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The role of energy poverty in gender inequality across health, employment, and education: A case study of ASEAN countries

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Abstract

With the increasing use of machinery in production and the proliferation of appliances that make life easier due to technological advancements, energy plays a crucial role in both the production sector and improving the quality of life. Therefore, societies without access to energy have faced significant disadvantages in this regard, making energy deprivation a subject of academic studies. Similarly, the deprivation of certain rights or opportunities solely based on gender constitutes another critical topic in social science. Although these two important issues have been extensively addressed in the literature through numerous studies, only a few works examine the relationship between them. In this context, this study aims to fill this gap and contribute to the literature by analyzing the effect of energy deprivation on gender inequality in the fields of education, employment, and health across five ASEAN countries from 1990 to 2021, using the Dynamic Ordinary Least Squares-Mean Group (DOLS-MG) method. The findings of the study provide evidence that energy deprivation exacerbates gender inequality in all three areas. However, the impact of energy deprivation is most pronounced in the health sector, followed by employment, and is least significant in education. Based on the results, the study offers several policy recommendations to address these critical issues and provides suggestions for future research on the topic.

Keywords: Energy Poverty, Access to Electricity, Gender Inequality **JEL Codes:** D16, O13, Q43

Enerji yoksulluğunun sağlık, istihdam ve eğitimde cinsiyet eşitsizliği üzerindeki rolü: ASEAN ülkeleri örneği

Öz

Üretimde makinelerin artan kullanımı ve teknolojik ilerlemeler sayesinde yaşamı kolaylaştıran cihazların çoğalması ile enerji, hem üretim sektöründe hem de yaşam kalitesini artırmada hayati bir rol oynamaktadır. Bu nedenle enerjiye erişimi olmayan toplumlar, bu konuda önemli dezavantajlarla karşılaşmış ve enerji yoksunluğu akademik çalışmaların bir konusu haline gelmiştir. Benzer şekilde, yalnızca cinsiyete dayalı olarak bazı hakların veya fırsatların yoksunluğu, sosyal bilimler açısından başka bir önemli konu oluşturmaktadır. Bu iki önemli konu literatürde birçok çalışma ile geniş bir şekilde ele alınmış olsa da, bunlar arasındaki ilişkiyi inceleyen sadece birkaç çalışma bulunmaktadır. Bu bağlamda, bu çalışma, 1990-2021 yılları arasında beş ASEAN ülkesinde enerji yoksunluğunun eğitim, istihdam ve sağlık alanlarındaki cinsiyet eşitsizliği üzerindeki etkisini Dinamik Ordinary Least Squares-Mean Group (DOLS-MG) yöntemi ile analiz ederek bu boşluğu doldurmayı ve literatüre katkı sağlamayı amaçlamaktadır. Çalışmanın bulguları, enerji yoksunluğunun her üç alanda da cinsiyet eşitsizliğini şiddetlendirdiğine dair kanıtlar sunmaktadır. Ancak, enerji yoksunluğunun etkisi sağlık sektöründe en belirgin olup, onu istihdam ve eğitim izlemektedir. Sonuçlara dayanarak, çalışma bu kritik sorunları ele almak için birkaç politika önerisi sunmakta ve bu konuya yönelik gelecekteki araştırmalar için önerilerde bulunmaktadır.

Anahtar Kelimeler: Enerji Yoksunluğu, Enerji Erişimi, Cinsiyet Eşitsizliği **JEL Kodları:** D16, O13, Q43

Introduction

With the Industrial Revolution, the integration of technological machines into the production process made energy an essential input for production. Consequently, energy usage became a critical factor in driving production and GDP growth, leading to the relationship between energy and production becoming a central focus of numerous studies (e.g., Garba & Bellingham, 2021; Ullah et al., 2021; Doğanalp et al., 2021). Along with technological advancements, simple technological tools that entered our lives have become irrevocable parts of daily life. As a result, energy is no longer limited to the production sector but has come to be seen as a necessity in every aspect of life. Therefore, the concept of energy poverty, which is mostly used to represent inaccessibility to energy, has not only been associated with the production levels of a country or different regions within the same country. It is also associated with the quality of life of individuals in society by impacting their ability to meet daily needs such as heating, lighting, and using electrical household appliances. This deprivation also deters them from accessing opportunities

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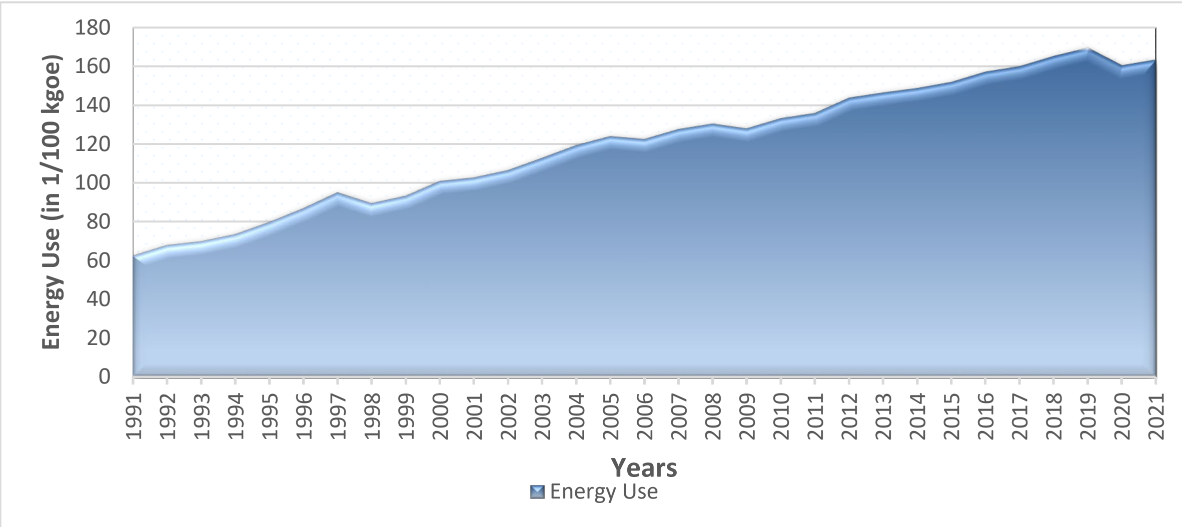
for self-development, such as education and healthcare (Oum, 2019). As a result, it leads to a society with lower-skilled and lower-income individuals. For low-income individuals, accessing energy becomes even more difficult, further exacerbating poverty and creating a vicious cycle. Given the significant importance of energy poverty, it has become one of the Sustainable Development Goals (SDGs) established by the United Nations in 2015, identified as SDG 7 affordable and clean energy. As of 2023, the number of people worldwide without access to electricity is 750 million (IEA, 2024).

