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A Development Dilemma: How Does Energy Poverty Improvement Affect Fossil Fuel Energy Consumption in Southeast Asian Countries in the 21st Century?*

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Abstract

Governments worldwide have actively addressed energy poverty through extensive subsidy policies; however, these efforts face the complex challenge of balancing improved energy access with long-term sustainable development goals. This study examines the effects of energy poverty improvement (EPI) on fossil fuel consumption using a cubic form of the Environmental Kuznets Curve in five Southeast Asian countries—Philippines, Indonesia, Malaysia, Thailand, and Vietnam—over 2000–2020, employing GLS panel regression. A new EPI indicator is constructed by combining binary data on access to clean cooking energy and rural electricity. Results reveal a non-linear relationship: fossil fuel consumption per capita increases with EPI until a peak value of 91.88, after which it declines, supporting the EKC hypothesis. The findings underscore the need for policies promoting renewable energy adoption to ensure that gains in energy access are consistent with environmental sustainability.

Keywords: energy poverty; fossil fuel consumption; Southeast Asia; Environmental Kuznets Curve; panel regression

JEL Classification Codes: C23; C51; O13; I32; Q43

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1. Introduction

Southeast Asia is widely regarded as one of the regions most affected by energy poverty. Approximately 50% of the global population without access to electricity resides in Asia (Asian Development Bank, 2013). This issue is particularly acute in rural areas, where traditional fuels such as wood, charcoal, and animal dung are still commonly used for cooking. Despite being unhygienic and inefficient, these fuels remain the primary energy source for many households, contributing significantly to global warming. Even as poverty levels improve, reliance on traditional fuels is expected to persist in some communities (Dimnwobi et al., 2022) due to limited access to cleaner technologies such as renewable electricity.

In contrast, more developed economies have made notable progress in transitioning to renewable energy sources, including solar photovoltaics, wind power, and tidal energy (Asiedu et al., 2021). However, the causal relationship between energy poverty and fossil fuel consumption remains unclear. Many studies in environmental and development economics apply the Environmental Kuznets Curve (EKC) hypothesis, which suggests that environmental degradation rises with economic development until it reaches a peak, after which it declines (Stern, 2017). The question remains whether emerging economies in Southeast Asia have reached this turning point. Most empirical research examining the EKC in Asian countries uses GDP per capita as a proxy for economic development and carbon dioxide (CO_2) emissions as a proxy for environmental degradation. Studies that explore the EKC using alternative indicators are relatively rare.

This paper addresses the research gap by introducing the Energy Poverty Improvement Index (EPI) as an alternative to conventional GDP-based measures in examining the relationship between energy access and fossil fuel consumption in Southeast Asian countries. Using panel data from 2000 to 2020 and a cubic functional form of the Environmental Kuznets Curve (EKC), the study captures potential asymmetries in the rise and fall of fossil fuel use as energy poverty improves. The cubic form allows for an unbalanced peak, reflecting the likelihood that fossil fuel consumption may increase more rapidly before the peak than it declines afterward. The analysis also incorporates tourism as a key factor influencing energy demand. By employing rigorous regression testing and robustness checks, this study aims to provide empirical evidence that can guide policymakers in designing strategies that simultaneously improve energy access and promote environmental sustainability.

2. Literature Review

This section reviews past and recent studies that analyze economic well-being in terms of energy poverty and its implications for environmental quality. It first discusses the concept of energy poverty and how it is measured, then summarizes relevant empirical research that investigates the causal relationship between energy poverty and environmental degradation. The section concludes by highlighting this study's contribution to the literature.

