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Article

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The Relationship Between Energy Consumption, Population and Economic Growth in Developing Countries

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ABSTRACT

The need for energy is increasing due to population growth and industrialization. The scarcity of energy resources on earth has pushed countries to research alternative energy sources and take new measures regarding energy. In the study, the relationship between variables was investigated using population, economic growth and energy consumption data of 7 countries in the developing countries category (China, India, South Africa, Indonesia, Turkey, Mexico, Thailand). The direction and magnitude of the impact of economic growth and population growth on energy consumption were examined using 1990-2022 data for 7 countries. The relationship between the variables was examined with Swamy's Random Coefficients Model and Seemingly Unrelated Regression (SUR) models, and the positive effect of economic growth on energy consumption was observed. The parameter of the economic growth variable varies between 0.49% and 0.81% for countries. However, it was concluded that the population variable had no effect on energy consumption in the 2 countries included in the analysis. The population variable is significant in explaining energy consumption at the 5% significance level for South Africa, Mexico and Thailand, and at the 10% significance level for Turkey and China, its statistically insignificant for India and Indonesia.

Keywords: Economic Growth, Energy Consumption, Population, Developing Countries
JEL Classifications: C23, Q43

1. INTRODUCTION

Energy is the most important input of the economy, the main driver of world politics, and one of the most effective future determinants of social, geographical and economic order factors in the world. One of the most important needs since the existence of humanity has undoubtedly been energy. Energy, which was used in different ways for basic needs in the early periods, later gained a new dimension with the industrial revolution and the transition to mass production. The increase in the need for energy along with industrialization caused people to gather in city centers and brought about rapid population growth. This situation has caused the need for energy to increase even more. Nowadays, energy has become an indispensable element of our lives with its increasing importance. In this respect, energy has become one of the most important inputs in social and economic development and one of the important factors in increasing the standard of living.

Increasing population and changing consumption structure, with the influence of technological progress, also increases energy consumption. The world population has increased significantly since the 1950s, and global energy consumption shows the same trend, especially in developing countries such as China and India (BP Statistical Review, 2021).

China and India are among the world's highest energy consuming countries and the world's most populous countries. Increasing energy demand as industrialization, urbanization and population

density increases poses a major challenge for economists and policymakers to deal with a variety of issues. Energy is widely used in most residential areas. Populated areas also bring about economic activities such as transportation and commercial activities. Population is inextricably linked to energy consumption (Batliwala and Reddy, 1993). Limited and depleted resources cause all countries to struggle for massive economic growth. The world population is increasing every year and energy resources are increasingly needed in many activities of human beings. However, limited energy resources can limit economic activities and therefore hinder economic development. People consume energy for various activities such as transportation, agriculture and industry. If a depleted energy occurs in the world, it can certainly cripple the economy of all countries. Population decline is likely to reduce energy demand, but reductions in energy consumption may impact economic growth. On the other hand, energy consumption is one of the performance indicators of economic activities and a country's economy. It is revealed in the literature that one of the main indicators of economic growth is electricity consumption.

The main objective of this study is to measure the direction and degree of the relationship between electricity consumption, economic growth and population in developing countries. In this context, population, economic growth and electricity consumption data of 7 countries (China, India, South Africa, Indonesia, Turkey, Mexico, Thailand) were used.

2. LITERATURE REVIEW

The fact that electrical energy is more convertible and easier to use than other types of energy, as well as being a cleaner type of energy, has made electrical energy the preferred and dominant energy type, especially in developed countries. It has given electrical energy an important role in improving living standards and technological and scientific progress. In this context, the relationship between electricity consumption and economic growth has become quite interesting. For this reason, this relationship has been the subject of many empirical studies and has been examined as a research topic by many economists.