While there is no universally agreed-upon definition of energy poverty in the literature (Sy & Mokaddem, 2022, p.1), it is generally used to describe the lack of access to affordable, reliable, and sustainable energy services (Gonzalez-Eguino, 2015, p.379). Similarly, although there is no universally agreed-upon indicator in the literature regarding energy poverty, metrics such as energy consumption, access to clean fuel for cooking, or usage of renewable energy are among the most commonly used ones. In this study, the only dataset without missing data and covering the longest period for the five selected countries is energy use per capita (kg of oil equivalent per capita), which has been utilized to represent energy poverty. The average values for those countries were calculated and are presented in Figure 2. As seen, energy use has increased every year. While there were rare instances of decreases in energy use in a few years, energy consumption, which was 6,000 kgoe in 1991, surpassed 16,000 kgoe by 2021.

Figure 1. The improvements in energy use



Sources: World Development Indicator

The massive increase in production with the Industrial Revolution also led to a significant rise in the GDP of countries. However, due to the unequal distribution of income among members of society, the incomes of some groups increased significantly, while the share of income received by others decreased. Consequently, income inequality, one of the issues largely associated with economic growth, became more pronounced. Another important form of inequality is gender inequality, which is one of the most discussed topics among academics and refers to the situation where women do not have equal opportunities with men in all aspects of life. The root of gender inequality lies in social norms or cultural expectations that assign specific roles to men and women in society. Gender inequality has been a subject attracting significant academic attention and has been extensively studied to understand its determinants. Due to its importance, this issue has been included among the SDG goals introduced by the United Nations in 2015, specifically SDG 5 identified as gender inequality.

The most fundamental areas affected by gender inequality are health, education, and employment (Nguyen and Su, 2021, p.36). When we consider the culturally assigned roles for women in social life such as cooking, house cleaning, and child-rearing (Braunstein et al., 2020), it becomes clear that women are the most affected gender in cases of energy poverty (Kaygusuz, 2011, p.936; Robinson, 2019, p.231; Butty et al., 2024, p.2).

In the economic domain, which is one of the most critical areas of social life, energy poverty creates significant barriers to women's participation in the workforce. Due to their culturally assigned roles, women often spend more time at home (Nguyen and Su, 2021, p.37), which limits their ability to engage in professional life. Moreover, when faced with energy poverty, tasks like collecting, chopping, carrying, and storing firewood or fetching water for heating and cooking take up nearly all hours of the day, further distancing women from the workforce (Pueyo & Maestre, 2019, p.170). Similarly, the lack of access to electricity prevents the use of even the simplest household appliances, forcing women to spend more time on housework. From this perspective, energy poverty is expected to exacerbate gender inequality in the labor market.

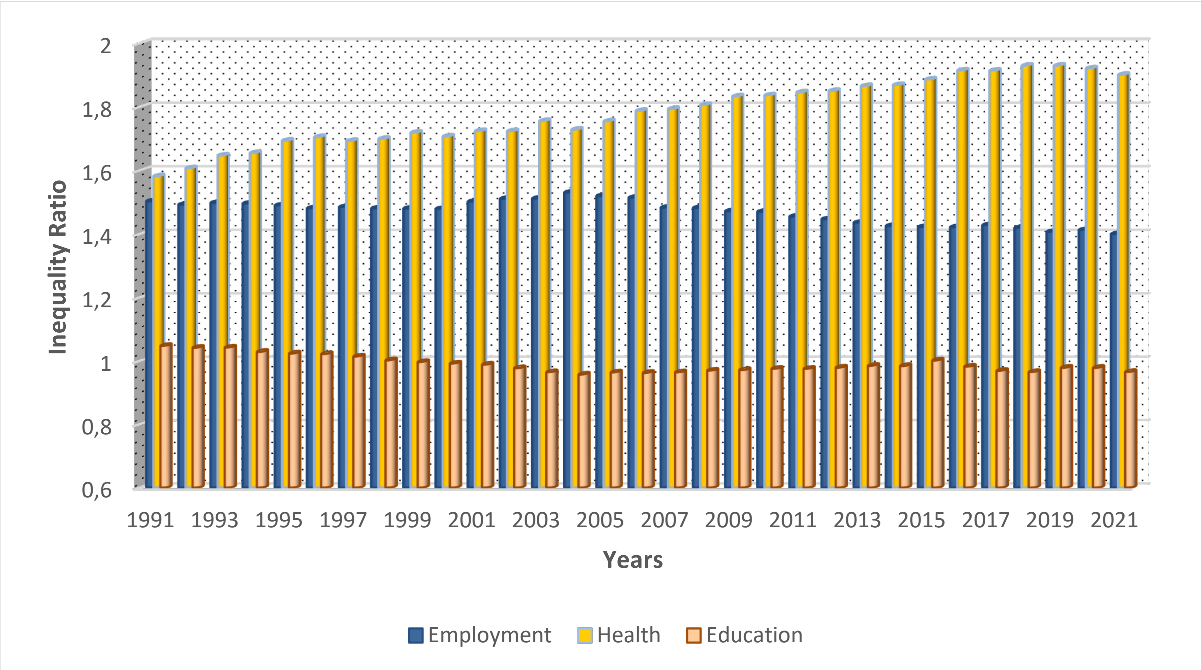
In terms of healthcare, a similar scenario arises. Due to energy poverty, women are more likely to rely on traditional energy sources such as fossil fuels for cooking and heating. This exposes them to high levels of carbon dioxide emissions or smoke from burning of biomass-related substances, which pose a significant threat to their health (Kaygusuz, 2011, p.940; Sule et al., 2022, p.1). Likewise, the risk of injuries while collecting fuel for cooking or heating further disadvantages women compared to men in terms of health and safety.