2.1. Energy poverty: concept and measurement

Humans need energy to sustain their lives, so any situation where people lack adequate energy to meet essential daily necessities can be defined as energy poverty. Energy poverty is a multi-dimensional concept that involves access to electricity, clean cooking facilities, and overall energy consumption levels. It reflects the inability to secure modern energy services that are essential for basic human well-being and economic productivity. The term can be easily confused with fuel poverty because it also considers the efficiency of energy used in operation. Energy poverty is generally defined as a level of consumable energy that does not satisfy basic needs (González-Eguino, 2015) such as clean cooking activities, which can be due to several factors not limited to lack of energy infrastructure, inequality in energy distribution (Jové-Llopis & Trujillo-Baute, 2024), and energy price structure (Shortt & Rugkåsa, 2007). Dong et al. (2022) also find that in technical aspects, low energy efficiency and a low proportion of clean energy consumption are the causes of energy poverty. Psychologically, poor mental health can even intensify energy poverty, as people experiencing poor mental health are linked with poorer saving habits and risks of gambling behaviors (Yang & Zikos, 2024). Climate change in terms of temperature fluctuations can also cause households to be energy poor (Churchill et al., 2022).

It is widely accepted that measuring energy poverty is complicated due to its intricate nature and spatial-temporal variations (Kashour & Jaber, 2024). In the European Union, where household situations can be tracked systematically, a precise measurement of energy poverty is from insufficient warmth within dwellings, owed energy bills, and dwelling quality issues (Kashour & Jaber, 2024). Technological approaches are seen to be common in measuring energy poverty, considering electricity and sources other than biomass for cooking and home heating (González-Eguino, 2015), as the two activities are the most vital ones for living in any region. Several studies use econometric tools to indicate energy poverty with demographic and socio-economic factors as the influence (Abbas et al., 2020; Castaño-Rosa et al., 2019).

2.2. Relevant research

The Environmental Kuznets Curve (EKC) hypothesis posits that improvements in people's well-being can initially lead to environmental degradation up to a peak, after which environmental quality improves as well-being continues to rise (Dinda, 2004). Numerous empirical studies have tested this theory across different contexts and time periods (Caporin et al., 2024; Hove & Tursoy, 2019). This paper extends the EKC framework by arguing that energy poverty improvement is a critical dimension of well-being that should be examined alongside the traditional income-based approach.

A review of the literature reveals four studies most relevant to this research (Table 1). Hassan et al. (2022) examine energy poverty and carbon emissions in BRICS countries (Brazil, Russia, India, China, and South Africa), using the percentage of the population with access to electricity as a proxy for energy poverty. They find that energy poverty increases carbon emissions, while education reduces them.

Introducing a world crisis like the 2019 Coronavirus Disease (COVID-19) into analysis, Batool et al. (2023) show that COVID-19 intensifies energy poverty in Pakistan, and the energy poverty—the use of traditional energy sources, the impact of load-shedding on daily activities as the components—itself worsens income, health, education poverty, and environmental situations. Ehsanullah et al. (2021) attempt to measure the energy poverty index in G7 countries (Group of 7 large-economy countries: Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) with greenhouse gas emissions as one of the components, which are found to be an effect rather than a cause in many papers; however, the paper concludes with country ranking instead of finding causalities among those variables, which should have been the core contribution.

In contrast, Oryani et al. (2022) put effort into examining the impact of energy poverty on environmental quality in South Korea with an energy poverty index, while considering environmental-related technologies, real GDP per capita, and financial development. The energy poverty index in this study is calculated by 5 elements: proportion of the urban population with access to electricity, percentage of the rural population with access to electricity, per-capita electricity consumption, per-capita total energy supply, and total final energy consumption per capita. The study reveals that the energy poverty index impacts the ecological footprint in both the short and long term.

Table 1: Summary of relevant research on energy poverty and environmental burden

Authors (Year)	Explanatory Variables	Dependent Variable(s)	Significant causalities
Hassan et al. (2022)	Economic Growth, Energy Poverty, Education, Income Inequality, Globalization	Carbon Emission	Economic Growth, Energy Poverty, Income Inequality, Education, Globalization
Batool et al. (2023)	Energy Poverty	Income Poverty, Health Poverty, Educational Poverty, Environmental Poverty	Energy Poverty
Ehsanullah et al. (2021)	Energy consumption, energy intensity, Greenhous Gases emissions	Energy Poverty Index (composite)	No causalities discussed
Oryani et al. (2022)	Energy Poverty Index, Environmental-Related Technologies, Real GDP per capita, Financial Development	Ecological Footprint	Energy Poverty Index, Real GDP per capita, Financial Development

Source: Authors' compilation.

