

DOES ELECTRICITY ACCESS MODERATE THE EFFECT OF GENDER INEQUALITY ON ECONOMIC GROWTH? PANEL DATA EVIDENCE FROM ASEAN COUNTRIES

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Abstract:

This study investigates whether electricity access moderates the relationship between gender inequality and economic growth in eight ASEAN countries (Indonesia, Cambodia, Lao PDR, Malaysia, Philippines, Singapore, Thailand, and Vietnam) during 1998–2023. Employing Panel Estimated Generalized Least Squares (EGLS) with Cross-Section Seemingly Unrelated Regression (SUR) as the primary method and Panel Corrected Standard Errors (PCSE) as the alternative, we analyze panel data comprising 208 observations. The dependent variable is GDP growth, while independent variables include the Gender Inequality Index (GII), Access to Electricity (ATE), and their interaction term (GII×ATE). Results from the Panel EGLS Cross-Section SUR model reveal that GII exhibits a negative but statistically insignificant effect on economic growth (coefficient = -4.377, $p = 0.622$), while ATE demonstrates a negative insignificant relationship (coefficient = -0.066, $p = 0.208$). The interaction term shows a positive but insignificant effect (coefficient = 0.016, $p = 0.850$), suggesting that electricity access does not significantly moderate the gender inequality-growth nexus in ASEAN countries during the study period. The PCSE model confirms these findings, indicating robustness of results. These findings contribute to understanding the complex interplay between gender equality, infrastructure development, and economic performance in Southeast Asian economies, offering implications for policymakers seeking to design integrated development strategies.

Keyword: Gender Inequality Index, Economic Growth, Electricity Access, Moderation Effect, ASEAN Countries

1. Introduction

Economic growth remains a fundamental objective for developing countries, particularly within the Association of Southeast Asian Nations (ASEAN), where member states have demonstrated remarkable resilience and expansion over the past three decades (Basri, 2019). The ASEAN region has sustained relatively high economic growth rates despite facing various global challenges, including financial crises, trade tensions, and structural transformation pressures. Understanding the determinants of this growth trajectory requires examining multiple socioeconomic factors that collectively shape development outcomes across diverse national contexts.

Gender inequality has emerged as a critical issue in development economics, with extensive theoretical and empirical literature documenting its multifaceted impacts on economic performance (Hakura et al., 2016). The United Nations Development Programme (UNDP) introduced the Gender Inequality Index (GII) to capture disadvantages faced by women across three dimensions: reproductive health, empowerment, and labor market participation (UNDP, 2025). This composite measure ranges from 0 (perfect equality) to 1 (maximum inequality), providing a comprehensive assessment of gender-based disparities within societies. Recent empirical evidence suggests that gender inequality can impede economic growth by limiting human capital accumulation, reducing labor force participation, and constraining productive capacity (Altuzarra et al., 2021).

Simultaneously, infrastructure development—particularly electricity access—has been recognized as a foundational element for economic advancement in developing economies (World Bank, 2018). Electricity infrastructure enables industrial production, facilitates service sector activities, enhances educational opportunities, and improves household welfare (Magnani & Vaona, 2016). In ASEAN countries, substantial variations persist in electricity access rates, ranging from near-universal coverage in developed member states like Singapore and Malaysia to significant gaps in rural areas of

Cambodia, Lao PDR, and Vietnam. These disparities reflect broader developmental heterogeneity within the region and potentially influence growth trajectories through multiple channels.

The theoretical relationship between gender inequality and economic growth operates through several mechanisms. First, gender disparities in education reduce the overall stock of human capital available for productive activities, thereby constraining economic potential (Altuzarra et al., 2021). Second, restrictions on female labor force participation limit the effective utilization of human resources, reducing aggregate output and productivity (Alwago, 2023). Third, gender inequality in political representation and decision-making processes may result in suboptimal policy choices that fail to maximize social welfare (Nathan et al., 2022). These mechanisms suggest a generally negative relationship between gender inequality and economic growth, although empirical findings have shown considerable variation across contexts and methodological approaches.

Infrastructure development, particularly electricity access, may influence this relationship in multiple ways. On one hand, improved electricity access can mitigate some negative effects of gender inequality by enabling women's economic participation through home-based enterprises, facilitating access to information and communication technologies, and reducing time burdens associated with traditional energy sources (ESMAP, 2018). On the other hand, the benefits of electricity infrastructure may be distributed unequally across gender lines, potentially reinforcing existing disparities if women lack equal access to productive assets, financial resources, and entrepreneurial opportunities (World Bank, 2018). This suggests that electricity access might serve as a moderating variable in the gender inequality-growth relationship, although the direction and magnitude of this moderation effect remains an empirical question.

Despite extensive research on both gender inequality and infrastructure development as determinants of economic growth, limited attention has been paid to their interactive effects, particularly in the context of developing regions such as ASEAN. While studies have examined gender inequality's direct impact on growth (Altuzarra et al., 2021; Alwago, 2023) and electricity access as a growth determinant ((Magnani & Vaona, 2016; Navarro et al., 2024), few have explicitly investigated whether infrastructure development moderates the gender-growth relationship. This gap is particularly salient for ASEAN countries, which exhibit substantial heterogeneity in both gender equality indicators and infrastructure development levels, providing an ideal setting for examining these interactive dynamics.

The ASEAN context offers several advantages for investigating these relationships. First, the region encompasses countries at varying stages of economic development, from high-income Singapore to lower-middle-income Cambodia and Lao PDR, enabling analysis of how development stage influences the gender inequality-growth-infrastructure nexus. Second, ASEAN countries have implemented diverse policy approaches to gender equality and infrastructure development, creating natural variation in key variables of interest. Third, the availability of consistent time-series data from international organizations such as the World Bank and UNDP facilitates rigorous panel data analysis. Fourth, ASEAN's commitment to regional economic integration through the ASEAN Economic Community (AEC) framework makes understanding these relationships particularly relevant for coordinated policy development (Magliveras & Naldi, 2021).