The study of Kraft and Kraft (1978) pioneered studies on the relationship between economic growth and energy consumption. Many empirical studies have been conducted since this study. In general, these studies show the existence of a strong relationship between the two variables (Ferguson et al., 2000). However, the existence of a strong relationship between electricity consumption and economic growth does not necessarily mean that there is a causality relationship. In this regard, the direction of the relationship between the variables remains unclear. As stated in Yoo and Lee (2010), the important question to be answered is, does electricity consumption stimulate economic growth, or does economic growth lead to electricity consumption? However, many studies in the literature show that electricity consumption is the cause of economic growth. Ghosh (2002), Abbas and Choundhury (2013) in India, Wolde-Rufael (2006) in six African countries, Mozumder and Marathe (2007) in Bangladesh, Squalli (2007) in four OPEC countries, Narayan and Prasad (2008) show that economic growth is the cause of electricity consumption in six OECD countries. Bampatsou and Hadjiconstantinou (2009), in their study examining the relationship between population, energy consumption and environmental pollution based on 2004 data for 31 European countries, reveal that there is a positive relationship between per capita income and environmental pollution in the long term.

Belke et al., (2010), in their study where they tested the relationship between economic growth, electricity consumption and electricity prices in 25 OECD countries between 1981 and 2007, obtained the result that the variables are cointegrated. Based on this, a positive relationship can be mentioned between economic growth and electricity consumption. Kouakou (2011) shows that industrial production is the cause of electricity consumption in Ivory Coast. Bekhet and Othman (2011), in their study on Malaysia for the period 1980-2009, tested the income elasticities of electricity demand for rural and urban populations. The relationship between the urban population and the electricity consumption demand of the population living in the city is more meaningful than that of consumers living in rural areas. Shaari et al. (2013), in their analysis of Malaysia for the period 1980-2010, state that there is a long-term relationship between electricity consumption and Gross Domestic Product growth.

Asghar and Hussain (2014) used the panel causality test to analyze the relationship between variables in their study using a data set of 15 developing countries and based on the 1978-2012 period of these countries. In the conclusion part of the study, the causality relationship is unidirectional from the economic growth variable to the financial development variable in Chile, Egypt, Sri Lanka, China, Thailand and Chile; Evidence that it is bidirectional has been obtained in Bangladesh, Indonesia, the Philippines and Mauritius.

Shahzad et al. (2017), in their study for Pakistan based on annual data for the period 1971-2011, examined the relationship between carbon emissions, energy consumption, financial development and trade openness. According to the results of the study using the Granger causality test, there is a one-way causality relationship between energy consumption and economic growth, from trade openness; It has been determined that the causality relationship between the energy consumption series and the financial development series is reciprocal.

Intisar et al. (2020) examined the relationship between trade openness and economic growth for 19 Asian countries based on the period 1985-2017. Empirical findings have shown that trade openness and economic growth variables have bidirectional causality in West Asia and unidirectional causality in South Asia.

Lawal et al. (2020) examined the relationship between economic growth and electricity consumption variables in Sub-Saharan African countries between 1971 and 2017. In the study conducted using the Generalized Method of Moments (GMM), it was determined that there is a two-way relationship between electricity

consumption and economic growth variables in the relevant countries.

Magazzino et al. (2021) examined the relationship between Information and Communication Technologies, electricity consumption, economic growth and environmental pollution variables in 16 European countries between 1990 and 2017 with panel data analysis. As a result of the study, it was stated that economic growth also has a driving force on electricity consumption. Additionally, it was emphasized that a 1% economic growth causes a 0.13% increase in per capita electricity consumption.

Qi et al. (2022) in their study examining the relationship between energy consumption, economic growth and trade openness in West Africa, they concluded that the effect of trade openness on economic growth is much more remarkable in countries with low economic development levels in West Africa.

In their study, Shaari et al. (2023) examined the relationship between population, energy consumption and economic growth for Malaysia. According to the results of the cointegration model, they showed that there is a cointegration equation that reveals the long-term relationship between population, energy consumption and economic growth in Malaysia. It also showed that population has an impact on energy consumption in Malaysia and energy consumption contributes to economic growth.