There are other options to analyze the linkage between energy usage and the environment in emerging countries like Southeast Asian countries, such as using the human development index (Das & Chakraborty, 2024) or conventional income level measurement like GDP per capita (Premashthira, 2024). However, there is still room for improvement in developing better indicators to examine the association between energy poverty and the environment. The authors have hardly found recent research illustrating this linkage in Southeast Asian countries, which are supposed to be among the most rapidly changing regions in the world. Hence, the results of this paper should contribute to environmental economics and development economics by providing a clearer context of how fossil fuel consumption changes when energy poverty improves in the region.

3. Data and Methods

3.1. Variables and data sources

The data used in this study is a balanced panel dataset covering five countries over 21 years, from 2000 to 2020. The countries included in this study are Indonesia, the Philippines, Malaysia, Thailand, and Vietnam, selected due to the availability of data. Detailed information for each variable is presented in Table 2. Due to the limited number of observations, this paper limits the explanatory variables to only two, in order to maintain focus in the regressions. Fossil fuel is known to be the main culprit of environmental degradation (Wuebbles & Jain, 2001); therefore, fossil fuel energy consumption per capita, sourced from Our World in Data (OWD) (Energy Insittute, 2024), is designated as the dependent variable of this study.

For more than half a century, Southeast Asia has been a well-known destination for international tourism, which has helped boost the region's economies; however, the growth in tourism comes with costs. Tourism depends largely on energy consumption, which leads to the exploitation of fossil fuels in emerging countries (Jabeen et al., 2024; Nepal et al., 2019), and the region is no exception. As a result, tourism is also introduced into the analysis, using the number of international arrivals per year from The World Bank's World Development Indicators (WDI) (World Bank, 2023). Energy poverty improvement indicators are explained in section 3.2.

Table 2: Variables and data used in the study

Abbreviation	Description	Unit	Source
FOSSC	Fossil fuel energy consumption per capita (Average consumption of energy from coal, oil and gas per person)	Kilowatt-hours per person.	OWD, 2023
ACFTR	Percentage of the rural population that Use clean energy and technology for cooking under the guidelines of WHO	% of total rural population	WDI, 2023
AER	The proportion of the population that can access electricity outside the urban area.	% of total rural population	WDI, 2023
TOUR	Number of international tourist arrivals per year	Number of arrivals	WDI, 2023

Source: Authors' compilation.

3.2. Derivation of Energy Poverty Improvement Index (EPI)

Sy and Mokaddem (2022) conduct a meta-narrative review and categorize energy poverty measurements into six approaches-engineering-based, economic-based, sustainability-based, binary, multifaceted, and target-based. The binary approach appears in several papers, including Oryani et al. (2022), as shown in the literature review section. Being the most fundamentally vital, two indicators of the binary–multidimensional measurement approach are introduced in this paper to represent energy poverty improvement: the percentage of the rural population that uses clean energy and technology for cooking under the guidelines of the World Health Organization (ACFTR), and the proportion of the population that can access electricity in rural areas (AER). The data are derived from The World Bank's World Development Indicators (World Bank, 2023).

To avoid possible problems such as multicollinearity, this paper improves the effectiveness of the energy poverty index from Oryani et al. (2022) by consolidating the two components into an "Energy Poverty Improvement Index" (EPI), calculated as follows (unit in percent):

$$EPI = \frac{ACFTR \times AER}{100}$$

This formulation ensures no severe multicollinearity as well as cointegration effects in the dataset. The EPI can be interpreted such that when a country has an increase in either the percentage of the rural population using clean energy for cooking, or the percentage of the rural population with access to electricity, energy poverty in the country should be seen as "improved." The EPI will be used in a cubic form to test the relationship with the innovative unbalanced peak form of the Kuznets curve theory, illustrated in Figure 1.

The reason behind using a cubic form is that a conventional parabolic form would limit the relationship between EPI and fossil fuel energy consumption to a symmetrical balance before and after the peak. The authors suspect that if there are any peaks, increasing fossil fuel consumption can be more rapid and effortless, while reducing it can be more ambitious and complicated. This paper aims to challenge the relationship analysis with a non-linear functional form that allows for an unbalanced peak.