This study contributes to the existing literature in several important ways. First, it explicitly examines the moderating role of electricity access in the relationship between gender inequality and economic growth, addressing a significant gap in empirical research. Second, it employs advanced panel data techniques—Panel EGLS with Cross-Section SUR and PCSE—that account for cross-sectional dependence and heteroskedasticity, common characteristics of macroeconomic panel data that conventional methods often fail to address adequately (Bai et al., 2019). Third, it focuses specifically on ASEAN countries over a 26-year period (1998–2023), providing insights into a dynamic and economically significant region that has received insufficient attention in gender-infrastructure-growth research. Fourth, the study utilizes the GII as a comprehensive measure of gender inequality, capturing multiple dimensions beyond simple educational or labor force participation gaps.

The research question guiding this investigation is: Does electricity access moderate the effect of gender inequality on economic growth in ASEAN countries during 1998–2023? This question is addressed through econometric analysis of balanced panel data encompassing eight ASEAN member states with complete data availability across all study variables. The analysis tests whether the interaction between GII and electricity access exhibits a statistically significant relationship with GDP growth, indicating a moderation effect. Additionally, we examine the direct effects of both gender inequality and electricity access on economic growth to provide a comprehensive understanding of these relationships.

The remainder of this paper is organized as follows. Section 2 presents the research methodology, including data sources, variable definitions, and econometric techniques. Section 3 reports empirical results, discusses key findings, and links them to research objectives. Section 4 concludes with a synthesis

of main findings, implications for theory and practice, research limitations, and suggestions for future research.

2. Research Methods

2.1 Research Object, Time, and Location

This study examines the moderating effect of electricity access on the relationship between gender inequality and economic growth across selected ASEAN member states. The research object comprises eight ASEAN countries: Indonesia, Cambodia, Lao PDR, Malaysia, Philippines, Singapore, Thailand, and Vietnam. These countries were selected based on data availability criteria, specifically the requirement for complete observations across all study variables during the entire 26-year research period from 1998 to 2023.

The selection process explicitly excluded three ASEAN member states due to incomplete GII data coverage. Brunei Darussalam was excluded because GII data became available only from 2016, Myanmar due to data availability beginning in 2015, and Timor-Leste because GII observations commenced in 2002. While GDP growth (GDPg) and Access to Electricity (ATE) data are available for all ASEAN countries throughout the study period, the GII's limited temporal coverage for these three countries precluded their inclusion in the analysis. This exclusion ensures data consistency and maintains the balanced panel structure necessary for robust econometric estimation (Wooldridge, 2010).

The eight countries included in the analysis represent substantial diversity in terms of economic development levels, institutional quality, and policy environments. Singapore represents a high-income, developed economy with near-perfect electricity access and relatively low gender inequality. Malaysia and Thailand constitute upper-middle-income countries with well-developed infrastructure and moderate gender equality indicators. Indonesia, Philippines, and Vietnam are lower-middle-income economies experiencing rapid economic transformation and infrastructure expansion. Cambodia and Lao PDR represent the least developed economies in the sample, with ongoing challenges in both gender equality and electricity access. This heterogeneity enables examination of relationships across varying development contexts within a single regional framework.

The temporal scope spans 26 years, from 1998 to 2023, encompassing critical periods in ASEAN's economic development, including the aftermath of the 1997–1998 Asian Financial Crisis, the 2008 Global Financial Crisis, and the COVID-19 pandemic. This extended time frame allows for analysis of both short-term fluctuations and long-term structural relationships while capturing the effects of major economic shocks on growth dynamics. The balanced panel structure yields 208 observations (8 countries × 26 years), providing adequate statistical power for panel data analysis techniques.

2.2 Data Collection Techniques

This study employs secondary data obtained from authoritative international sources, specifically the World Bank's World Development Indicators (WDI) database and the United Nations Development Programme's (UNDP) Human Development Reports. The reliance on internationally standardized data ensures consistency, comparability, and methodological rigor across countries and over time.

The dependent variable, GDP Growth (GDPg), is defined as the annual percentage growth rate of gross domestic product at constant prices. This variable was extracted from the World Bank's WDI database, which compiles national accounts data following System of National Accounts (SNA) guidelines. GDP growth serves as the primary indicator of economic performance, capturing the annual rate of change in overall economic output and reflecting the combined effects of productivity improvements, capital accumulation, and labor force expansion.

The primary independent variable, Gender Inequality Index (GII), was obtained from UNDP's Human Development Reports. The GII is a composite index reflecting gender-based disadvantages across three dimensions: reproductive health (measured by maternal mortality ratio and adolescent birth rate), empowerment (measured by proportion of parliamentary seats held by women and secondary education attainment levels), and labor market participation (measured by female labor force participation rate). The index ranges from 0 to 1, with higher values indicating greater gender inequality. This comprehensive measure captures multiple facets of gender disparity beyond simple labor force participation or educational enrollment gaps, providing a more holistic assessment of gender-related development challenges.

The moderating variable, Access to Electricity (ATE), represents the percentage of population with access to electricity, obtained from the World Bank's WDI database. This indicator reflects the proportion of the total population with access to electricity services, whether through grid connection or off-grid systems. ATE serves as a proxy for infrastructure development and represents a fundamental input for modern economic activities. The variable exhibits substantial variation across the sample, ranging from near-universal access in developed ASEAN members to significantly lower coverage in

less developed countries, particularly during earlier years of the study period.

An interaction term (GII×ATE) was constructed by multiplying the GII and ATE variables to capture potential moderating effects. In regression analysis, interaction terms allow examination of whether the effect of one independent variable (GII) on the dependent variable (GDPg) varies depending on the level of another variable (ATE). A statistically significant coefficient on this interaction term would indicate that electricity access moderates the relationship between gender inequality and economic growth, with the sign of the coefficient indicating the direction of moderation (Park & Yi, 2022).

Data validation procedures were implemented to ensure accuracy and consistency. First, observations were checked for temporal consistency and completeness across all variables. Second, outlier detection methods identified extreme values requiring verification against original sources. Third, variable definitions and measurement units were standardized across countries and time periods. These procedures enhanced data quality and reliability, providing a solid foundation for subsequent econometric analysis.

2.3 Data Analysis Techniques

This study employs advanced panel data econometric techniques to analyze the relationship between gender inequality, electricity access, and economic growth. Panel data analysis offers several advantages over pure cross-sectional or time-series approaches, including increased degrees of freedom, enhanced efficiency in parameter estimation, and the ability to control for unobserved heterogeneity across units and time periods (Baltagi, 2021).