Studies that empirically address the relationship between economic growth and electricity consumption around the world are presented in the table below. As a result, the results in studies on electricity consumption and economic growth vary from country to country (Table 1).

As a result, accurately determining the relationship between electricity consumption and economic growth constitutes a very important information input for the decisions policy makers will make.

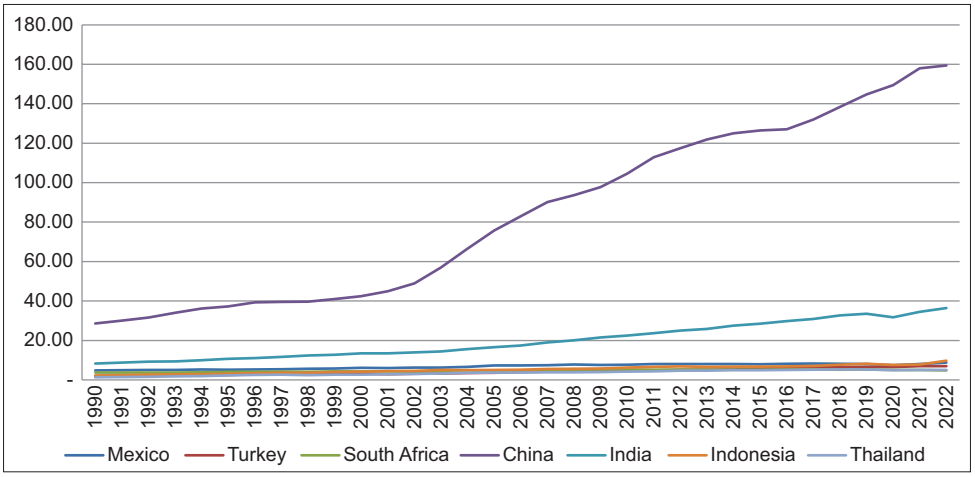
3. DATA SET, METHOD AND FINDINGS

The study aims to test the relationship between population, economic growth and energy consumption variables in developing countries (China, India, South Africa, Indonesia, Turkey, Mexico, Thailand). 1990-2022 data for 7 countries were used to measure the direction of the impact of economic growth and population growth on energy consumption and the degree of the relationship. It is possible to see the energy consumption data of the countries in Graph 1. In 2022, China alone consumes 26.4% of all energy

Table 1: Summary of literature on the subject

Author	Country/Period	Variables	Method	Result
Murry and Nan (1996)	15 Countries/1970-1990	Electricity consumption, Real GDP	Granger Causality -VAR Analysis	Energy consumption is the reason for growth in Canada, Pakistan, Singapore, Hong Kong, Turkey, Malaysia and South Korea.
Fatai et al.(2004)	New Zeland/1960-1999	Real GDP, employment electricity consumption	Toda-Yamamato test, Engle-Granger Test	There is bidirectional causality between variables.
Yoo (2006)	ASEAN countries/1971-2002	Real GDP, Electricity consumption	Hsiao's Granger Causality Test, Johansen Cointegration Test	There is a long-term positive relationship between the variables.
Narayan and Prasad (2008)	G-7 countries/1960-2002	Electricity consumption, Real GDP	SVAR (structural VAR)	Electricity consumption is the reason for growth in all countries except the USA.
Chontanawat (2008)	Developing 12 Asian country/1971-2005	Real GDP -Final electricity consumption	Panel Cointegration Test, Panel causality test	There is a long-term positive relationship.
Yoo and Kwak (2010)	7 South America Country/1975-2006	Real GDP-Electricity consumption per capita	Johansen Cointegration Test, Granger Causality Test (Hsiao)	There is bidirectional causality in Venezuela, and unidirectional causality from energy consumption to growth in Argentina, Brazil, Chile, Colombia and Ecuador. In Peru, there is no causal relationship.
Intisar et al.(2020)	19 Asian countries/1985-2017 period	consumption per capita trade openness and economic growth	Panel Causality Test	Trade openness and economic growth variables have bidirectional causality in West Asia and unidirectional causality in South Asia.
Syzdykova et al. (2020)	CIS countries/1992-2018	energy consumption, economic growth	Cointegration and causality	There is a two-way causality between energy consumption and economic growth in CIS countries.
Qi et al.(2022)	West Africa	energy consumption, economic growth and trade	Panel Cointegration Test	The effect of trade openness on economic growth is much more striking in countries with low levels of economic development in West Africa.
Shaari et al.(2023)	Malaysia	Openness population, energy consumption and economic growth	Cointegration model	There is a long-term relationship between population, energy consumption and economic growth.