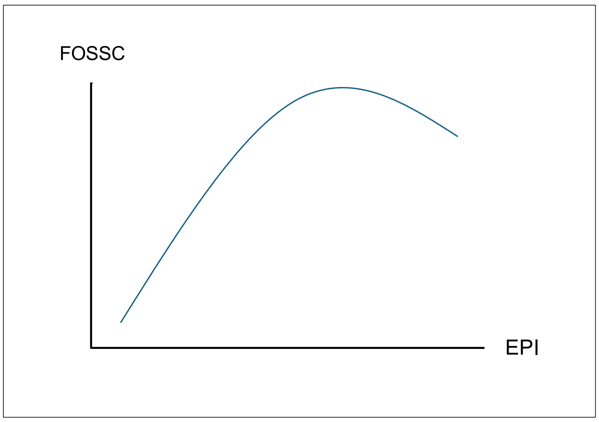

Figure 1: Energy poverty improvement and fossil fuel consumption expected in Kuznets curve form

Source: Authors' illustration.

3.3. Regression analysis framework

Based on the definitions in Table 1 and the theoretical framework, the panel data regression model is shown as follows:

$$FOSSC_{it} = \beta_0 + \beta_1 EPI^3{}_{it} + \beta_2 EPI^2{}_{it} + \beta_3 EPI_{it} + \beta_4 TOUR_{it} + \varepsilon_{it}$$

where i represents five countries (i = 1, 2, ...,5), t represents the years in the study (t = 2000, 2001, ..., 2020), β are the coefficients that describe the long-term relationship of the energy poverty improvement (EPI), tourism development (TOUR), and the intercept β_0. The lefthand side is the dependent variable, the per-capita amount of energy consumption from fossil fuels (FOSSC) taken by natural log to maintain stability. ε represents the error term. Additionally, the study applies the Environmental Kuznets Curve (EKC) hypothesis for the volume of fossil fuel energy consumption. This hypothesis will be confirmed when $\beta_3 > 0$ and $\beta_3 < 0$ with significance. Therefore, our hypotheses are developed as follows:

H1: The energy poverty improvement is associated with fossil fuel consumption per capita.

H2: International tourist arrival is associated with fossil fuel consumption per capita.

The research framework is illustrated in Figure 2 below, according to the description and hypotheses mentioned. This paper tests the credibility of the EPI index in identifying impacts on fossil fuel consumption based on the two basic life-requirement components of EPI—clean energy use for cooking and electricity access. The improvement in energy poverty is then expected to change the level of fossil fuel energy consumption in both unbalanced directions—an increasing trend before the peak, and a decline after the peak, as shown in the figure.

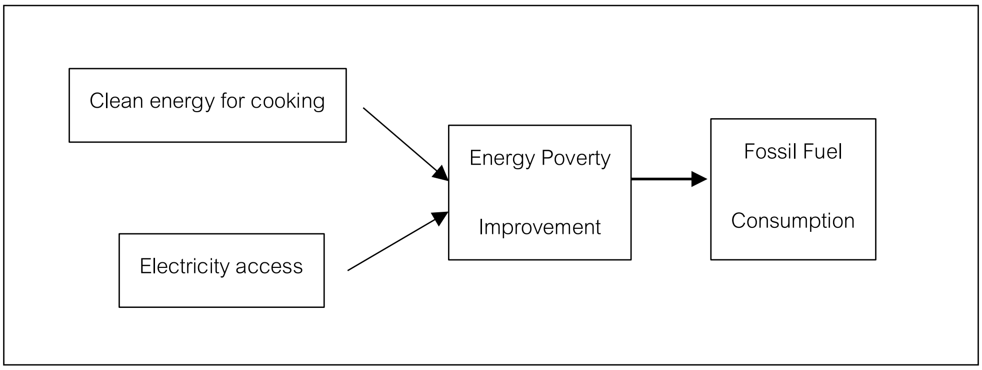

Figure 2: Research framework

Source: Authors' illustration.