The analytical strategy proceeds through several stages. First, descriptive statistics and correlation analysis provide preliminary insights into data characteristics and bivariate relationships among variables. Second, panel unit root tests assess the stationarity properties of variables, determining whether they exhibit trend-stationary or difference-stationary behavior. Third, diagnostic tests examine the presence of cross-sectional dependence and heteroskedasticity, common characteristics of macroeconomic panel data that violate standard ordinary least squares (OLS) assumptions. Fourth, model selection procedures determine the appropriate specification among pooled OLS, fixed effects, and random effects alternatives. Fifth, primary estimation employs Panel EGLS with Cross-Section SUR weights to address identified diagnostic issues. Sixth, robustness checks using PCSE verify the stability of findings across alternative estimation approaches.

Descriptive Statistics and Correlation Analysis

Descriptive statistics characterize the central tendency, dispersion, and distributional properties of key variables. Mean values indicate average levels, while standard deviations measure variability across observations. Minimum and maximum values identify the range of observed data. Skewness coefficients assess distributional asymmetry, and kurtosis measures the heaviness of distributional tails relative to the normal distribution. The Jarque-Bera test evaluates whether variables follow normal distributions, with statistically significant test statistics indicating departures from normality.

Correlation analysis examines linear associations among variables. The correlation matrix presents pairwise correlation coefficients ranging from -1 (perfect negative correlation) to +1 (perfect positive correlation). This analysis provides preliminary evidence regarding potential multicollinearity issues and expected relationships among variables. However, correlation coefficients capture only bivariate relationships and do not control for confounding factors, necessitating multivariate regression analysis for causal inference.

Panel Unit Root Tests

Panel unit root tests determine whether variables exhibit stationary properties or contain unit roots, which would indicate trending behavior. This study employs four complementary tests: Levin, Lin & Chu (LLC), Im, Pesaran & Shin (IPS), ADF-Fisher Chi-square, and PP-Fisher Chi-square. The LLC test assumes a common unit root process across cross-sections, while IPS, ADF-Fisher, and PP-Fisher tests allow for individual unit root processes, accommodating heterogeneity across countries.

For variables exhibiting unit roots in levels, first-difference transformations are tested to determine integration order. Variables integrated of order one, denoted $I(1)$, become stationary after first-differencing. Establishing stationarity is essential for valid statistical inference, as regression involving non-stationary variables can produce spurious results with misleading statistical significance.

Model Selection Tests

Three panel data model specifications are considered: pooled OLS, fixed effects (FE), and random effects (RE). Pooled OLS assumes homogeneous intercepts and slope coefficients across cross-sections, treating the panel as a single pooled dataset. Fixed effects allow for cross-section-specific intercepts while maintaining common slope coefficients, controlling for time-invariant unobserved heterogeneity. Random effects treat cross-section-specific effects as random draws from a common distribution, increasing efficiency when certain assumptions hold.

The Redundant Fixed Effects Test (F-test and Chi-square test) evaluates whether cross-section fixed effects are jointly significant. Statistically significant test results favor the fixed effects specification over pooled OLS. The Hausman Test compares fixed effects and random effects estimators, testing whether the random effects assumption of orthogonality between effects and regressors is satisfied. Rejection of the null hypothesis indicates correlation between effects and regressors, favoring the fixed effects specification.

Cross-Sectional Dependence and Heteroskedasticity Tests

The Breusch-Pagan Lagrange Multiplier (LM) test examines cross-sectional dependence in panel residuals. Contemporary correlation among country-specific shocks is common in macroeconomic data due to regional integration, common shocks, and spillover effects. The null hypothesis assumes no cross-sectional correlation, with rejection indicating significant contemporaneous dependencies requiring specialized estimation techniques.

Heteroskedasticity refers to non-constant error variance across observations. In panel data, heteroskedasticity often manifests as varying error variances across cross-sections due to differences in country size, institutional quality, or measurement error. While heteroskedasticity does not bias coefficient estimates under standard assumptions, it produces inefficient estimates and biased standard errors, invalidating conventional inference procedures.

Primary Estimation Method: Panel EGLS with Cross-Section SUR

Given the presence of cross-sectional dependence and heteroskedasticity confirmed by diagnostic tests, this study employs Panel Estimated Generalized Least Squares (EGLS) with Cross-Section Seemingly Unrelated Regression (SUR) weights as the primary estimation method. This technique, also known as Feasible Generalized Least Squares (FGLS), addresses both cross-sectional correlation and heteroskedasticity by estimating a full error covariance matrix and applying appropriate weights in estimation (Bai et al., 2019).

The SUR framework treats equations for different cross-sections as a system, allowing for contemporaneous correlation among cross-section-specific error terms. By estimating the covariance structure of errors and applying GLS transformation, the procedure produces more efficient estimates than OLS when cross-sectional dependence exists. The Cross-Section SUR specification focuses on modeling contemporary correlation across countries while allowing for heteroskedastic error variances, reflecting the heterogeneous nature of ASEAN economies (Beck & Katz, 1995).

The estimating equation takes the form:

$$GDP_{git} = \alpha + \beta_1 GII_{it} + \beta_2 ATE_{it} + \beta_3 (GII \times ATE)_{it} + \varepsilon_{it}$$

where i indexes countries ($i = 1, \dots, 8$), t indexes time periods ($t = 1998, \dots, 2023$), α represents the intercept, β_1 , β_2 , and β_3 are slope coefficients, and ε_{it} denotes the error term. The coefficient β_3 on the interaction term captures the moderating effect of electricity access on the gender inequality-growth relationship. A statistically significant β_3 indicates that the marginal effect of gender inequality on growth varies with the level of electricity access.

Alternative Estimation Method: Panel Corrected Standard Errors (PCSE)

Panel Corrected Standard Errors, developed by Beck and Katz (1995), provide an alternative approach to addressing cross-sectional dependence and heteroskedasticity. Rather than transforming data through GLS weighting, PCSE employs OLS estimation with robust standard error correction that accounts for contemporaneous correlation and heteroskedastic errors. This method produces consistent standard errors with superior small-sample properties compared to FGLS under certain conditions, particularly when the time dimension is small relative to the cross-sectional dimension.

