, and in part innovation all help to lower South Korea's overall energy intensity.

The factors which influences energy intensity are secondary sector, provincial gross domestic product, investment (fixed), capital-labor ratio, foreign direct invest and energy reserve (coal, oil & natural gas). In China and Pakistan case, the study of Jiang et al. (2014) and Mirza and Fatima (2016) found that energy intensity decreases due to capital-labor ratio decreases through the channel of efficiency. FDI is also negatively linked with energy intensity according to the studies of Jiang et al. (2014) and Adom (2015). In contrast, the study of Tenaw (2021) foreign direct investment increases the energy intensity in Ethiopia. Trade openness is another variable that are helpful in determining the energy intensity. According to the Adom (2015) and Samargandi (2019) trade openness is the main contributing factor in reducing energy intensity.

Energy intensity increases due to income according to the study of the Mirza and Fatima (2016). While Malik (2019) found that increase in per capita income leads to the reduction in energy intensity by using the advanced technological equipment. In addition, this study result reveals that industrialization (Tenaw, 2021) and poor institutional quality influence the energy intensity positively. However, urbanization is adversely associated with energy intensity. Moreover, energy intensity determines through financial development (Lan et al., 2022) and it lowers the energy intensity. In addition, energy intensity increases through economic development in China. Patino et al. (2021) analyzed the factors which affect the energy intensity and carbon emission during the period of 1971 to 2017 in Colombia. The empirical evidence indicates that energy intensity decreases due to sectoral energy intensity reduction. The summary regarding the review of literature on determinants of energy intensity are provided in Table 1.

Table 1: Summary of Literature Review on the Energy Intensity Determinants

Studies	**Countries & Sample**	**Methodology**	**Determinants**
Adom (2015)	Nigeria (1971-2011)	FMOLS	Energy price, industrial value added, foreign direct investment, economic integration
Yu (2012)	China (1988-2007)	Spatial panel data model	Per capita GDP, level of marketization, transportation infrastructure, scientific and technological input
Samargandi (2019)	OPEC countries (1990-2016)	ARDL Panel	Technological innovation, Trade openness, GDP, renewable energy, energy price
Lan et al. (2022)	China (1985-2019)	ARDL	Energy price, technology, economic development, and financial development
Malik (2019)	Pakistan (1971-2017)	Cointegration, VECM	Income per capita, urbanization, industrialization, institutional quality
Rudenko and Tansov (2020)	Indonesia (1990-2016)	Cointegration	Crude oil, industry value added, FDI, trade openness, financial development, alternative and nuclear energy
Sun et al., (2022)	30 Emerging Countries (1970-2016)	LMDI approach	Energy price
Tenaw (2021)	Ethiopia (1990-2017)	ARDL	Real GDP per capita, industrialization, energy price FDI, institutional quality, modern renewable energy
Metcalf (2008)	USA (1970–2003)	Fixed effects	Energy price, per capita income