4. Results and Discussion

A summary of the collected data is shown in Table 3. As can be seen, the EPI score ranges from 1.4% (Indonesia, 2000) to 100% (Thailand, 2020), with an average of 53.7%, which is diverse enough for regression. For integrity, a graphical matrix of fossil fuel consumption per capita – energy poverty index – tourist arrivals is illustrated in the Appendix. The graphs between EPI and FOSSC, and between TOUR and FOSSC, correspondingly support the associations among variables. The dataset contains 105 observations across five country groups (21 observations per country, which aligns with the 21-year period).

Table 3: Summary statistics of the dataset

Variable	Mean	Std. Dev.	Min	Max	Unit	Obs.
FOSSC	12727.1	10821.17	2166	35262	Kwh/person	105
EPI	53.72053	36.02	1.4328	100	%	105
TOUR	11.6 mil	9243065	14.8 mil	39.9 mil	Arrivals	105

Source: Authors' calculation.

For completeness, a graphical matrix of fossil fuel consumption per capita – energy poverty index – tourist arrivals is illustrated in Figure 3 below.

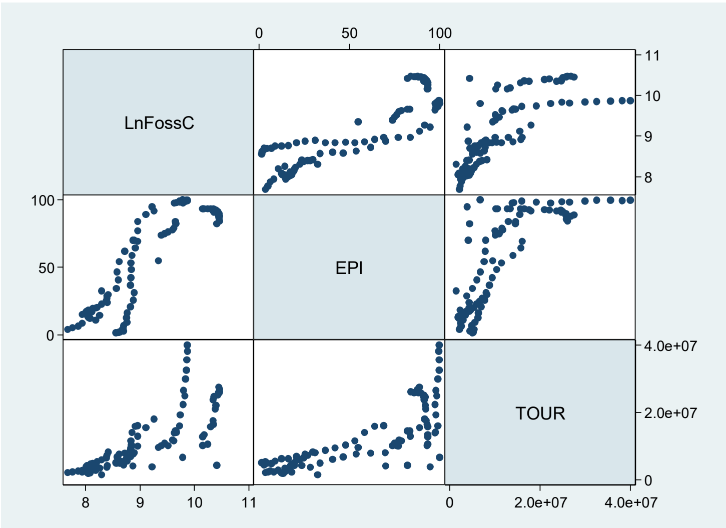

Figure 3: Graphical matrix of the study variables

Source: Authors' calculation.

The regression results shown in Table 4 explain the impact of energy poverty improvement and tourism on fossil fuel consumption across six ASEAN countries from 2000 to 2020, with 70.39% explanatory power (Overall $R^2 = 0.7039$). In terms of random effect quality, sigma_u = 0 indicates no variation attributed to country-specific random effects. This implies negligible unobserved country-specific effects in the model, which the EPI terms may be capturing effectively. The large within-group standard deviation reveals that time-varying factors within each country remain across the 2000–2020 period, suggesting that a longer time series in the future could improve the model. The zero intraclass correlation (rho) also shows that the observations within each country group are not correlated with each other. In addition, the Wald chi-square test (237.74, p-value < 0.0001) indicates that the model is statistically significant. Significance tests confirm that the H1 and H2 hypotheses are satisfied, owing to the significance of their parameters. The tourism arrivals result shows that every additional million arrivals cause an increase of 392 Kwh/person in fossil fuel energy use, implying that increased tourism activity contributes to higher energy consumption, likely due to greater transportation, infrastructure, and service demands.

Table 4: Regression result (GLS random effect)

Variable	Coefficient	Std. Error	z	P>|z|
EPI^3	-0.08867	0.029734	-2.98	0.003
EPI^2	15.344	4.656264	3.3	0.001
EPI	-572.719	206.901	-2.77	0.006
Tour	0.000392	0.000109	3.61	0.000
Constant	6817.122	2265.49	3.01	0.003
sigma_u = 0	sigma_e = 1383.7294	rho = 0		
Wald chi^2 = 237.74				

Source: Authors' calculation.