Gender inequality in education is also adversely affected by energy poverty. The lack of energy hampers education for both genders by limiting lighting and the use of digital materials. However, the situation is especially detrimental to girls, as they are often expected to assist their mothers with household responsibilities. This places girls in a disadvantaged position in education and acts as a barrier to their academic progress. Moreover, along with energy deprivation, the dependence on more expensive traditional energy sources proportionally increases energy expenses within the budget. This condemns low-income groups to even greater poverty, thereby leading households to further reduce their educational expenditures for girls (Nguyen & SU, 2021, p.37). Sovacool (2013, p.311) also confirms that when low-income groups gain increased access to renewable energy and their financial conditions improve, they tend to encourage girls to pursue education, thereby reducing gender inequality in education in favor of women. Furthermore, when energy poverty necessitates walking long distances to school, issues such as inadequate lighting along the way often discourage families from sending girls to school, while boys are allowed to attend. This further exacerbates gender inequality in education to the detriment of girls.

The average values of gender inequality in employment, education, and health for five Asian countries are represented in Figure 1 over the period 1991–2021. For the three indicators, the ratio of males is placed in the numerator, while the percentage of females is placed in the denominator. Therefore, any value greater than one indicates inequality in favor of males, while values lower than one indicate the opposite situation.

The blue bars indicate that the value is consistently greater than one, showing gender inequality in favor of males. However, this value demonstrates a consistent reduction during the period. In other words, the ratio of female employers to the female population takes a lower value than the ratio of male employers to the male population in the labor market, but this inequality in employment is gradually improving. Inequality in education, represented by green bars, shows a similar pattern to inequality in employment in terms of closing the gap between males and females. In contrast to employment, in some years, the value falls below one, indicating that the percentage of secondary school-age girls attending school is higher than that of secondary school-age boys. Overall, it can be said that there is minimal gender inequality in education for these five countries, as the value fluctuates around one during the period. The yellow bars represent gender inequality in health, showing a steady increase over the period in favor of males. Specifically, the ratio of the probability of female deaths to the probability of male deaths is always greater than one and continues to increase over the period.

Figure 2. Changes in Gender Inequality Across Employment, Education, and Health



Source: World Development Indicator

According to data from the World Bank Indicator, the global average values of gender inequality in employment, health, and education in 1991 were 1.7, 1.1, and 1.6, respectively, which were close to those in ASEAN countries. By 2021, the global average values for these three areas (1.6, 1.1, and 1.9, respectively) had surpassed those of ASEAN countries. This suggests that, on average, gender inequality worldwide has decreased more than in ASEAN countries. In 1991, the average gender inequality values in developing countries (1.5, 1.06, and 1.62, respectively) were also similar to those in ASEAN countries. By 2021, the gender inequality value in health for developing countries (1.6) was lower than that of ASEAN countries, indicating that ASEAN countries had greater gender equality in this area. In employment, developing countries had a value of 1.6 in 2021, making them more equitable than ASEAN countries. In education, both ASEAN and developing countries had a similar value of 1, reflecting comparable levels of gender equality.

Energy deprivation and gender inequality are two critically important indicators that significantly impact both human and social life. However, the number of studies in the literature looking at the impact of energy poverty on gender inequality together is notably limited. Therefore, this study aims to fill the existing gap in the literature and offers the following key contributions: This study is the first to examine the impact of energy deprivation on gender inequality across three critical areas, namely work life, health, and education using data from five ASEAN countries (Thailand, Vietnam, the Philippines, Malaysia, and Indonesia). Additionally, the Dynamic Ordinary Least Square Mean Group (DOLSMG) method employed in this study is noteworthy for providing more accurate and reliable results owing to its ability to account for cross-sectional dependence and heterogeneity among countries. Furthermore, since this method captures long-term relationships between variables, it is particularly effective in observing the long-term impact of energy deprivation on gender inequality. Lastly, usage of the most recent available data regarding the employed variables further enhances the study's contributions.

The structure of the study is organised as follows: In the introduction, definitions of energy deprivation and gender inequality are presented, emphasizing their significance in economic and social life, as well as the relationships between them. The literature review section evaluates the existing studies on this subject, highlighting the differences between this study and current research and reiterating its contribution to the literature. In the data and methodology section, definitions of the variables used in the study, their statistical summaries, the prerequisite tests applied, and the techniques employed are explained in detail. The empirical findings and discussion section reports the results and discusses the coefficients of the variables in detail. Finally, in the conclusion, the findings are summarized, and policy recommendations are made in light of the results. Suggestions for future research in this field are also provided.

1. Literature Review

Energy deprivation has consequences that extend beyond the economic realm, significantly impacting daily life, as energy is considered a fundamental part of everyday activities. In recent years, electricity, which serves as both a facilitator and an essential component of modern life, has become a topic of academic interest. Its widespread use in critical areas such as education, health, and the economy has drawn the attention of numerous researchers and scholars. Moreover, the number of people still without access to energy has brought the issue of energy deprivation to the forefront, prompting studies on its impact on various indicators.