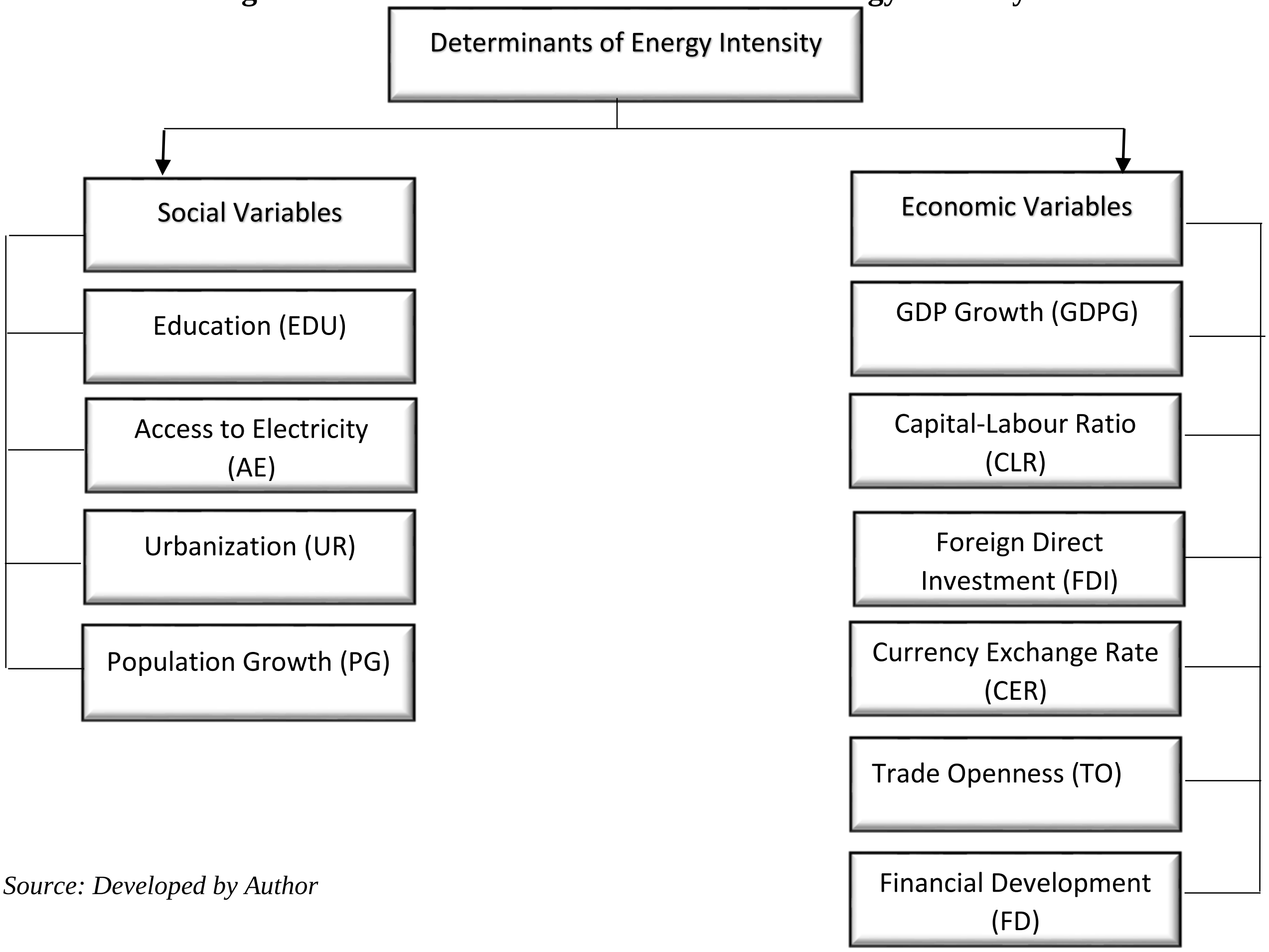
Mirza and Fatima (2016)	Pakistan (1980–2009)	Partial Adjustment Model	Income, capital-labor ratio, and energy price
Aboagye and Alagidede (2016)	36 SSA countries (1980–2015)	GMM	Income, FDI, trade openness, inflation, and secondary school enrolment
Whang and Han (2017)	China (2003–2012)	Driscoll–Kraay Panel regression	Industrial structure, Indigenous R&D stock, and GDP per capita
Deichmann et al., (2018)	137 countries (1990–2014)	Fixed effects model	Growth income
Abbas et al., (2018)	42 countries (1981–2015)	Fixed effects model	Per capita income
Robaina et al., (2019)	Portugal (1995–2015)	Model of Bayesian VAR regression	Industry Value Added, Energy Prices, Total Factor Productivity, and GDP
Aboagye et al., (2019)	Ghana (1980–2016)	ARDL model	Industrial activities, private sector expansion, population growth, urbanization, FDI, literacy level, trade openness, technological advancement, and energy prices

3. Methodology and Model

The current study objective is to analyze the socio-economic determinants of energy intensity in the developed and developing countries. Theoretically, the relationship between GDP growth (GDPG) and energy intensity is complex; while GDP growth often leads to increased energy consumption due to industrial output and consumption, mature economies adopting more efficient technologies and shifting to less energy-intensive industries may reduce energy intensity. The capital-to-labor ratio (CLR) links higher mechanization and automation with increased energy consumption, but its impact depends on the efficiency of the capital used. Foreign direct investment (FDI) can influence energy intensity both positively and negatively: FDI may increase energy use if invested in energy-intensive sectors or reduce it by introducing advanced energy-efficient technologies. Education (EDU) contributes to reduced energy intensity by fostering awareness and adoption of energy-saving practices.

Trade variables, such as exchange rates (CER) and trade openness (TO), affect energy intensity by influencing energy prices and facilitating the adoption of more energy-efficient technologies. Financial development (FD) provides access to capital, which can either support energy-intensive or energy-efficient infrastructure. Urbanization (UR) typically increases energy demand due to higher needs for transportation, housing, and services, though economies of scale and better infrastructure may reduce energy intensity. Access to electricity (AE) generally increases energy use, but integrating it with efficient technologies and infrastructure can lower energy intensity. Finally, population growth (PG) typically raises energy demand, but its effect on energy intensity depends on the adoption of energy-efficient technologies and practices.

Figure 1: Socio-Economic Determinants of Energy Intensity



Source: Developed by Author

Hence, this study follows the work of Malik (2019), Samargandi (2019), Rudenko and Tanasov (2020), and Lan *et al.* (2022) to determine the socio-economic drivers of energy intensity. The current study demonstrates a comprehensive set of determinants by including the variables of GDP growth (GDPG), capital-labor ratio (CLR), foreign direct investment (FDI), education (EDU), currency exchange rate (CER), trade openness(TO), population growth (PG), access to electricity (AE), financial development (FD), as well as urbanization (UR). The symbol ε_{it} shows the error term. The socio-economic energy intensity (EI) determinants are outlined in equation 3.1. The equation is formulated in this regard, which is given below.

$$EI_{it} = f(GDPG_{it}, CLR_{it}, FDI_{it}, EDU_{it}, CER_{it}, TO_{it}, FD_{it}, UR_{it}, AE_{it}, PG_{it}) \dots\dots\dots\dots..(1)$$