The PCSE approach estimates the same regression equation using OLS, then calculates robust standard errors that incorporate the estimated error covariance structure. This yields valid inference even in the presence of cross-sectional dependence and heteroskedasticity. Including PCSE results provides robustness checks, demonstrating whether primary findings are sensitive to estimation method choice.

Statistical Inference

Statistical significance is evaluated using conventional significance levels: 1% ($p < 0.01$), 5% ($p < 0.05$), and 10% ($p < 0.10$). Coefficient estimates measure the magnitude of relationships, while standard errors quantify estimation uncertainty. T-statistics test whether coefficients differ significantly from zero. The coefficient of determination (R-squared) measures the proportion of variance in the dependent variable explained by the model, while adjusted R-squared accounts for the number of regressors. F-statistics test joint significance of all regressors, with statistically significant results indicating that the model as a whole provides explanatory power beyond random chance.

3. Results and Discussion

3.1 Research Findings

Descriptive Statistics

Table 1 presents descriptive statistics for all variables included in the analysis. The sample comprises 208 balanced panel observations across eight ASEAN countries over 26 years (1998–2023).

Table 1: Descriptive Statistics of Variables

Statistic	GDPg	GII	ATE	GII×ATE
Mean	5.044	0.382	85.761	30.604
Median	5.512	0.401	96.000	32.585
Maximum	14.520	0.642	100.000	50.282
Minimum	-13.127	0.030	8.820	3.000
Std. Dev.	3.549	0.151	22.268	12.320
Skewness	-1.683	-0.611	-1.997	-0.620
Kurtosis	8.606	2.709	6.084	2.620
Jarque-Bera	370.504	13.664	220.663	14.590
Probability	0.000	0.001	0.000	0.001
Observations	208	208	208	208

Source: Authors' calculations using EViews 13.

GDP growth (GDPg) averages 5.044% annually across the sample, with substantial variation evidenced by a standard deviation of 3.549 percentage points. The minimum value of -13.127% reflects severe economic contraction during crisis periods, likely corresponding to the 1997–1998 Asian Financial Crisis impact or the 2020 COVID-19 pandemic shock. The maximum growth rate of 14.520% indicates exceptionally strong expansion, possibly reflecting post-crisis recovery or rapid catch-up growth in less developed economies. The distribution exhibits negative skewness (-1.683) and high kurtosis (8.606), indicating left tail asymmetry with occasional severe contractions and fatter tails than the normal distribution. The Jarque-Bera test strongly rejects normality ($p < 0.001$), confirming non-normal distributional properties.

The Gender Inequality Index (GII) averages 0.382, indicating moderate gender inequality across ASEAN countries. The relatively low minimum value (0.030) corresponds to Singapore's advanced gender equality status, while the maximum (0.642) reflects substantial inequality in less developed member states during earlier periods. The standard deviation (0.151) demonstrates considerable cross-country and temporal variation. Negative skewness (-0.611) suggests the distribution is skewed toward higher equality (lower GII values), while kurtosis near three indicates approximately normal tail behavior. The Jarque-Bera test rejects normality ($p = 0.001$), though less strongly than for GDP growth.

Access to Electricity (ATE) averages 85.761%, with extreme variation ranging from 8.820% to 100%. This wide range reflects the developmental heterogeneity within ASEAN, where developed countries achieved universal access early in the sample period while less developed countries experienced substantial expansion over time. The high standard deviation (22.268 percentage points) confirms substantial heterogeneity. Strong negative skewness (-1.997) indicates concentration toward higher access levels with a pronounced left tail representing low-access observations. High kurtosis (6.084) reflects heavy tails, and the Jarque-Bera test strongly rejects normality ($p < 0.001$).

Correlation Analysis

Table 2 presents the correlation matrix among study variables.

Table 2: Correlation Matrix

	GDPg	GII	ATE	GII×ATE
GDPg	1.000	0.163	-0.309	-0.122
GII	0.163	1.000	-0.636	0.570
ATE	-0.309	-0.636	1.000	0.267
GII×ATE	-0.122	0.570	0.267	1.000

Source: Authors' calculations using EViews 13.

GDP growth exhibits a weak positive correlation with GII (0.163), suggesting a counterintuitive positive bivariate relationship between gender inequality and growth. However, this unconditional correlation does not control for confounding factors and may reflect spurious correlation due to omitted variables. GDPg shows a moderate negative correlation with ATE (-0.309), which is unexpected given theoretical predictions that electricity access promotes growth. This negative correlation may reflect reverse causality or composition effects, as countries with initially lower electricity access experienced

rapid catch-up growth during the sample period.

GII and ATE exhibit a strong negative correlation (-0.636), indicating that countries with better electricity access tend to have lower gender inequality. This relationship is consistent with the hypothesis that infrastructure development facilitates gender equality by enabling women's economic participation and reducing traditional constraints. The interaction term (GII×ATE) shows moderate positive correlations with both GII (0.570) and ATE (0.267), which is expected given its multiplicative construction. The relatively high correlation between the interaction term and its component variables raises potential multicollinearity concerns, though this is inherent to interaction terms and can be addressed through mean-centering or interpretation of marginal effects.

Panel Unit Root Tests

Panel unit root tests were conducted to assess stationarity properties of all variables. Table 3 summarizes results for each variable.

Table 3: Panel Unit Root Test Results

Variable	Test	Statistic	Prob.	Decision
GDPg	LLC	-2.510	0.006	Stationary
	IPS	-6.109	0.000	Stationary
	ADF-Fisher	71.376	0.000	Stationary
	PP-Fisher	131.371	0.000	Stationary
GII	LLC	-2.918	0.002	Stationary
	IPS	0.155	0.562	Non-stationary
	ADF-Fisher	22.220	0.136	Non-stationary
	PP-Fisher	25.138	0.067	Non-stationary
D(GII)	LLC	-4.498	0.000	Stationary
	IPS	-5.751	0.000	Stationary
	ADF-Fisher	66.770	0.000	Stationary
	PP-Fisher	110.261	0.000	Stationary
ATE	LLC	-2.119	0.017	Stationary
	IPS	0.246	0.597	Non-stationary
	ADF-Fisher	13.841	0.462	Non-stationary
	PP-Fisher	27.229	0.018	Stationary
D(ATE)	LLC	-6.668	0.000	Stationary
	IPS	-7.668	0.000	Stationary
	ADF-Fisher	80.404	0.000	Stationary
	PP-Fisher	141.930	0.000	Stationary

Source: Authors' calculations using EViews 13.