Since energy poverty is an important topic due to its critical role in human life, the determinants of energy poverty have been the focus of numerous studies, whereas its relationship with the economic conditions of countries has been addressed by relatively fewer studies (Igawa & Managi, 2022, p.2). For instance, Nguyen and Nasir (2021) examined the impact of energy poverty on income inequality, a crucial economic indicator, across 51 countries between 2002 and 2012. They found that energy poverty increases income inequality. Similarly, Acheampong et al. (2021) investigated this issue for 166 countries, Dong et al. (2022) for 30 provinces in China, and Song et al. (2023) for 77 countries, concluding that increased energy access is associated with a reduction in income inequality.

The impact of energy poverty is not limited to economic indicators; its influence on critical socio-economic indicators such as health and education has also been the subject of some studies in the literature. For example, Oum (2019) examined the effects of energy deprivation on education and health in the country of Lao PDR. The study's findings revealed that children from energy-deprived households spent fewer years in education and that temporary health problems among household members increased. A similar study was conducted by Sule et al. (2022), investigating the impact of energy deprivation on health and education in 33 African countries. The findings indicated that increased access to energy reduced the under-5 child mortality rate and enhanced participation in education. Similarly, Apergis et al. (2022), for 30 developing countries, and Crentsil (2019), for Ghana, concluded that there is a positive relationship between energy access and education. Meanwhile, Njiru and Letema (2018), for Kenya, and Nawaz (2021), for Pakistan, examined the relationship between energy and health and found that energy poverty has a negative impact on health.

There have been a few of studies examining the relationship between energy poverty and gender inequality. For example, Pueyo and Maestre (2019, p.173) stated that the benefits of productive use of energy (PUE) would not be the same for men and women. This is because the sectors in which women are generally employed are small-scale or related to household tasks (such as cooking or handicrafts). Therefore, PUE interventions are unlikely to have a significant positive impact on the markets where women participate. In contrast, in production sectors or large-scale firms where men predominantly work, and where electricity is used as a crucial input, the contribution of PUE is much greater, leading to higher benefits for men. Similarly, Robinson (2019, p.231) highlights that energy poverty leads to gender-specific disadvantages in England. This is because, considering that household chores and childcare are predominantly undertaken by women, a problem in accessing energy would lead to women spending more time on tasks such as cooking and fetching fuel, thereby increasing their unpaid roles. Additionally, the use of biomass for cooking or heating exposes women to indoor air pollution, adversely affecting their health and causing greater harm to them compared to men.

The study most similar to the current research in the literature was conducted by Nguyen & Su (2021). Their study examined the impact of energy poverty on gender inequality across various sectors, from employment to political rights, using 20 different indicators. This analysis was carried out without regional distinction, covering 51 developing countries from 2002 to 2017, employing the GMM method. To the best of our knowledge, based on a thorough literature review, no other studies examine the impact of energy poverty on gender inequality.

The main differences of this study from the study of Nguyen & Su (2021) are the use of a method that accounts for cross-sectional dependence, the focus on a group of countries with similar characteristics, 5 ASEAN countries, the utilization of the most updated data, and the emphasis on gender inequality in employment, health, and education, which are the most significant indicators of economic and social dimensions. In this context, considering the highlighted differences, this study makes significant contributions to the literature by being the first to consider the specified differences and to focus on a group of 5 ASEAN countries.

2. Data, Empirical Process and Methodology

The impact of energy poverty on gender inequality in the fields of employment, health, and education is assessed using the Dynamic Ordinary Least Squares Mean Group (DOLSMG) method over the period 1991–2022 for five ASEAN countries (Indonesia, Malaysia, Philippines, Thailand, and Vietnam). The main reason for selecting these five ASEAN countries is data availability, particularly for education data, as some missing data prevents the application of the DOLSMG method. To analyze the link between energy poverty and gender inequality in these three areas, three separate models are established as follows:

$$lnEM_{i,t}= \alpha_i + \beta 1lnEP_{,t} + \beta 2lnGDPi_{,t} + \beta 3lnTO_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$lnED_{i,t}= \alpha_i + \beta 1lnEP_{i,t} + \beta 2lnGDPi_{,t} + \beta 3lnTO_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$lnHE_{i,t}= \alpha_i + \beta 1lnEP_{i,t} + \beta 2lnGDPi_{,t} + \beta 3lnTO_{i,t} + \varepsilon_{i,t} \quad (3)$$

In Equation 1, lnEM refers to the logarithm of gender inequality in employment, lnEP stands for the logarithm of energy poverty and is used in all equations. As discussed in the introduction section, GDP is one of the key determinants of gender inequality. Therefore, its logarithmic form, represented as lnGDP, is included in all equations. Another widely used determinant of inequality is trade openness (see Aguayo-Tellez, 2012; Pieters, 2018). The reason trade openness is considered a determinant of gender inequality is related to the gender composition of employment in the export and import sectors. In countries where heavy industries such as machinery, equipment, and automobiles dominate exports, men are more likely to be employed in these sectors, creating a disadvantage for women in the labor market. Conversely, if imports primarily consist of goods from industries with a high concentration of female employment, such as textiles and apparel, this can also lead to employment disadvantages for women. From a health perspective, in sectors considered hazardous, such as heavy industries, men working in export-related jobs may face disadvantages. Therefore, the significant impact of exports and imports on gender inequality justifies the inclusion of this variable in all three models. Its logarithmic form is denoted as lnTO.. In Equations 2 and 3, t the dependent variables are the logarithms of gender inequality in education (lnED) and gender inequality in health (lnHE), respectively. Details regarding the variables used are provided in Table 2.