Equation (3.4) is specified in log linear form with lag of dependent variable as energy intensity in current time period is also determine by the previous year value. The specified equation (3.5) is as follows:

$$lnEI_{it} = \alpha_i + \beta_0 lnEI_{it-1} + \beta_1 lnGDPG_{it} + \beta_2 lnCLR_{it} + \beta_3 lnFDI_{it} + \beta_4 lnEDU_{it} + \beta_5 lnCER_{it} + \beta_6 lnTO_{it} + \beta_7 lnFD_{it} + \beta_8 lnUR_{it} + \beta_9 lnAE_{it} + \beta_{10} lnPG_{it} + \varepsilon_{it} \dots\dots\dots.(2)$$

The lag of energy intensity is used to capture its persistence over time, reflect gradual adjustments to changes, address endogeneity issues, and improve model robustness. It helps account for how past energy usage patterns influence current trends, providing valuable insights for policy and analysis. The amount of energy used associated with each GDP unit, or an economy's energy intensity (EI), is determined by a number of macroeconomic variables. These variables influence energy intensity through complicated and diverse pathways. The determinants related to energy intensity are categorizes in terms of social and economic variables. These socio-economic determinants are given in figure 1.

3.1 Variables and Data Sources

The study utilizes a comprehensive dataset comprising both developing and developed countries during the period of 1990 to 2023. The socio-economic determinant of energy intensity variables description, unit of measurement and data sources are mention below in Table 2.

Table 2: Variables Description, Measurement, and Data Sources

Variables	Description	Measurement	Sources
Energy Intensity	The proportion of the supply of primary energy to the gross domestic product assessed at power purchasing parity	level of primary energy (MJ/$2011 PPP GDP)	WDI
Access to Electricity	Having access to electricity can be described as the proportion of the populace that has the capability to use power	Percentage of population	WDI
GDP Growth	The GDP growth rate, represented as a percentage, is influenced through the fixed local currency and market pricing	Annual Percentage	WDI
Foreign Direct Investment	The foreign direct investment refers to net investments made to purchase a long-term management position (ten percent or more of the voting stock) in a business operating in a nation other than the investor's own	FDI inflows as percentage of GDP	WDI
Population Growth	The yearly rate of population growth for year t is the percentage representation of the exponential growth rate that occurs in the population at the midyear mark from year t-1 to year t	Annual percentage	WDI
Urbanization	It indicates the population who reside within urban areas	Urban population as percentage of total population	WDI
Trade Openness	The total amount of the goods and services that a nation buys and exports	Nation exports as percentage of GDP	WDI
Education	The average years of education for individuals of age twenty five and older, calculated from educational levels through the specified duration of every level	Mean year of schooling	UNESCO
Financial Development	Domestic credit to the private sector includes loans, asset purchases, and financing from banks, leasing companies, and insurers, supporting private and some state-owned enterprises	Domestic credit to private sector as percentage of GDP	WDI

Currency Exchange Rate	An exchange rate is the cost of a currency in one nation compared to another country's currency	Country currency exchange to US dollar	OECD
Capital-Labor Ratio	The capital-labor ratio is the ratio of formation of gross capital to labor force participation	Capital measured in term of gross fixed capital formation, and while labor force participation used for labor	WDI

3.2 Generalized Method of Moments (GMM)

In the current study, Generalized Moments Method (GMM) is used to estimate the coefficients of formulated models. It allows us to control the temporal and individual specific effects. Moreover, to remedying the explanatory variables' endogeneity biases through instrumental variables. Other methods of evaluating instrumental variables, such as 3SLS and 2SLS, have difficulty in selecting one or more theoretically uncorrelated instrumental factors from the explanatory variables and residuals. In the 1990s, the popularity of the difference and system GMM instrumental variables estimators increased rapidly (Arellano and Bond, 1991; Arellano and Bover, 1995; and Blundell and Bond, 1998).

Arellano and Bond (1991) were the first who developed the GMM first difference valuation process to solve endogeneity problem. This endogeneity issue is addressed by instrumenting the endogenous variable with a lag of at least two periods and the predefined or weakly exogenous variables with lags of at least one period. The current values of exogenous variables are used as instruments. However, the effect of time-invariant factors could not be identified by this method.

In fact, Bond and Blundell (1998) demonstrated that when the instruments are weak, the GMM in finite samples, the first difference estimator uses Monte Carlo simulations to produce biased findings. Initially presented by Bover and Arellano (1995), they suggested the system GMM technique as a solution to these issues. This approach combines the model in both its differences and levels, providing a more robust estimation. According to Bond and Blundell (1998), this system estimator lessens the asymptotic imprecision as well as the bias potential in limited samples which are associated with difference estimator.

The GMM estimator efficacy is dependent on the validity of two assumptions namely as the nonexistence of autocorrelation of error terms and legitimacy of instruments. Arellano and Bond (1991), Blundell and Bond (1998), and Arellano and Bover (1995) recommend the over-identification tests of Hansen/Sargan to evaluate the applicability of lagged variables as instruments.

4. Results and Discussions

4.1 Results of Descriptive Statistics and Correlation Analysis

The descriptive statistics regarding the determinants of energy intensity (EI) are given in Table 3. It reveals the substantial variability in the data, with EI showing right-skewed and leptokurtic distribution, indicating extreme outliers and non-normality confirmed by the Jarque-Bera test. While most regions have lower EI values, a few have exceptionally high values. Access to electricity (ATE) is high in most regions, but a few areas with limited access skew the distribution leftward. The currency exchange rate (CER) data also shows significant variation with outliers, reflecting wide economic disparities and non-normal distribution. The capital-to-labor ratio (CLR) and financial development (FD) both exhibit right-skewed distributions, with outliers inflating the means. The same applies to foreign direct investment (FDI) and GDP growth (GDPG), where a few extreme values create heavy tails, as confirmed by the rejection of normality.