Graph 1: Energy consumption of countries (Exajoules)



Source: Authors created with data from BP (2023)

consumption in the world, while India's share is 6%. China's energy consumption has been on a sharp upward trend since the 2000s. The remaining 5 countries account for a total of 5.9% of the world's energy consumption.

The estimating equation of the econometric model can be stated as follows:

$$econ_{it} = \beta_{oi} + \beta_{1i}\, growth_{it} + \beta_{2i} population_{it} + \varepsilon_{it}$$

In the model, the *econ* variable represents energy consumption, the *growth* variable represents economic growth, and the *population* variable represents the population. All data has been converted into an increase rate. The data used in the study were obtained from the World Bank database.

In panel data models, predictions are made under the assumption that the slope parameter is constant. However, this assumption sometimes does not come true. In this case, heterogeneous models are used. Because if heterogeneous models are estimated with the assumption of homogeneity, serious deviations may occur in parameter estimates. The random coefficients model is a heterogeneous static regression model developed by Hildreth-Houck based on Swamy's model. In the random coefficient models of Hildreth and Houck (1968) and Swamy (1970), random intercept and slope parameters vary around cross-sectional units, that is, general averages. It consists of the sum of random parameters, general mean and error term. This model does not assume heteroskedasticity and autocorrelation to create the covariance matrix in the panel. Whether or not the random coefficients model should be used or not, that is, the homogeneity of the parameters, is tested with the F test or a Hausman type test. The estimation results of the model with the random coefficients linear regression model are given in Table 2.

According to the results above, the Wald statistic, which measures the significance of the independent variables economic growth and population variables together on the dependent variable energy consumption, is significant, but although the economic growth variable is statistically significant, the population variable is not

Table 2: Random coefficients model results

The dependent variable	Energy consumption
Independent variables	Coefficients/Probability values
growth	0.7371*** (0.0000)
population	1.5102 (0.4102)
c	−0.1973 (0.1360)
Wald test	77.80 (0.0000)
Hausman test	89.41 (0.0000)

,* indicate 5% and 1% significance levels, respectively

significant in explaining energy consumption. A 1% increase in economic growth increases energy consumption by an average of 0.75%. According to the result of the Hausman test statistics, which was performed to determine whether the parameters change from unit to unit, H_0 is rejected, therefore it is accepted that the parameters are not constant.

When the units are examined separately (Table 3), it is seen that the parameters differ from each other. According to the results, the economic growth variable is statistically significant in explaining energy consumption for all countries considered. A 1% increase in economic growth increases energy consumption. The parameter of the economic growth variable varies between 0.49% and 0.81 for countries. The population variable is significant in explaining energy consumption at the 5% significance level for South Africa, Mexico and Thailand, and at the 10% significance level for Turkey and China, its statistically insignificant for India and Indonesia. A 1% increase in population increases energy consumption, this parameter is between 1.23 and 1.59% for all countries.