Table 1. Data Description

Variable	Symbol	Definition	Source
Gender Inequality in Employment	lnEM	It represents the ratio of female employers to the female population in the labor market, divided by the ratio of male employers to the male population in the labor market	
Gender Inequality in Education	lnEM	It is the ratio of the percentage of secondary school-age girls attending school to that of secondary school-age boys attending school.	
Gender Inequality in Health	lnHE	It demonstrates the ratio of the probability of a woman dying before the age of 60 per 1,000 people to the probability of a man dying before the age of 60 per 1,000 people.	
Energy Poverty	lnEP	Energy use is the total amount of primary energy consumed before being converted into other types of fuels for final use.	
Gross Domestic Product	lnGDP	GDP represents the total gross value added by all resident producers within an economy over a given year. The GDP in dollars is converted from local currencies using the official 2015 exchange rates.	World Development Indicator
Trade Openness	lnTO	It indicates the ratio of the total value of exports and imports to a country's GDP.	

Statistical information on the series incorporated in the models is reported in Table 2. The highest standard deviation is observed in the energy poverty variable, at 7.04, indicating significant variation in energy usage across countries and over time. This is followed by GDP, with a standard deviation of 6.30. On the other hand, the least variation is observed in gender inequality in employment, with a standard deviation of 0.064, suggesting that most countries in the sample have similar levels of gender inequality in employment. When looking at the minimum values of the variables related to gender equality, it is evident that, except in the field of education, there are no years in which the ratio of males is lower than that of females in employment or health fields, as the values are non-negative. Further details on these statistics are provided in the table.

Table 2. Descriptive Statistics Overview

Variable	Obser.	Mean v.	Stand. Dev.	Minimum	Maximum
lnEM	155	0.3700529	0.1759368	0.0636355	0.6238057
lnED	155	-0.0140981	0.079813	-0.1406144	0.2009568
lnHE	155	0.5464506	0.2545863	0.1549937	0.9019046
lnEP	155	9.03377	0.8662229	7.046264	10.5407
lnGDP	155	8.044174	0.6297923	6.548834	9.316011
lnTO	155	4.549838	0.4733652	3.495664	5.395475

Initially, examining the presence of cross-sectional dependence (CS) in individual variables or in a model is an important step before conducting the prerequisite tests. The availability of CS violates the assumption of the first-generation tests, which assumes uncorrelated error terms across different units. It is crucial to keep in mind that the presence of CS should be accounted for in both prerequisite tests and the method applied in order to analyzing the relationship between energy poverty and gender inequality. Although several tests are available for detecting CS, the most appropriate one for our model in which the number of units (N) is lower than the time period (T) the Breusch-Pagan LM test, its equality is shown below:

$$LM = \sum_{i=1}^{N-1}\sum_{ş=i+1}^{N} T_{ij}\hat{\rho}_{ij} \qquad X^2\frac{N(N-1)}{2} \quad (4)$$

where $\hat{\rho}$ stands for the values of correlation.

In addition, the Pesaran (2004) CD test and the Baltagi et al. (2012) bias-corrected scaled LM test are also employed as robustness checks. Their equations are represented as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j}^{N} = i + 1\rho ij\right), \text{N(01)} \quad (5)$$

$$LM_{BC} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T_{ij}\hat{\rho}^2_{ij}-1) - \frac{N}{2(T-1)} \qquad N(0,1) \quad (6)$$

Another essential step before proceeding with the cointegration test is to check for slope heterogeneity in the model, as ignoring this issue can yield misleading results. To address this, the homogeneity test introduced by Pesaran and Yamagata (2008) is applied based on the following equation:

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}S\% - k}{\sqrt{2k}}\right) \text{ and } \tilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}S\% - k}{\sqrt{\frac{2k(T-k-1)}{T+1}}}\right) \quad (7)$$

In the presence of cross-sectional dependency and in the series incorporated into the models and heterogeneity of the variables' slope coefficients, selecting an appropriate unit root test that accounts for cross-sectional dependency (CS) and heterogeneity plays a crucial role in ensuring accurate findings. Therefore, two widely used unit root tests in the literature, namely the Cross-Section Dependence Augmented Dickey-Fuller (CADF) and the Cross-Sectionally Augmented Im-Pesaran-Shin (CIPS) tests, are applied to analyze whether the variables are stationary at the level or in their first differences.

CADF equation is written below based on the study of Mabrokuki (2023, p.3036).

$$\Delta Y_{it} = \alpha_i + \lambda_i Y_{i,t-1} + \beta_i \bar{Y}_{t-1} + \sum_{j=0}^{k} \gamma_{ij} Y_{t-1} + \sum_{j=1}^{k} \delta_{ij} \bar{Y}_{t-1} + \varepsilon_{it} \quad (8)$$

where $\bar{Y}_{t-1}$ and $\bar{Y}_{t-1}$ refers to the lags of each cross-sectional series individually and the average values of the first differences.

The CIPS test is derived from the CADF test shown as follows:

$$CIPS = \frac{1}{N}\sum_{1}^{n} CADF_i \quad (9)$$

According to the results of the prerequisite tests, a method should be chosen that accounts for any issues detected by those tests, which will be reported in the following section. The Westerlund (2008) cointegration test was chosen for examining the long-run correlation among the variables. Its advantages lie in its ability to address both cross-sectional dependence (CS) and slope heterogeneity. The test statistics are shown below:

$$G_t = \frac{1}{N}\sum_{i=1}^{N} \frac{\acute{\alpha} i}{SE(\acute{\alpha} i)} \quad (10)$$

$$G_\alpha = \frac{1}{N}\sum_{i=1}^{N} \frac{T\acute{\alpha} i}{\acute{\alpha} i(1)} \quad (11)$$