Education (EDU) shows more symmetry in distribution with moderate variability, while population growth (PG) and trade openness (TO) both display positive skewness and non-normality due to a few high values. Urbanization (UR) is slightly left-skewed, with most regions showing higher urbanization, but a few areas with low levels pulling down the mean.

Table 4 present the results of correlation analysis for energy intensity determinants and shows no multicollinearity among the variables. The relationships between GDP growth, FDI, and energy intensity are weakly negative, indicating that higher energy intensity has a minimal negative impact on GDP and FDI. Conversely, energy intensity shows a moderate positive association with access to electricity (0.339), urbanization (0.280), and population growth (0.154), suggesting that higher energy intensity is linked to better energy infrastructure and urbanization. Financial development also shows a weak positive correlation (0.156) with energy intensity. A negative association is observed between energy intensity and education (-0.250), implying that regions with higher energy intensity may have lower educational attainment. Other variables like trade openness, capital-to-labor ratio, and currency exchange rate show weak correlations, indicating minimal influence of energy intensity on them. Overall, energy intensity is most strongly associated with urbanization and access to electricity, reflecting its role in urban growth and energy infrastructure, while its impact on economic and social variables is relatively small.

Table 3: Results of Descriptive Statistics for the Energy Intensity Determinants

	EI	**AE**	**CER**	**CLR**	**FD**	**FDI**	**GDPG**	**EDU**	**PG**	**TO**	**UR**
Mean	5.43	80.80	1089052	186530	63.60	5.50	5.98	8.04	1.58	86.64	60.40
Med	4.31	99.24	6.7362	1.07E-05	44.93	2.260	4.07	8.40	1.27	68.65	63.82
Max	43.61	137.7	6.7E+09	8592224	729.24	497.86	319.9	14.60	19.36	1466	100
Min	0.039	0.53	2.4E-09	0	0.0444	2.0E-06	0.003	0.20	0.0003	0.0209	6.27
SD	3.84	29.90	8.6E+07	751820	64.32	19.31	11.07	3.21	1.32	87.56	22.57
Skew	3.18	-1.34	23.3488	7.4621	2.97	15.014	13.55	-0.28	3.71	7.5832	-0.32
Kurt	19.6	3.316	589.115	65.3572	19.32	288.56	283.1	2.12	35.80	91.1741	2.13
J-B	56657	1308	61709620	573731.4	53874.	1471709	141410	192	201969	1428840	210.52
Prob	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum	23297	346159	4.7E+10	9.2E+10	27246	23567	25624	34444	6782	371182	258782

Table 4: Results of Correlation Analysis for the Energy Intensity Determinants

Variables	**EI**	**GDPG**	**AE**	**FDI**	**PG**	**UR**	**TO**	**FD**	**CLR**	**EDU**	**CER**
EI	1.000										
GDPG	-0.071	1.000									
AE	0.339	0.022	1.000								
FDI	-0.078	0.003	0.078	1.000							
PG	0.154	0.062	-0.412	-0.042	1.000						
UR	0.280	-0.091	0.689	0.130	-0.193	1.000					
TO	0.089	-0.033	0.125	0.213	0.058	0.232	1.000				
FD	0.156	0.003	0.413	0.127	-0.251	0.330	0.113	1.000			
CLR	0.076	0.015	0.024	-0.042	-0.071	-0.131	-0.111	0.028	1.000		
EDU	-0.250	-0.070	0.733	0.133	-0.441	0.665	0.105	0.478	-0.079	1.000	
CER	0.090	0.024	-0.065	-0.010	0.000	-0.061	-0.008	-0.039	-0.006	-0.005	1.000

4.2 Results of Panel Unit Root Test

In panel data setting, he order in which the variables are integrated must be examined in order to choose the right estimation procedure. Table 5 presents the panel unit root test results of the determinants of energy intensity. Panel unit root results indicates the variable of access to electricity, population growth, foreign direct investment, and urban population are stationary at level. However, the variable of energy intensity, GDP growth, trade, and technology, and financial development, capital to labour ratio, education, and currency exchange rate are at first difference, they remain stationary.

Table 5: Results of Panel Unit Root for the Energy Intensity Determinants

Variables	LLC	IPS	FADF	FPP	Order of Integration
EI_{it}	-14.1331	-17.0669	791.781	1618.92	I(1)
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
$GDPG_{it}$	-15.2350	-32.3028	1608.15	2758.53	I(1)
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
AE_{it}	-12.562	-6.4515	412.253	652.211	I(0)
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
FD_{it}	-5.6626	-8.7403	510.654	725.104	I(0)
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
PG_{it}	-4.4124	-11.014	665.577	471.282	I(0)
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
UR_{it}	-2.8412	-42.473	399.977	873.087	I(0)
	(0.0022)	(0.0000)	(0.0000)	(0.0000)	
TO_{it}	-24.2532	-26.2807	1168.31	1940.20	I(1)
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
FD_{it}	-14.6259	-15.8845	733.368	1201.20	I(1)
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
CLR_{it}	-1.2E+09	-48.1915	2177.802	2902.85	I(1)
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
EDU_{it}	-12.9003	-18.5675	851.446	1802.40	I(1)
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
CER_{it}	-44.3675	-29.4472	1153.34	1571.54	I(1)
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	

Note: P-values are displayed in parenthesis.