In the seemingly unrelated regression method, there is no relationship between the equations. What is meant by the relationship or non-relationship of the regression models in the equation system is the existence or non-relationship between the error terms of the models in question. Seemingly Unrelated Regression models, introduced by Zellner in 1962, consist of classical linear regression models in which no variable in the equation system is included in another equation, that is, the system of equations is not a simultaneous system. If there is a correlation between units in panel data models, the units cannot

Table 3: Random coefficients model results of unit-specific models

Countries/ Variables	Coef.	Standard Error.	z	P>|z|	(95% Conf. Interval)	
India						
growth	0.596666	0.080011	7.03	0.0000	0.461130	0.663456
population	2.013103	1.673012	1.45	0.4090	−1.287132	5.268073
c	1.509420	2.533022	0.83	0.5521	−3.443355	6.444569
South Africa						
growth	0.490009	0.060441	9.01	0.0000	0.490287	0.679658
population	2.993700	0.930055	3.40	0.0021	1.103349	4.867780
c	0.886408	0.628320	1.09	0.3280	−0.48877	2.267039
Indonesia						
growth	0.826380	0.066070	8.37	0.0000	0.644033	1.078895
population	0.696175	1.071306	0.69	0.7044	−1.273421	2.867349
c	−1.693392	0.907836	−1.70	0.0600	−3.680791	0.117348
Turkiye						
growth	0.810099	0.178903	6.70	0.0000	0.520880	1.197863
population	2.866437	1.440235	1.88	0.0504	−0.064981	5.876095
c	−4.304063	3.378390	−1.49	0.8070	−10.68877	2.198768
China						
growth	0.620063	0.137036	4.33	0.0000	0.345673	0.704436
population	−3.34707	1.627315	−1.84	0.0530	−6.634573	0.011099
c	6.503008	2.234560	2.93	0.0041	2.088331	10.97008
Mexico						
growth	0.690963	0.104433	6.73	0.0000	0.580673	1.067094
population	1.597066	1.587799	2.42	0.0237	0.540693	6.654990
c	0.107749	1.607061	0.09	0.3769	−3.038709	3.227093
Thailand						
growth	0.637088	0.102301	6.40	0.0000	0.448956	0.827359
population	1.235544	0.897061	2.07	0.0064	0.670843	4.179986
c	−1.865066	1.097820	−1.99	0.0748	−4.020224	0.290064

be considered independently of each other and the system can be analyzed with the help of a seemingly unrelated regression model. Seemingly unrelated regression is used because the constant and slope parameters vary across units, but it is thought that there is a connection between the error terms of the units. For this reason, it can be an alternative to estimators that take into account the correlation between units. The results obtained from estimating the model with the Apparently Unrelated Regression model are given in Table 4. The results of the mean square error, R2 and Wald test statistics for all submodels of the units are given here. The fact that Wald test statistics are significant for all models indicates the general significance of the models. When we look at R^2, the lowest value is in the China with 42% and the highest value is in South Africa with 78%.

The results for the units are given in Table 5. The economic growth variable is statistically significant in explaining energy consumption for each country. When there is a 1% increase in economic growth, energy consumption also increases, all with positive signs. The population variable is insignificant for Indonesia, but is significant in explaining energy consumption for all other countries. In India, a 1% increase in economic growth increases energy consumption by an average of 0.49%, and a 1% increase in population increases energy consumption by an average of 3.96%. In South Africa, a 1% increase in economic growth increases energy consumption by an average of 0.48%, and a 1% increase in population increases energy consumption by an average of 2.01%. A 1% increase in economic growth in Indonesia increases energy consumption by an average of 0.53% and the population variable is insignificant. A 1% increase in economic growth in Turkey increases energy consumption by an average of 0.80%, and a 1% increase in population increases energy consumption by an average of 1.36%. In China, a 1%