The association between the EPI and fossil fuel energy consumption can be explained by a cubic functional form. The negative coefficient of EPI^3 means energy consumption drops after reaching its peak. In contrast, the positive coefficient of EPI^2 shows an increasing trend before the peak. The weaker negative sign of EPI suggests a slight decrease in fossil fuel energy consumption at the lowest level of the EPI index (EPI less than 23.31), which can be regarded as one of the limitations of this model. According to the estimated cubic function, fossil fuel energy consumption peaks at EPI = 91.88 and begins to decline afterward. At the peak, the estimated per capita consumption reaches 14,954.6 Kwh/person. Figure 2 illustrates the estimated per capita fossil energy consumption subject to the energy poverty improvement index, aligning with the Kuznets Curve theory.

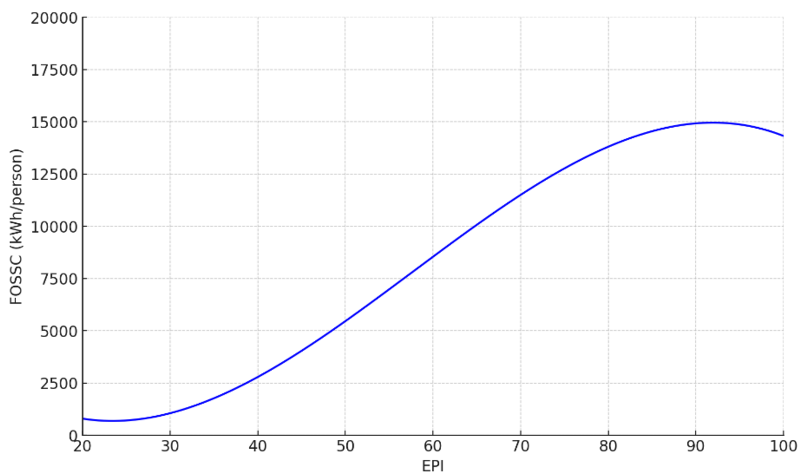

Figure 4: Estimated energy poverty improvement and fossil fuel consumption in a cubic form

Source: Authors' calculation.

Cabañero (2023) suggests that increases in government spending and foreign direct investment contribute to higher long-term carbon emissions. These macroeconomic finances may help people alleviate energy poverty but can lead to higher fossil fuel consumption. Although energy poverty is a serious challenge that must be addressed in all countries, public policies are necessary to curb fossil fuel exploitation. Domguia et al. (2024) recommend that environmental taxes can control dirty energy use while also helping reduce energy poverty. Environmental taxes can be structured to support the transition to a greener economy with renewable energy. Zhao et al. (2022) also suggest that renewable energy can disrupt sole dependence on fossil-based energy resources and help alleviate energy poverty. Hence, improvements in energy access are increasingly dependent on government initiatives to promote clean and renewable energy sources—such as solar, hydro, and wind—to reduce dependency on fossil fuels, with large corporations playing a key role.

Limitations of this study include the observation size, which is based on a 21-year period, and the inability to support a two-stage analysis such as vector autoregression, which requires a larger sample size. The model also struggles to accurately predict the association at EPI levels below 23.

5. Conclusion

The results of this study confirm that the Energy Poverty Improvement Index (EPI) is a robust indicator with a significant association to fossil fuel consumption levels in Southeast Asian countries. As energy poverty declines, fossil fuel consumption per capita generally rises until EPI reaches its peak, after which consumption begins to fall. This pattern suggests that while improved energy access enhances living standards, it can also heighten dependence on fossil fuels unless accompanied by proactive policies encouraging renewable energy adoption.

These findings highlight the importance of integrating energy poverty alleviation strategies with clean energy policies to prevent potential environmental trade-offs. Governments should prioritize investment in renewable energy infrastructure, promote technology transfer, and incentivize private sector participation to accelerate the transition away from fossil fuels.

Given the study's limitations—including its 21-year observation period and the inclusion of only five countries—future research should expand the temporal and geographic scope and consider additional variables such as energy pricing structures, environmental taxes, and climate policies. Such work can provide deeper insights into balancing energy access, economic growth, and environmental sustainability.

This research provides evidence-based insights relevant to several United Nations Sustainable Development Goals: No Poverty (SDG 1), Decent Work and Economic Growth (SDG 8), Responsible Consumption and Production (SDG 12), Climate Action (SDG 13), and Partnerships for the Goals (SDG 17).

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