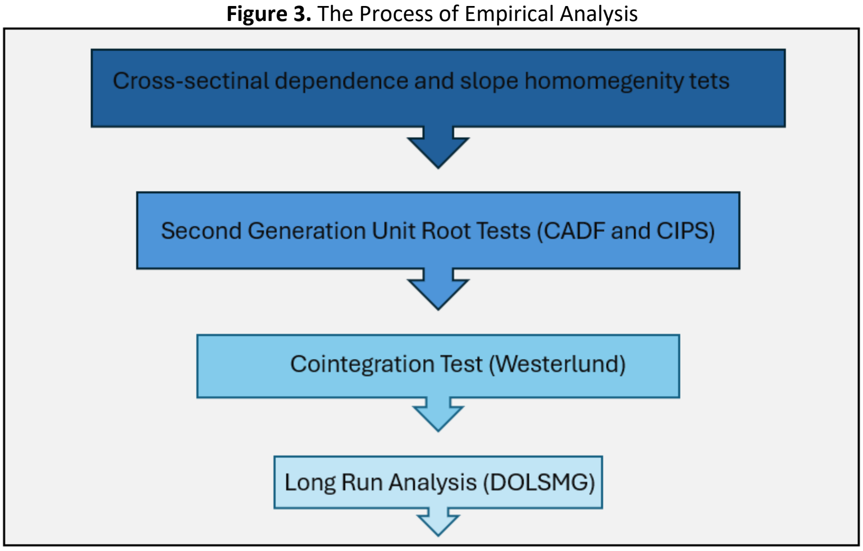
$$P_t = \frac{\acute{\alpha}}{SE(\acute{\alpha})} \quad (12)$$

$$P_\alpha = T\acute{\alpha} \quad (13)$$

The Dynamic Ordinary Least Square Mean Group (DOLSMG) technique introduced by Pedroni (2001) overcomes the endogeneity issue that occurs when there is a correlation between error terms (u_{it}) and explanatory variables. It is achieved by including the lags and leads of independent variables as predictor variables in the model (Wagner & Hlouskova, 2009, p.192). Furthermore, this method also addresses the issue of serial correlation as incorporating the lagged and lead values of the variables. Additionally, this approach can be applied to panel regressions involving heterogeneity as it estimates regression separately for each unit and provides a general result by averaging the individual estimates. Another essential advantage of the method over the first-generation ones (POLS, FE, RE, etc.) is its ability to account for cross-sectional dependency among cross-units, which leads to consistent and reliable findings (Shahbaz et al., 2019, p.48). Compared to the FMOLS method, this technique yields more promising estimators for panel regressions in the long run (Baltagi, 2005, p.258).

The entire process, from the prerequisite tests to the main method used for analysis, is summarized in Figure 3.

Figure 3. The Process of Empirical Analysis



4. Empirical Findings

4.1. Preliminary Test Results

The analysis begins by checking for the presence of cross-sectional dependence (CD) in each series using three tests: the Breusch-Pagan LM, Pesaran Scaled LM, and Bias-corrected Scaled LM tests. The results are presented in Table 3. These three tests are applicable in cases where N<T. The findings clearly indicate that all variables exhibit issues with cross-sectional dependence, as the null hypothesis of no CD is rejected at the 1% significance level.

Table 3. Findings of the Cross-Sectional Dependence Test for Variables

Variables	Breusch-Pagan LM	Pesaran Scaled Lm	Bias-corrected Scaled LM
lnEM	70.89***	13.62***	13.53***
	(0.000)	(0.000)	(0.000)
lnED	57.33***	10.58***	10.50***
	(0.000)	(0.000)	(0.000)
lnHE	184.46***	39.01***	38.93***
	(0.000)	(0.000)	(0.000)
lnEP	235.87***	50.51***	50.42***
	(0.000)	(0.000)	(0.000)
lnGDP	296.58***	64.08***	63.99***
	(0.000)	(0.000)	(0.000)
lnTO	81.50***	15.99***	15.90***
	(0.000)	(0.000)	(0.000)

Note: P-values are provided in parentheses. (*), (**), and (***) refer to the significance level of 1%, 5%, and 10%, respectively[1].

Additionally, the availability of CS for the panel is examined using the same tests applied to the individual series. The findings are reported in Table 4, indicating its presence in the three separate models, as the p-values are lower than 0.01, leading to the rejection of the null hypothesis of non-CS.

Table 4. Findings of the Cross-Sectional Dependence Test for the Models

Models	Breusch-Pagan LM	Pesaran Scaled Lm
Model 1	169.39***	35.64***
$lnEM_{it} = f\ (lnEP_{it}, lnGDP_{it}, lnTO_{it})$	(0.000)	(0.000)
Model 2	69.89***	13.40***
$lnED_{it} = f\ (lnEP_{it}, lnGDP_{it}, lnTO_{it})$	(0.000)	(0.000)
Model 3	142.04***	29.52***
$lnHE_{it} = f\ (lnEP_{it}, lnGDP_{it}, lnTO_{it})$	(0.000)	(0.000)

To check slope homogeneity, which assumes a uniform relationship among units, the homogeneity test introduced by Pesaran and Yamagata (2008) is used. The reason for choosing this test is to account for the presence of cross-sectional dependence (CS). Based on the findings shown in Table 5, the statistics of tilde delta and adjusted delta are greater than the critical values for the three models, indicating that the null hypothesis of slope homogeneity is rejected. This, in turn, demonstrates the presence of heterogeneous slope coefficients.

Table 5. Findings of the Heterogeneity Test for the Models

Models	$\tilde{\Delta}$ Statistic	$\tilde{\Delta}_{adj}$ Statistic
Model 1	12.38***	13.52***
$lnEM_{it} = f\ (lnEP_{it}, lnGDP_{it}, lnTO_{it})$	(0.000)	(0.000)
Model 2	7.55***	8.25***
$lnED_{it} = f\ (lnEP_{it}, lnGDP_{it}, lnTO_{it})$	(0.000)	(0.000)
Model 3	14.09***	15.39***
$lnHE_{it} = f\ (lnEP_{it}, lnGDP_{it}, lnTO_{it})$	(0.000)	(0.000)

To examine the stationarity of the series, the CADF unit root test is preferred due to its ability to address the issue of cross-sectional dependence (CS) by incorporating the lagged and average cross-sectional values of the dependent variable. The findings reported in Table 6 indicate that all variables are non-stationary at their levels. However, after being differenced to the first order, they are integrated of order 1; in other words, they achieve stationarity at their first differences.