Table 4: Overall results of the seemingly unrelated regression model

Units	R^2	CHI^2	P-value
India	0.7500	70.39	0.0000
South Africa	0.7803	98.77	0.0000
Indonesia	0.7572	65.81	0.0000
Turkiye	0.5705	19.03	0.0000
China	0.4237	27.97	0.0000
Mexico	0.7537	72.80	0.0000
Thailand	0.7732	45.96	0.0000

Table 5: Seemingly unrelated regression model coefficient results

Units	Growth	Population
India	0.4923***	3.9607**
	(0.0000)	(0.0324)
South Africa	0.4807***	2.0137***
	(0.0000)	(0.0001)
Indonesia	0.5310***	−0.9092
	(0.0000)	(0.9003)
Turkiye	0.8099***	1.3609***
	(0.0000)	(0.0030)
China	2.9975***	4.0105**
	(0.0000)	(0.0271)
Mexico	0.8766***	1.0941**
	(0.0000)	(0.0260)
Thailand	0.5399***	1.0860***
	(0.0000)	(0.0010)

,* indicate 5% and 1% significance levels, respectively

Table 6: Seemingly unrelated regression model correlation matrix

Units	India	South Africa	Indonesia	Turkiye	China	Mexico	Thailand
India	1.000						
South Africa	0.078	1.000					
Indonesia	0.279	0.399	1.000				
Turkiye	−0.079	0.129	0.208	1.000			
China	0.592	0.171	0.062	−0.317	1.000		
Mexico	−0.157	0.695	0.025	0.258	−0.219	1.000	
Thailand	0.178	0.082	0.037	0.137	0.307	−0.163	1.000

increase in economic growth increases energy consumption by an average of 2.99%, and a 1% increase in population increases energy consumption by an average of 4.01%. In Mexico, a 1% increase in economic growth increases energy consumption by an average of 0.87%, and a 1% increase in population increases energy consumption by an average of 1.09%. In Thailand, a 1% increase in economic growth increases energy consumption by an average of 0.53%, and a 1% increase in population increases energy consumption by an average of 1.08%.

Looking at the inter-unit correlation matrix of the residues (Table 6), it is seen that there is a correlation of over 50% between Mexico and South Africa, and between the India and China. As a result of the Breusch-Pagan Lagrange Multiplier test for inter-unit correlation ($Chi^2(28) = 40.207$ and P-value: 0.0297), it is proven that the H0 hypothesis is rejected and there is a general inter-unit correlation. For this reason, correlation between units can be tested with this estimator and separate predictions can be made for each unit, taking into account the existence of correlation between units. In order for SUR models to be estimated, the Breush Pagan Lagrange Multiplier test must give a result that rejects the null hypothesis.

4. CONCLUSION

Over the last half century, many developing countries have experienced a huge increase in exports, imports and energy consumption to support economic growth. The need for energy, which has been one of the vital resources for states and societies throughout human history, increases with the growth of country economies. In addition, the increase in the rate of urbanization along with the industrialization process creates an accelerating effect on the energy needs of countries, and the intensive use of energy has a positive effect on both the total production and the welfare level of the countries. The increasing world population, developments in the industrial sector and rising living standards also increase energy consumption and therefore energy demand. The relationship between energy and economic growth has been widely examined in the literature, especially after the oil shocks of the early 1970s. Accurately determining the relationship between energy consumption and economic growth constitutes a very important information input for the decisions policy makers will make. In this study, based on 1990-2022 data for 7 developing countries (China, India, South Africa, Indonesia, Turkey, Mexico, Thailand), it was concluded that economic growth and population variables positively affect energy consumption. While China and India are the countries with the largest populations in the world, they are also countries that import energy from foreign countries. Bottlenecks that may occur in the energy sector in all countries included in the analysis may negatively affect production and employment, and therefore economic growth. All countries should continue to implement energy sector development policies. Countries that are significantly dependent on foreign energy should ensure energy supply security, that is, diversify their energy sources. In addition, it is inevitable to increase efficiency in energy consumption and give importance to renewable energy sources.

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