4.3 Results of Dynamic System GMM

The system GMM technique is applied to estimates the coefficients of the determinants of energy intensity for full panel, developing panel, and developed panel. The system GMM results are presented in Table 6 for determinants of energy intensity for all three cases as mentioned earlier. Moreover, diagnostic test are provided in the Table 6 lower panel, indicating that there is no problem of autocorrelation as indicated by AR(2). Further, Hansen test shows that the instruments are valid as we are unable the null hypothesis is to be rejected. Results of GMM analysis show that the lagged value coefficient of energy intensity (EI) is positive and statistically significant for each panel. It indicates that there is a one percent association between the energy intensity of the current period and the energy intensity of the previous period, assuming other things being equal in all the three cases of full panel, developing, and developed panel. Moreover, it implies that the impact of past energy intensity is significant in determining the current energy intensity level, confirming a dynamic effect.

Estimation results show energy intensity and GDP growth (GDPG) have a negative coefficient across all panels. It reveals that energy intensity reduces as GDP growth increases. The results obtained from this study align with those of Hannesson (2009), Jimenez and Mercado (2014), Mahmood and Ahmed (2018), and Malik (2019). It is argued that a decrease in energy intensity occurs due to energy-saving measures in the commercial and residential sectors. Furthermore, a shift of economy towards the services sector contribute to the GDP by utilizing less energy. In addition, investments in energy-efficient infrastructure, technical progress, and structural transformation increase GDP growth while the energy intensity in the process of production is low. It is noteworthy that the environmental awareness and goals of sustainability across the globe forces economies to expand their size by keeping in view the environmental hazards. Therefore, the results show that GDP is increasing in developing and developed countries but the utilization of energy is low, hence putting less pressure on the environment.

The nations that are developed, the coefficient of access to electricity (ATE) has a negative effect on energy intensity, but in full and developing panels, it has a statistically significant and positive association. The positive association indicates that increase in access to electricity leads to greater energy intensity due to industrialization, rising home consumption, and urbanization. The findings are aligned with the study of Jin (2022). However, this positive connection has sound economic justification since industrialization helps in the expansion of the economy, decreases poverty, increases employment, and raises people's standard of living. On the other hand, negative association between these two variables can be attributed to technological improvement. It leads to use of energy more efficiently and thereby reduces energy intensity. The magnitude of the coefficient in case of developed panel is significantly high. It indicates that higher access to electricity in these countries result in more energy saving and efficient techniques, therefore significantly reduces the energy intensity.

In the case of the developed, developing, and entire panel, the foreign direct investment (FDI) coefficient is negative and significant. It implies that increase in FDI reduces the energy intensity because foreign investors bring energy-efficient and energy-saving technology that boosts output while consuming less energy. This outcome is consistent with previous research by Elliot et al. (2013), Jiang et al. (2014), Adom (2015), Mirza & Fatima (2016), and Aboagye (2019). The impact of foreign direct investment (FDI) on energy intensity passes through two primary channels. The first is evident and is illustrated by the fact that foreign companies from technologically advanced countries have far more advanced management systems and far more advanced levels of knowledge (skills, methods, abilities, and techniques), which result in lower energy intensity and lower energy use. Three methods are used to demonstrate the second channel about an indirect influence of FDI: (i) vertical linkages; (ii) labor turnover; and (iii) demonstration impacts.

The demonstration's impact relates to the potential for local businesses to reduce the use of energy by utilizing reverse engineering and imitation to acquire cutting-edge technology from foreign businesses. Labor turnover is established on the idea that employees or trainees in overseas businesses might spread technology through switching employers or forming their own businesses. Finally, vertical links suggest that technology transfer can be advantageous for foreign enterprises' customers of finished products and suppliers of intermediate goods. Moreover, it is argue that foreign businesses greatly increase the level of competitiveness in the home market, which pushes home businesses to raise the productivity of all inputs used in production, including energy. One may anticipate that FDI will have favorable impact on energy intensity if these transmission channels are operational.

The coefficient of population growth (PG) is positive in all three panels. These results are coherent with the York et al. (2003) and Jimenez & Mercado (2014), and Aboagye (2019). It postulates that more population growth causes a rise in energy intensity via following channels. For instance, the population growth increase consumer demand for goods and services, which require more energy to increase output level. Further, it is also effects the energy consumption of transportation sector, as more transportation networks and routes are needed to facilitate the higher population. The negative consequences of rapid population growth is not limited. First, it increases energy demand which consequently deplete natural resources due to the excessive extraction of fossils fuels, water, and minerals. In addition, every new household influences the residential energy consumption due to increase in cooling, heating, cooking, power appliance, and lighting energy usage. Thus, the total energy consumption of a home rises in tandem with the number of households, resulting in a higher energy intensity.