Table 6. Findings of the CADF Unit Root Test

	Level [I (0)]		First Difference [I (1)]	
Variables	CADF Statistics	Critical Value (%5)	CADF Statistics	Critical Value (%5)
lnEM	-2.120	-2.33	-3.086***	-2.33
lnED	-1.183	-2.33	-3.604***	-2.33
lnHE	-2.101	-2.33	-3.147***	-2.33
lnEP	-1.752	-2.33	-3.355***	-2.33
lnGDP	-1.974	-2.33	-2.648**	-2.33
lnTO	-1.041	-2.33	-3.439***	-2.33

In addition to the CADF unit root test, the CIPS unit root test derived from CADF, as detailed in the previous section, is also applied here as a robustness check. The results presented in Table 7 are similar to those obtained by CADF, showing that all the variables are non-stationary at

[1] In the following tables, the significance levels of 1%, 5%, and 10% will be represented by *, **, and ***, respectively. Additionally, if applicable, p-values will be reported in parentheses.

their levels but become stationary at their first differences.

Table 7. Findings of the CIPS Unit Root Test

	Level [I (0)]		**First Difference [I (1)]**	
Variables	CIPS Statistics	Critical Value (%5)	CIPS Statistics	Critical Value (%5)
lnEM	-2.290	-2.33	-4.764***	-2.33
lnED	-1.038	-2.33	-4.222***	-2.33
lnHE	-2.085	-2.33	-4.544***	-2.33
lnEP	-1.946	-2.33	-4.328***	-2.33
lnGDP	-1.899	-2.33	-4.179***	-2.33
lnTO	-0.984	-2.33	-5.057***	-2.33

After ensuring that all the series are stationary at their first differences, the cointegration test is applied to check if there is a long-term relationship among them. To ensure the reliability of the results from the cointegration test, the test should be selected based on the fact that the variables are cross-sectionally dependent (CD) and heterogeneous. The cointegration test preferred in this study, introduced by Westerlund (2008), takes into account both cross-sectional correlation and the heterogeneous nature of the coefficients, providing reliable results. The results for all three models are presented in Table 7 under the headings Model 1, Model 2, and Model 3. The results of GT and GA are related to the group-based test, while PT and PA are linked to the entire panel test. The findings show that for all three models, the null hypothesis of GT, PT, and PA statistics is rejected, indicating the existence of a long-run relationship. However, the hypothesis of the GS statistic is not rejected due to the higher p-value, which may be because GT focuses on the average of the individual countries, while GA is based on the pooled average. Since the panel used in this study shows heterogeneity, the GT statistics seem more reliable. At the same time, PT and PA also confirm the presence of cointegration, just as GT does, so these results are interpreted as showing the presence of a long-term relationship between the variables.

Table 8. Results of the Panel Cointegration Test for Model 1

Statistics	Value	Z-Value	P-Value	H_0: No Cointegration
Model 1				
Gt	-3.607***	-3.258	0.001	Rejected
Ga	-4.896	1.930	0.973	Not Rejected
Pt	-8.608***	-4.081	0.000	Rejected
Pa	-12.679**	-1.780	0.038	Rejected
Model 2				
Gt	-3.512***	-3.033	0.001	Rejected
Ga	-12.500	-0.487	0.313	Not Rejected
Pt	-8.504***	-3.984	0.000	Rejected
Pa	-18.411**	-3.734	0.038	Rejected
Model 3				
Gt	-3.454**	-1.927	0.027	Rejected
Ga	-12.728	0.779	0.782	Not Rejected
Pt	-7.539**	-2.158	0.015	Rejected
Pa	-11.500**	-2.254	0.012	Rejected

4.2. DOLS-MG Estimation Results and Discussion

As put forth by the Westerlund (2008) cointegration test, which indicates the presence of cointegration between the series, the effect of energy poverty on gender inequality is examined using the DOLSMG method. This method yields consistent and reliable results in the case of cross-sectional dependence (CS) and heterogeneity of slopes in the long run. Initially, gender inequality in the field of employment is analyzed, and the results are shown in Table 10. As observed, a reduction in energy poverty is associated with a higher level of gender equality in employment. More specifically, a 1% increase in energy usage leads to a 2.91% reduction in gender inequality in ASEAN countries. The possible reason for the reduction effect of access to energy on gender inequality in the labor market may be explained through time channel: The efforts spent by women to access energy in cases of energy deprivation (e.g., gathering wood to light stoves, collecting, cutting, and storing fossil fuels such as wood and dung for cooking household meals) are returned to women as time once access to energy is provided. This additional time allows women to contribute to the household economy by creating opportunities for employment. The reduction in energy poverty, which leads to an increase in women's participation in the labor market, also contributes to an increase in the number of women in employer roles in the labor market. This helps to shift the disparity between male and female employers in favor of women, thereby contributing to a reduction in gender inequality.

GDP and trade openness are also incorporated into the model to analyze their effect on gender inequality in employment as control variables. As an indicator of a country's development level, as GDP rises, income inequality and gender inequality are expected to decline. As anticipated, the negative and significant coefficient of GDP reveals that a 1% increase in the real GDP of these five ASEAN countries is associated with a 0.087% reduction in gender inequality in employment, holding other factors constant.

The effect of trade openness on gender inequality, however, is opposite of that of GDP, as it increases inequality. More specifically, a 1% increase in trade openness leads to a 0.26% increase in gender inequality. When considering the leading sectors involved in exports and imports, the findings support the Heckscher-Ohlin theory. In other words, the sectors engaged in trade, such as automobiles, mining, machinery, and equipment, are predominantly male-dominated fields. Growth in these sectors results in higher employment for men, positioning them more frequently as employers in these areas. This pattern shifts the inequality between female and male employers in favor of men, thus inducing gender inequality.