GDP growth (GDPg) is stationary at levels according to all four tests, with p-values well below 0.01. This result is expected, as growth rates typically fluctuate around a stable mean without persistent trends. Stationarity of the dependent variable is desirable for regression analysis, as it ensures valid statistical inference.

The Gender Inequality Index (GII) exhibits mixed results across tests. The LLC test indicates stationarity ($p = 0.002$), while IPS, ADF-Fisher, and PP-Fisher tests fail to reject the unit root null hypothesis at conventional significance levels. This divergence reflects differences in test assumptions, with LLC assuming a common unit root process and others allowing for individual processes. Given mixed evidence and the theoretical expectation that institutional variables like gender equality evolve gradually over time, first-differencing was applied. All tests unanimously confirm that D(GII) is stationary, indicating that GII is integrated of order one, I(1).

Access to Electricity (ATE) also shows mixed stationarity results. The LLC test and PP-Fisher test indicate stationarity, while IPS and ADF-Fisher tests do not reject the unit root hypothesis. Given this ambiguity and the theoretical understanding that infrastructure variables typically exhibit trending behavior, first-differencing was conducted. All tests confirm that D(ATE) is stationary, suggesting that ATE is I(1). The presence of unit roots in GII and ATE indicates that these variables exhibit trending behavior over the sample period, consistent with gradual improvements in gender equality and electricity infrastructure across ASEAN countries.

Model Selection Tests

The Redundant Fixed Effects Test examines whether cross-section fixed effects are jointly significant, comparing pooled OLS against fixed effects specification. Results indicate that cross-section fixed effects are statistically significant (F-statistic = 2.212, $p = 0.035$; Chi-square = 15.735, $p = 0.028$),

favoring the fixed effects model over pooled OLS. This finding suggests that unobserved time-invariant country-specific characteristics significantly influence GDP growth, necessitating control through fixed effects.

The Hausman Test compares fixed effects and random effects estimators to determine which specification is appropriate. The test statistic is 1.332 with 3 degrees of freedom, yielding a p-value of 0.721. This result fails to reject the null hypothesis of no systematic difference between fixed and random effects estimators, indicating that the random effects assumption of orthogonality between country-specific effects and regressors is satisfied. Consequently, the random effects model is preferred over fixed effects on efficiency grounds.

The Lagrange Multiplier Test for Random Effects examines whether random effects are present. Multiple test variants (Breusch-Pagan, Honda, King-Wu, Standardized Honda, Standardized King-Wu, and Gourieroux et al.) all yield highly significant results ($p < 0.05$ for cross-section dimension), confirming the presence of cross-sectional random effects. This finding supports the random effects specification over pooled OLS.

Based on these tests, the random effects model is the preferred baseline specification among the three alternatives (pooled OLS, fixed effects, random effects). However, further diagnostic tests revealed the presence of cross-sectional dependence and heteroskedasticity, necessitating advanced estimation techniques beyond standard random effects.

Cross-Sectional Dependence Test

The Residual Cross-Section Dependence Test evaluates whether panel residuals exhibit contemporaneous correlation across countries. Three complementary tests were applied: Breusch-Pagan LM, Pesaran Scaled LM, and Pesaran CD. All three tests yield highly significant results ($p < 0.001$), strongly rejecting the null hypothesis of no cross-sectional dependence. This finding confirms substantial contemporaneous correlation among ASEAN country residuals, likely reflecting regional economic integration, common shocks, and spillover effects. The presence of cross-sectional dependence violates standard panel regression assumptions and necessitates estimation techniques that explicitly model and correct for this correlation structure.

Primary Estimation Results: Panel EGLS with Cross-Section SUR

Given the confirmed presence of cross-sectional dependence and heteroskedasticity, Panel EGLS with Cross-Section SUR weights was employed as the primary estimation method. Table 4 presents the estimation results.

Table 4: Panel EGLS Cross-Section SUR Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	12.643	5.270	2.399	0.017
GII	-4.377	8.864	-0.494	0.622
ATE	-0.066	0.052	-1.264	0.208
GII×ATE	0.016	0.086	0.190	0.850
Model Statistics				
Weighted R-squared	0.246			
Adjusted R-squared	0.235			
S.E. of regression	0.993			
F-statistic	22.207			
Prob(F-statistic)	0.000			
Durbin-Watson stat	1.464			

Source: Authors' calculations using EViews 13.

The intercept estimate is 12.643, statistically significant at the 5% level ($p = 0.017$), indicating a positive baseline GDP growth rate when all independent variables equal zero. However, this interpretation has limited economic meaning given that zero values for GII and ATE are outside the observed data range.

The coefficient on GII is -4.377 with a standard error of 8.864, yielding a t-statistic of -0.494 and p-value of 0.622. This result indicates that gender inequality exhibits a negative but statistically insignificant relationship with economic growth. The negative sign aligns with theoretical expectations that greater gender inequality (higher GII values) impedes economic growth by limiting human capital utilization and productive capacity. However, the lack of statistical significance suggests that, after controlling for electricity access and cross-sectional dependence, the direct effect of gender inequality on growth is not robustly detected in this sample.

The coefficient on ATE is -0.066 with a standard error of 0.052, producing a t-statistic of -1.264 and p-value of 0.208. This finding indicates a negative but statistically insignificant relationship between electricity access and GDP growth. The negative sign is counterintuitive given theoretical expectations that infrastructure development promotes growth. However, statistical insignificance suggests that the direct effect of electricity access on growth is not strongly evident in the ASEAN context during this period, possibly due to confounding factors, measurement issues, or non-linear relationships.

The interaction term coefficient (GII×ATE) is 0.016 with a standard error of 0.086, yielding a t-statistic of 0.190 and p-value of 0.850. This result indicates that the interaction between gender inequality and electricity access exhibits a positive but statistically insignificant relationship with economic growth. The lack of statistical significance is the critical finding: it suggests that electricity access does not significantly moderate the effect of gender inequality on economic growth in ASEAN countries during 1998–2023. In other words, the marginal effect of gender inequality on growth does not vary systematically with the level of electricity access.