Estimation result indicates that urbanization (UR) coefficient is positive in all panels. The outcomes are same as the study of Sadorsky (2013), Aboagye and Amponsah (2016), Elliott et al. (2017), and Aboagye (2019). It implies that urban resident are more dependent on the electrical appliances, for example air conditioning and heating raises the energy demand and ultimately raises the energy intensity. Another factor is mega structures and networks of transport sector which increases more demand for energy in urban areas as compared to rural areas. Commercial and industrial hubs are typically located in more energy-intensive urban areas. These commercial and industrial buildings, such as offices, factories, and retail stores, use a lot of energy for lighting, HVAC, and heating systems. In highly populated urban areas, treatment plants for wastewater and solid waste management facilities are also energy-intensive and require substantial amounts of energy. Moreover, the demands of new buildings, roads, bridges, and public transit systems in urban areas increases energy usage along with the need of input like steel, cement, and all the machinery.

Table 6: Results of GMM for the Energy Intensity Determinants

Panels Variables	Full Panel Coefficients	Developing Panel Coefficients	Developed Panel Coefficients
$lnEI_{it-1}$	0.9315*** (0.0026)	0.9266*** (0.0044)	0.9216*** (0.0197)
$lnGDPG_{it}$	-0.0046*** (0.0003)	-0.0041*** (0.0004)	-0.0057** (0.0024)
$lnAE_{it}$	0.0267*** (0.0027)	0.0441*** (0.0033)	-14.5602* (7.9346)
$lnFDI_{it}$	-0.0051*** (0.0003)	-0.0060*** (0.0004)	-0.0066*** (0.0014)
$lnPG_{it}$	0.0055*** (0.0009)	0.0112** (0.0017)	0.0091*** (0.0027)
$lnUR_{it}$	0.1093*** (0.0090)	0.0180** (0.0089)	0.3732*** (0.0719)
$lnTO_{it}$	0.0161*** (0.0008)	0.0191*** (0.0017)	-0.0441** (0.0182)
$lnFD_{it}$	0.0274*** (0.0016)	0.0138*** (0.0028)	0.0263** (0.0106)
$lnCLR_{it}$	0.0003*** (0.00005)	0.0103*** (0.0008)	-0.0014*** (0.0002)
$lnEDU_{it}$	-0.1400*** (0.0057)	-0.0931*** (0.0083)	-0.1803*** (0.0280)
$lnCER_{it}$	0.0110*** (0.0007)	0.0094*** (0.0005)	0.0228*** (0.0074)
Constant	-0.1625*** (0.0153)	-0.0567*** (0.0165)	29.1121* (15.9687)
	Diagnostic Test		
No. of Obs.	4158	2871	1287
No of countries	126	87	39
Instruments	112	79	35
AR(1) P-values	-23.13 (0.000)	-19.98 (0.000)	-2.05 (0.040)
AR(2) P-values	-0.25 (0.801)	-0.31 (0.754)	-0.23 (0.814)
Hansen Test P-values	112.60 (0.183)	70.67 (0.356)	26.36 (0.284)

Note: ****, **, and * shows p-value significant at 1%, 5%, and 10% level of significance. Standard error of coefficients are given in brackets (). Under diagnostic test, AR (1), AR (2), and Hansen p-values are given in brackets ().*

Hence, economic activities that requires more energy is associated with urbanization. It is emphasized that urbanization is linked with increasing demand for goods and services and putting more pressure on the facilities and services of the cities. In addition, substantial use of energy for both new construction and the continuous operation and maintenance of all these activities, could ultimately result in a boost in energy intensity.

There is a positive association between the coefficient of trade openness (TO) and energy intensity in developing and full panel nations, but negative sign of a coefficient is reported in developed countries. Trade has an influence on energy intensity based on the energy saved from imports and the energy needed for exports. Research by (Cole, 2006; Aklin 2016; Pan et al., 2019; and Aboagye, 2019) supports the idea that developing nations experience higher energy intensity as a result of imbalanced trade pattern. There are some economic reasons for positive link between energy intensity and trade openness. Firstly, trade openness leads to an expansion of energy intensive industries includes cement, chemicals, steel, and aluminum which raises the energy consumption and thereby increases the energy intensity.

Secondly, countries with trade liberalization policies usually increase production to fulfill the demand for both domestic and international markets. More energy consumption might result from this, particularly if the industrial processes are energy-intensive. So, more production for export has the potential to raise the economy's energy intensity. Thirdly, countries often invest in port and highway development, railway construction, and other infrastructure projects to ease the growth of trade. The building and maintenance of such infrastructure are both energy intensive, which leads to an increase in consumption of energy. Finally, the scale effect also describes that trade openness raises the total amount of economic activity which ultimately leads to the greater total energy intensity.

However, trade openness reduces energy intensity in developed nations because it increases access to advanced foreign technology and allows for more efficient deployment of resources. The greater share of export results in economies of scale and learning by exporting, which reduce energy intensity. This finding is similar with what Chen et al. (2022) and Samargandi (2019) found. Trade openness mostly influences energy intensity through the export channel, which is economically justified. Learning through exporting is an area where export trade shines. By expanding their manufacturing capacity, exporters can take advantage of economies of scale and tap into a wider global market. This economy of scale allows companies to efficiently reduce manufacturing costs through learning and sharing processes. To further reduce energy intensity, it can promote energy centralization, which in turn reduces energy consumption.