Table 9. Long Run Results for Gender Inequality in Employment

Variable	Coefficients	t-statistics
lnEP	-0.2912**	-2.243
lnGDP	-0.0870***	-5.782
lnTO	0.2614***	5.418

The analysis results of the effect of energy poverty on gender inequality in the education area are presented in Table 10. The negative and significant coefficient of lnEP indicates that an increase in energy use reduces gender inequality in the education sector in favor of women. In other words, a 1% increase in energy consumption results in a 0.022% increase in the percentage of women enrolled in secondary school compared to the percentage of men enrolled. As previously explained, when access to energy increases, the efficiency of the education system improves due to less dependence on daylight, and the household workload becomes easier and quicker to complete within energy access. This, in turn, increases the percentage of girls attending school and enables a fairer disparity rate in school enrolment between males and females. The effect of control variables shows similar results, parallel to the previous estimates.

Table 10. Long Run Results for Gender Inequality in Education

Variable	Coefficients	t-statistics
lnEP	-0.0221***	-4.842
lnGDP	-0.1126***	3.989
lnTO	0.0251***	4.626

The long-term implications of energy deprivation on gender inequality in the health sector are presented in Table 11. The negative and significant coefficient of the lnEP variable, which represents energy usage, indicates that gender inequality in this field decreases as energy usage increases. Specifically, a 1% increase in energy consumption improves gender equality in the health sector by 0.38% in favor of women. When examining the coefficients of the control variables, while they exhibit similarities in terms of significance with the previously estimated results, it is observed that the coefficient for GDP is positive. Considering that the development of countries increases alongside GDP, it is important to note that measures taken to mitigate risks faced by individuals, particularly male workers employed in heavy industries and other hazardous sectors, may lead to a greater reduction in male mortality compared to female mortality. Consequently, these measures could result in a GDP-driven increase in health sector inequality in favor of men.

Table 11. Long Run Results for Gender Inequality in Health

Variable	Coefficients	t-statistics
lnEP	-0.3778***	-9.77
lnGDP	0.4159***	7.522
lnTO	0.1373***	11.33

These findings of the negative effect of energy poverty on gender inequality in employment, education, and health align with studies conducted by Nguyen and Su (2021). However, compared to the magnitude of the negative coefficients of energy poverty in the three areas, the findings of this study show an opposite pattern to the findings of Nguyen and Su (2021). Since the reduction in energy poverty has the greatest impact on gender inequality in the health aspect, it is expected that women, who use fossil fuels for cooking and firewood for heating in the household throughout the day, are more negatively affected in terms of health compared to men. The second area where energy access most reduces gender inequality is employment. Since women are typically responsible for household chores and childcare, the inability to use household appliances that would ease these tasks due to energy poverty significantly increases the time women spend on these duties. Furthermore, the difficulty of gathering, storing, and burning firewood for heating, lighting, and cooking limits their ability to participate in the workforce or start their own businesses. As a result, the second greatest contribution of energy access to reducing inequality is in the employment sector. Finally, the impact of energy access on gender inequality in education is approximately 15 times less than in the other two sectors. Given that the education level is measured by enrolment in secondary school, and that cultural and social norms often place household chores primarily under women's responsibility, the positive effect of energy access on education is expected to be the smallest, as secondary school-aged girls are not burdened as much as adults.

Conclusion, Policy Recommendations, And Future Studies

With industrialization, the use of machines in production has made electricity an essential input for manufacturing. Furthermore, technological advancements have facilitated human life and enhanced quality of life through household appliances (ranging from heating to lighting, robotic vacuum cleaners to washing machines) and technological devices used in education, healthcare, and other sectors. As a result, the demand for electricity has extended beyond production, becoming a fundamental necessity in every aspect of life. Consequently, energy poverty, generally defined as the lack of access to electricity, and its significant impact on other critical areas of society, has been a subject of many studies. However, except for a few studies, its effect on gender inequality, another substantial societal issue, has not been extensively explored in the literature. For this reason, the impact of energy poverty on gender inequality in three key areas of life, namely employment, health, and education, was analyzed for five ASEAN countries over the 1990–2021 period using the DOLS-MG method to contribute to the literature.

The results of the analysis reveal a positive relationship between energy poverty and gender inequality. In other words, decreasing energy poverty reduces gender inequality in employment, education, and health, favoring women. Among these, the most significant impact of energy access on gender inequality is observed in the health aspect, followed by employment, while the least impact is seen in the education area.

Based on the findings, several policy implications can be suggested. Reducing energy poverty will primarily contribute to achieving SDG 7, which focuses on access to affordable and clean energy, thereby supporting sustainable development. Moreover, a reduction in energy poverty will decrease gender inequality in the three critical areas, contributing to SDG 5, which aims at achieving gender equality, and thus significantly lending support to sustainable development. However, since the most substantial impacts of energy access are observed in employment and health, energy poverty reduction alone is not sufficient to address gender inequality in the education sector. To address inequality in education, policies that encourage sending girls to school should be implemented. Additionally, making education compulsory up to a certain level and imposing penalties on families that do not send their daughters to school could be effective. Furthermore, reducing gender inequality in education and health can enable women from low-income groups to become healthier and more educated, thus more qualified for better positions in the job market, allowing them to earn higher incomes. This, in turn, can reduce income inequality between groups, contributing to SDG 10 (reduced inequality) and SDG 1 (no poverty). Given the potential of energy poverty reduction to address these challenges, it is crucial for policymakers to prioritize this issue and take prompt action to implement solutions.

Future studies in this area can analyze the impact of energy poverty on gender inequality in fields such as policy, governance, or administration. These analyses could also use alternative measures of energy poverty, such as access to clean energy for cooking. Furthermore, comparative analyses could be conducted by dividing two different groups of countries based on specific characteristics instead of focusing on a single country or group of countries.

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