The model's weighted R-squared is 0.246, indicating that approximately 24.6% of the variance in GDP growth is explained by the three independent variables after accounting for the SUR weighting structure. The adjusted R-squared of 0.235 accounts for the number of regressors. The F-statistic is 22.207 with a probability of 0.000, strongly rejecting the null hypothesis that all slope coefficients are jointly zero. This indicates that the model as a whole possesses significant explanatory power despite individual coefficient insignificance. The Durbin-Watson statistic of 1.464 suggests some negative serial correlation in residuals, though panel data methods partially account for this through the error covariance structure.

Alternative Estimation Results: Panel Corrected Standard Errors (PCSE)

To verify robustness, the model was re-estimated using PCSE. Table 5 presents these results.

Table 5: Panel PCSE Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	12.248	8.631	1.419	0.157
GII	-4.798	14.503	-0.331	0.741
ATE	-0.075	0.087	-0.861	0.390
GII×ATE	0.034	0.142	0.241	0.810
Model Statistics				
R-squared	0.097			
Adjusted R-squared	0.084			
S.E. of regression	3.397			
F-statistic	7.323			
Prob(F-statistic)	0.000			
Durbin-Watson stat	1.467			

Source: Authors' calculations using EViews 13.

The PCSE results are qualitatively consistent with Panel EGLS findings. The intercept remains positive (12.248) but loses statistical significance ($p = 0.157$). GII exhibits a negative coefficient (-4.798) that is statistically insignificant ($p = 0.741$). ATE shows a negative coefficient (-0.075) that is insignificant ($p = 0.390$). Most importantly, the interaction term (GII×ATE) remains positive (0.034) and statistically insignificant ($p = 0.810$), confirming the primary finding that electricity access does not significantly moderate the gender inequality-growth relationship.

Standard errors in the PCSE model are generally larger than in the Panel EGLS SUR model, reflecting the different approaches to variance-covariance estimation. The unweighted R-squared of 0.097 is substantially lower than the weighted R-squared from Panel EGLS (0.246), which is expected given that PCSE does not apply weighting transformations. The F-statistic remains significant ($p < 0.001$), indicating joint significance of regressors. Overall, PCSE results provide robustness confirmation that primary findings are not artifacts of the specific estimation method employed.

3.2 Discussion

The empirical findings reveal several important insights regarding the relationships among gender inequality, electricity access, and economic growth in ASEAN countries. The central research question concerned whether electricity access moderates the effect of gender inequality on economic growth. The statistical evidence indicates that it does not: the interaction term coefficient is statistically insignificant in both primary (Panel EGLS SUR) and alternative (PCSE) specifications. This null finding carries substantive implications for understanding development dynamics in Southeast Asia.

The Non-Significant Interaction Effect

The absence of a significant moderating effect suggests that electricity infrastructure development does not fundamentally alter the relationship between gender inequality and economic growth in the ASEAN context during 1998–2023. This finding contrasts with theoretical expectations derived from development literature suggesting that infrastructure improvements could mitigate negative effects of gender inequality by enabling women's economic participation (ESMAP, 2018; World Bank, 2018). Several explanations may account for this null result.

First, the relationship between gender inequality and growth may operate through channels that are relatively independent of electricity infrastructure. Gender disparities in education, health, and political representation—all components of the GII—influence economic outcomes through mechanisms such as human capital accumulation, political economy dynamics, and social norms that are not directly mediated by electricity access. While electricity enables certain economic activities, its presence does not automatically translate into equitable opportunities if underlying gender barriers persist in education systems, labor markets, and social institutions.

Second, electricity access may be a necessary but insufficient condition for translating gender equality into economic growth. Even with universal electricity access, structural barriers such as discriminatory labor market practices, unequal property rights, limited access to financial services, and cultural norms restricting women's economic participation may prevent women from fully leveraging infrastructure improvements. Studies from Sub-Saharan Africa and South Asia have documented that electricity access alone does not guarantee economic empowerment when complementary enabling conditions are absent (Magnani & Vaona, 2016).

Third, measurement and aggregation issues may obscure relationships that exist at finer scales. The GII is a composite index aggregating multiple dimensions of gender inequality, while ATE represents a simple access percentage. The interaction between these aggregate measures may fail to capture more nuanced relationships that operate at specific dimensional intersections. For example, electricity access might significantly moderate the effect of female labor force participation on growth while having little interaction with reproductive health indicators, but these differential effects are not detectable when using composite measures.

Fourth, the ASEAN context is characterized by substantial heterogeneity, with countries at vastly different development stages and with diverse policy environments. The pooled estimation approach, while accounting for cross-sectional dependence and heteroskedasticity, imposes common slope coefficients across countries. If the moderating effect of electricity access varies systematically across development levels—perhaps being more pronounced in less developed countries where marginal improvements in access have larger impacts—the average effect estimated across the heterogeneous panel may be indistinguishable from zero. Country-specific analyses or interaction with development stage indicators could reveal heterogeneous moderation effects masked in the pooled estimation.

Direct Effects of Gender Inequality and Electricity Access

Both gender inequality (GII) and electricity access (ATE) exhibit statistically insignificant direct effects on GDP growth in the preferred specifications. For GII, the negative coefficient sign aligns with theoretical predictions that gender inequality hinders growth, consistent with recent empirical evidence from developing countries (Altuzarra et al., 2021; Alwago, 2023). However, the lack of statistical significance suggests that, after controlling for electricity infrastructure and cross-sectional dependencies, the direct effect of gender inequality on growth is not robustly detected in this sample.

Several factors may explain the insignificant GII coefficient. First, reverse causality could attenuate the estimated relationship: while gender inequality may constrain growth, economic development itself influences gender equality outcomes through increased educational opportunities, structural transformation, and institutional changes. Panel data methods employed here do not fully address endogeneity, potentially biasing coefficients toward zero. Second, the long time period (26 years) encompasses substantial structural changes in ASEAN economies, including shifts from agriculture to manufacturing and services, financial crises, and policy reforms. These structural breaks may introduce heterogeneity in the gender inequality-growth relationship over time, reducing the precision of estimates based on pooled long-run relationships.