The financial development (FD) coefficient is positive and significant in all three panels. This result corresponds to the research conducted by Sadorsky (2010) and Pan et al. (2019). The three mechanisms via which financial development affects energy intensity are the wealth effect, business effect, and direct effect. Consumers can easily and affordably access money when financial markets are enhanced, according to the direct effect. It means investing in long-lasting consumer products that use energy. According to business effect, better financial development enables the organization to reach its full potential since easier and less expensive financial capital is available, which raises the need for energy.

The wealth effect refers to the idea that when businesses and consumers feel more confident because their wealth increases, often due to rising stock market values, they are likely to spend and invest more. This increase in spending and investment boosts economic activity, which in turn can expand the economy. As the economy grows, energy demand tends to rise because businesses produce more, and consumers use more energy for their daily activities. Essentially, a strong stock market can lead to higher confidence, increased economic activity, and raises energy intensity.

Furthermore, financial development boosts business activities, therefore it enables the businesses to engage in energy-intensive industries like manufacturing, mining, and construction, which increases energy consumption. Additionally, it is probable that consumers will spend money on goods and services that use a lot of energy such as cars and electronics, when they have easier access to credit and better financial services. Similarly, energy-intensive infrastructure projects such as power plants, highways, and bridges are easy to execute due to availability of better finances. Lastly, demand for energy-intensive activities is greater in urban areas because of better and organized financial services. The provision of funds to the financial and industrial sector at lower cost promotes the economic growth through intensifying economic activities which lead to amplify the energy demand.

The capital to labor ratio (CLR) coefficient is statistically significant and positive connection with energy intensity in full and developing panels, while it has a negative association in developed countries. The findings of developing countries and full panel are in line with the study of Amin et al. (2022). Firstly, these countries are more dependent on capital-intensive equipment (for example outdated automation and mechanization) that require substantial amount of energy during manufacturing processes. Secondly, higher capital expenditure to build the new transportation networks, utility systems, and industrial facilities added to the already high level of consumption of energy. Thirdly, installation and operation of multifaceted manufacturing equipment, as well as the growth of industries that use a lot of energy such as steel and cement production, necessitate larger amounts of energy. Moreover, the construction of energy-intensive businesses and houses is a direct result of urbanization and real estate expansion, which are in turn fueled through capital investment. Finally, investments in energy-intensive industries includes agriculture (for mechanized farming and irrigation systems) mining (for processing minerals) contribute to the energy intensity.

In contrast, the coefficient of capital-to-labor ratio is negative in developed countries. This finding is similar to the study of Jiang et al. (2014) and Aboagye (2019). It implies that a rise in the capital-to-labor ratio in these countries often lead to a reduction in energy intensity through a number of important economic factors. For instance, the increased capital investment allows the widespread adoption of technologies which are energy-efficient. This encompasses towards the automated systems that maximize output with minimal use of energy. Furthermore, the investment of capital in the renewable energy sources (hydroelectricity, wind, and solar) which are replaced with the fossils fuels, decreases the total energy consumption as well as energy intensity.

In developed nations, more finances induces the continuous R&D into energy-efficient transportation systems, construction materials and manufacturing procedures. It helps to lower use of energy without compromising economic production. The improvements in transportation networks and buildings that are part of infrastructure modernization projects often include energy-saving features. It includes more efficient lighting and heating systems, which further reduces the energy intensity. Last but not least, the overall use of energy declines due to shift towards the service-oriented economies, which have a lower energy intensity than traditional industries.

Education (EDU) exhibits a significantly negative coefficient in all three panels. The findings appear to coincide with the research conducted by Lutz et al. (2006), Mekonnen and Kohlin (2008), Sequeira and Santos (2018), and Aboagye (2019). The negative association implies that increase in education level decreases the energy intensity. The developing and developed nations shows beneficial effect of education on energy intensity. The use of energy-efficient technologies across industries, transportation, and construction is possible through higher education. Expenditure on research and development shifts the economies towards sustainable building designs and more energy-efficient manufacturing processes. It lowers the energy consumption per unit of production through technological innovation.

Moreover, agricultural industry is particularly take the benefit through the research because well-informed farmers use the more efficient irrigation systems and equipment which reduces energy intensity. Education create awareness to promote and enact the energy laws that encourage the renewable energy sources development and efficiency measures which affects both individual and corporate behavior. Hence, it ensure a more sustainable energy utilization through encouraging technical innovation and sustainable practices. Further, well-informed policy-makers in developed and developing nations, prioritize energy sector that may help in effecting energy intensity.

Estimation results of all three cases which include the developed, developing, and full panel indicates that currency exchange rate (CER) coefficient is positive and statistically significant. This implies that energy intensity raise due to higher exchange rate (higher value of national currency or appreciation of currency value). The economic rationale is that many imported commodities are become cheaper when currency value appreciates. It encourages the businessmen and consumers to buy more of these commodities, many of them are energy intensive which lead to a rise in energy usage and energy intensity. Moreover, the production expenses of domestic firms reduces due to cheaper imported raw materials and intermediary goods. This boosts industrial output, especially in energy-intensive industries like building, mining, and manufacturing. As a result disposable income raises, it enables the individuals to buy bigger houses, more cars, and electronics. Thus, it increases the demand for energy inside the country.