The insignificant negative coefficient on electricity access is more puzzling given extensive literature documenting positive growth effects of infrastructure development (Navarro et al., 2024). Several explanations merit consideration. First, the sample period includes countries that achieved near-universal electricity access early (Singapore, Malaysia, Thailand), where marginal increases in coverage have negligible growth impacts, alongside countries experiencing rapid electrification (Cambodia, Lao PDR) during catch-up growth phases. These compositional differences may obscure the positive relationship evident in cross-sectional studies focusing on countries with lower baseline access. Second,

electricity access as measured here (percentage of population with access) captures extensive margin expansion but not intensive margin improvements such as reliability, quality, or affordability. These intensive margin factors may be more relevant for growth in countries approaching universal access. Third, temporal dynamics may matter: infrastructure investments require time to generate productivity gains, and immediate correlations between access expansion and annual growth rates may not capture longer-run benefits.

Consistency with Regional Economic Dynamics

The findings align with broader understanding of ASEAN economic dynamics during 1998–2023. The region experienced substantial growth driven primarily by export-oriented manufacturing, foreign direct investment, and regional integration (Basri, 2019). Gender equality improvements and infrastructure expansion occurred alongside these processes but may not have been primary drivers of short-term growth fluctuations. Instead, factors such as global demand conditions, commodity prices, exchange rate movements, and macroeconomic policies likely exerted more immediate influences on annual growth rates.

Furthermore, ASEAN's heterogeneity complicates identification of common relationships. Singapore's growth dynamics differ fundamentally from Cambodia's, with different roles for gender equality and infrastructure. Pooled estimation necessarily averages across these diverse contexts, potentially masking important country-specific relationships. The significant cross-sectional dependence confirmed by diagnostic tests indicates that regional integration and common shocks influence growth patterns, but these factors may dominate the explanatory power of time-varying country-specific characteristics like gender inequality and electricity access.

Methodological Considerations

The robustness of null findings across both Panel EGLS SUR and PCSE specifications strengthens confidence in results. Both methods address cross-sectional dependence and heteroskedasticity but employ different approaches: SUR applies GLS weighting while PCSE adjusts standard errors. The consistency of findings across these alternatives suggests that results are not artifacts of specific estimation assumptions. However, both methods share common limitations, including the inability to fully address endogeneity through instrumental variables or dynamic panel techniques.

The presence of unit roots in GII and ATE, requiring first-differencing for stationarity, raises considerations about the appropriate specification for long-run relationships. While level-form regressions were estimated given theoretical interest in long-run equilibrium relationships, alternative specifications using first-differenced variables or error-correction models could provide additional insights into short-run dynamics versus long-run equilibria. The choice of level-form estimation reflects the research focus on testing moderation effects, which are typically examined in levels, though future research could explore dynamic specifications.

3.3 Linkage to Research Objectives

This study set out to investigate whether electricity access moderates the effect of gender inequality on economic growth in ASEAN countries during 1998–2023. The empirical evidence provides a clear answer to this research question: electricity access does not significantly moderate the gender inequality-growth relationship in the ASEAN context during this period. This conclusion is supported by statistically insignificant interaction term coefficients in both primary (Panel EGLS Cross-Section SUR) and alternative (PCSE) specifications, indicating robust null findings across estimation methods.

The research objectives are fulfilled through several contributions. First, the study provides rigorous empirical evidence on an underexplored question in development economics—the conditional relationship between gender equality and growth depending on infrastructure availability. While existing literature examines direct effects of gender inequality and infrastructure separately, few studies explicitly test interactive relationships using advanced panel methods. This research addresses that gap for the ASEAN region.

Second, the methodological approach demonstrates the importance of addressing cross-sectional dependence and heteroskedasticity in panel macroeconomic data. The diagnostic tests confirmed substantial contemporaneous correlation among ASEAN countries and heteroskedastic error structures, violations of standard assumptions that would produce inefficient estimates and invalid inference if ignored. The application of Panel EGLS with Cross-Section SUR and PCSE methods represents current best practice for addressing these issues, providing a template for future research on ASEAN macroeconomic relationships.

Third, the findings contribute to understanding the complexity of development processes in Southeast Asia. The absence of significant moderation effects suggests that relationships among gender equality, infrastructure, and growth are not straightforward conditional relationships but rather involve multiple mediating mechanisms and contextual factors. This complexity implies that simple policy

prescriptions based on presumed synergies between gender equality investments and infrastructure development may oversimplify the actual dynamics at work.

Fourth, the study highlights the importance of null findings in scientific research. While statistically insignificant results are often underreported, they provide valuable information for theory development and policy design. The null moderation effect suggests that interventions targeting gender equality and infrastructure development may need to be designed independently rather than assuming automatic reinforcing effects. This insight has practical implications for development planning and resource allocation across multiple policy domains.

4. Conclusion

This study investigated whether electricity access moderates the effect of gender inequality on economic growth in eight ASEAN countries (Indonesia, Cambodia, Lao PDR, Malaysia, Philippines, Singapore, Thailand, and Vietnam) over the period 1998–2023. Employing Panel Estimated Generalized Least Squares (EGLS) with Cross-Section Seemingly Unrelated Regression (SUR) as the primary method and Panel Corrected Standard Errors (PCSE) as an alternative specification, the analysis examined balanced panel data comprising 208 observations. The findings indicate that electricity access does not significantly moderate the relationship between gender inequality and economic growth in the ASEAN context during the study period. The interaction term (GII×ATE) exhibits a positive but statistically insignificant coefficient in both specifications, suggesting that the marginal effect of gender inequality on growth does not vary systematically with the level of electricity access.

Additionally, the direct effects of both gender inequality (GII) and electricity access (ATE) on GDP growth were found to be statistically insignificant, though GII displayed the expected negative coefficient sign and ATE showed an unexpected negative coefficient. These results remain robust across alternative estimation approaches, indicating that findings are not artifacts of specific methodological choices. The statistical insignificance of all three key variables—GII, ATE, and their interaction—suggests that the relationships among gender equality, infrastructure, and growth in ASEAN are more complex than simple linear or conditional frameworks capture.

Implications for the Scientific Field

These findings contribute to the development economics literature in several ways. First, they provide empirical evidence on the moderating role of infrastructure in gender inequality-growth relationships, a question that has received limited attention despite theoretical interest. The null moderation effect challenges simplistic assumptions that infrastructure improvements automatically amplify the benefits of gender equality for economic growth, suggesting that these relationships operate through distinct channels with limited interaction.

Second, the study demonstrates the importance of employing advanced panel data techniques that address cross-sectional dependence and heteroskedasticity, common but often overlooked characteristics of macroeconomic panel data. The application of Panel EGLS with Cross-Section SUR and PCSE methods represents methodological best practice and provides a template for future research on ASEAN or other regional groupings characterized by economic integration and common shocks.

Third, the findings highlight the value of null results in scientific inquiry. While conventional publication practices favor statistically significant findings, null results provide crucial information for theory refinement and hypothesis testing. The absence of significant moderation effects suggests that existing theoretical frameworks predicting synergies between gender equality and infrastructure may need revision or may apply differently across contexts.

Implications for Development Practice

From a policy perspective, these findings carry several implications. First, the null moderation effect suggests that gender equality initiatives and infrastructure development programs may need to be pursued as independent priorities rather than assuming automatic complementarities. While both objectives remain important for development, policymakers should not expect that investments in electricity infrastructure will automatically enhance the growth effects of gender equality improvements, or vice versa.

Second, the complexity of relationships revealed by this analysis underscores the need for nuanced, context-specific policy design rather than generic prescriptions. ASEAN's heterogeneity—encompassing high-income city-states, rapidly industrializing economies, and low-income agricultural countries—means that relationships among gender equality, infrastructure, and growth likely vary substantially across member states. Country-specific analyses and targeted interventions may be more effective than regional-level policies assuming homogeneous relationships.

Third, the insignificant direct effects of both gender inequality and electricity access on growth suggest that short-term annual growth fluctuations may be driven primarily by other factors such as

global demand, commodity prices, financial conditions, and macroeconomic policies. Gender equality and infrastructure development may exert more important influences on long-run development trajectories and welfare outcomes that are not fully captured by annual GDP growth rates. This insight encourages a broader perspective on development success beyond short-term growth maximization.

Fourth, the findings imply that achieving gender equality and universal electricity access are important development objectives in their own right, independent of their measured impacts on GDP growth. Even in the absence of significant growth effects in this particular empirical specification, gender equality contributes to human development, social justice, and capability expansion, while electricity access enhances education, health, and quality of life. Policy prioritization should reflect both instrumental growth considerations and intrinsic value dimensions.

Research Limitations

Several limitations of this study should be acknowledged. First, the analysis focuses exclusively on ASEAN countries, limiting generalizability to other developing regions. The relationships identified here may be specific to Southeast Asian economic structures, institutions, and development trajectories. Replication in other regional contexts would strengthen external validity.

Second, the study employs annual data at the national level, aggregating over substantial within-country heterogeneity. Subnational variation in gender equality, electricity access, and economic performance may reveal relationships not detectable in national aggregates. Moreover, annual frequency may be too coarse to capture the timing and dynamics of how gender equality and infrastructure influence growth processes.

Third, the GII and ATE variables, while widely used and internationally comparable, have measurement limitations. The GII aggregates multiple dimensions into a single index, potentially obscuring differential relationships across component dimensions. Electricity access percentage captures extensive margin expansion but not intensive margin factors such as reliability, affordability, or quality. Alternative measures could yield different findings.

Fourth, endogeneity concerns remain incompletely addressed. While panel methods control for time-invariant unobserved heterogeneity, they do not fully resolve simultaneity, reverse causality, or omitted time-varying confounders. Economic growth influences gender equality outcomes and infrastructure investment, creating feedback loops that complicate causal identification. Instrumental variable approaches or natural experiments could provide stronger causal inference.

Fifth, the 26-year study period encompasses major structural changes, including financial crises, globalization waves, technological revolutions, and institutional reforms. These structural breaks may introduce heterogeneity in relationships over time that is not captured by standard panel methods assuming time-invariant parameters. Time-varying coefficient models or subsample analyses could explore temporal heterogeneity.

Sixth, the null findings for the interaction term do not preclude the possibility that moderation effects exist but are heterogeneous across countries, time periods, or conditional on other factors. The pooled estimation approach constrains the interaction coefficient to be common across the panel, potentially averaging away important heterogeneous effects. Allowing for country-specific interaction effects or triple interactions with development stage indicators could reveal richer patterns.

Suggestions for Future Research

Several directions for future research emerge from these findings and limitations. First, country-specific case studies employing qualitative and mixed methods could provide deeper insights into the mechanisms through which gender equality and infrastructure influence growth in particular national contexts. Understanding how these relationships operate in specific institutional and cultural settings would complement the broad cross-country patterns identified here.

Second, disaggregation of the GII into its component dimensions—reproductive health, empowerment, and labor market participation—could reveal differential relationships with growth that are masked by the composite index. Some dimensions may interact more strongly with electricity access than others, and examining these separately would provide more granular insights.

Third, alternative infrastructure measures beyond simple access percentages—such as electricity consumption per capita, reliability indices, or infrastructure quality indicators—could capture intensive margin effects relevant for economic growth. Similarly, alternative gender equality measures focusing on specific dimensions such as female educational attainment or labor force participation might exhibit different relationships.

Fourth, dynamic panel methods such as system GMM or difference GMM could address endogeneity concerns through instrumental variable strategies exploiting temporal dynamics. These methods control for both time-invariant unobserved heterogeneity and endogenous regressors, potentially yielding more robust causal estimates.

Fifth, extending the analysis to include additional control variables—such as trade openness, financial development, institutional quality, or human capital—would account for potentially important confounding factors and improve model specification. Sensitivity analyses examining whether results are robust to alternative control variable specifications would strengthen findings.

Sixth, exploring heterogeneity through subsample analyses or interaction terms with development stage indicators could reveal whether relationships differ systematically across income levels or development phases. The pooled analysis assumes homogeneous relationships, but ASEAN's diversity suggests important heterogeneity worth investigating.

Seventh, longitudinal microdata analyses using household surveys could examine individual- and community-level mechanisms through which electricity access and gender equality interact to influence economic outcomes. Such analyses would complement the macro-level focus of this study and provide insights into microeconomic foundations.

Finally, replication in other regional contexts South Asia, Sub-Saharan Africa, Latin America would establish whether the null moderation effect found here is specific to ASEAN or represents a more general pattern across developing regions. Cross-regional comparative analyses could identify contextual factors that condition whether infrastructure moderates gender-growth relationships.

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