In addition, foreign direct investment into energy intensive sectors (includes automotive, chemicals, and heavy manufacturing) also encourage the investors due to lower costs of imported machinery and equipment. The results of current study are similar with the study of Ghosh and Kanjilal (2014) and Sadorsky (2011). These studies provide evidence that a rise in the value of a currency affects energy intensity as a result of increased consumption and manufacturing.

5. Conclusion and Policy Implications

The study utilizes the system GMM (Generalized Method of Moments) technique to evaluate the socio-economic determinants of energy intensity for three different panels: the full panel, developing countries, and developed countries during the period of 1990-2023. The results highlight several key findings across these panels.

The positive and significant coefficient of lagged energy intensity across all panels indicates a strong dynamic effect, where past energy intensity influences the current period's intensity. This reflects the persistence of energy consumption patterns over time. There is a negative connection between GDP growth and energy intensity across all panels. This suggests that as economies grow, energy intensity decreases, possibly due to increased energy efficiency, structural transformation towards sectors that consume less energy (e.g., services), and investments in energy-saving infrastructure. The effect of access to electricity differs in developed and developing panels. In developed nations, the relationship is negative, likely due to technological advancements leading to more efficient energy use. However, in developing countries, it is positive, implying that increased access to electricity fuels industrialization, urbanization, and household consumption, thus increasing energy intensity.

Across all panels, FDI has a negative and statistically significant link with energy intensity. FDI brings advanced energy-saving technologies and management practices that reduce energy consumption. This is achieved through direct and indirect effects such as vertical linkages, labor turnover, and demonstration effects. The positive relationship between population growth and energy intensity in all panels shows that higher populations drive energy demand in transportation, residential consumption, and production of goods and services, which increases energy intensity. Moreover, urbanization is also positively associated with energy intensity across all panels. The residents of urban areas rely more on modern transportation, energy-intensive appliances, and industrial infrastructure, all of which contribute to increased energy demand and higher energy intensity.

Trade openness also diverse on its impact with respect to regions. It positively affects energy intensity in developing and full panels due to the expansion of energy-intensive industries, increased production for export markets, infrastructure development. In developed countries, however, trade openness reduces energy intensity, as it facilitates access to advanced technologies and enhances efficiency. The next determinant is financial development that has positive affects energy intensity in all panels. It enables consumers and businesses to access financial resources, which increases energy consumption through purchases of durable goods, industrial expansion, and energy-intensive infrastructure projects. The capital-to-labor ratio has contrasting effects. It is positively associated with energy intensity in developing countries, where capital-intensive industries consume large amounts of energy. In developed countries, however, the negative coefficient implies more investments in energy-efficient technologies and renewable energy sources.

Education has a negative and statistically significant association with energy intensity across all panels. Higher education levels lead to increased adoption of energy-efficient technologies and practices, especially in developed countries, where educated individuals drive research, development, and policy-making that promote sustainability. All panels demonstrate a positive correlation between energy intensity and the currency exchange rate. A stronger currency reduces the cost of imported goods, encouraging consumption of energy-intensive products and boosting industrial output, which raises energy demand.

The study offers valuable insights into the factors that influence energy intensity in various economic environments. In light of the findings, the following policy suggestions are proposed. Particularly in industries with high energy use, governments ought to encourage investments in technologies that save energy, such as manufacturing, transportation, and residential areas. Encouraging the transition to renewable energy sources, particularly in developing countries, can help reduce energy intensity while fostering economic growth. Attracting FDI in energy-efficient industries can significantly reduce energy intensity by transferring advanced technologies and practices.

Urbanization policies should focus on energy-efficient infrastructure, includes public transportation, smart grids, and energy-saving building designs, to mitigate the rise in energy intensity. Enhancing education systems to promote innovation and energy-saving technologies will lead to sustainable energy practices. This is crucial in both developing and developed economies. Policymakers should ensure that financial development supports investments in energy-efficient industries rather than fostering excessive consumption of energy-intensive goods and services. By addressing these key factors, governments can develop policies that balance economic growth with energy sustainability, reducing energy intensity and mitigating environmental degradation.

Governments need to integrate energy efficiency targets into national development plans and climate action policies. Collaborative efforts to share best practices, technologies, and funding can address the disparities in energy intensity between developed and developing countries. Engaging the private sector to invest in energy-efficient infrastructure and innovation is crucial. By understanding these determinants, policymakers can design targeted interventions to reduce energy intensity while supporting economic growth, ensuring that both developed and developing nations move toward long-term sustainability.

Future studies on the socio-economic determinants of energy intensity should address several limitations to improve the robustness and applicability of findings. One key limitation is the availability and quality of data, particularly in developing countries where energy consumption and economic indicators are often underreported or inconsistent. Future research should focus on improving data collection methods and using more granular data, particularly at the sectoral level, to better understand how energy intensity varies across industries. Additionally, the complex interactions between socio-economic factors make it challenging to isolate individual effects; future studies could employ advanced statistical techniques, such as structural equation modeling or machine learning, to more accurately capture these relationships. Future studies should also consider the heterogeneity of results across different regions, sectors, and income levels, exploring the impact of varying policy environments and energy infrastructures. By addressing these limitations and exploring new avenues, future research can provide more comprehensive insights into the socio-economic determinants of energy intensity and contribute to global efforts in achieving energy sustainability.

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