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Panel Econometric Analysis of Energy-Efficient Appliance Adoption in Malaysian Households

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ABSTRACT

This study analyses ten years of panel data (2014-2023) across various states in Malaysia to investigate key factors influencing the adoption of energy-efficient appliances (EEAs) in households. Employing panel econometrics, with the fixed effects model as the most appropriate, both simultaneous and individual determinants of EEA adoption are examined. Findings reveal that energy rates, clean energy policies, and inflation affect EEA adoption. The study emphasises the need for targeted energy pricing interventions and policy frameworks to enhance adoption. Additionally, regional disparities highlight the need for location-specific strategies to improve adoption rates. These insights provide a robust foundation for policymakers to develop effective measures promoting sustainable energy practices and facilitating widespread adoption of EEAs.

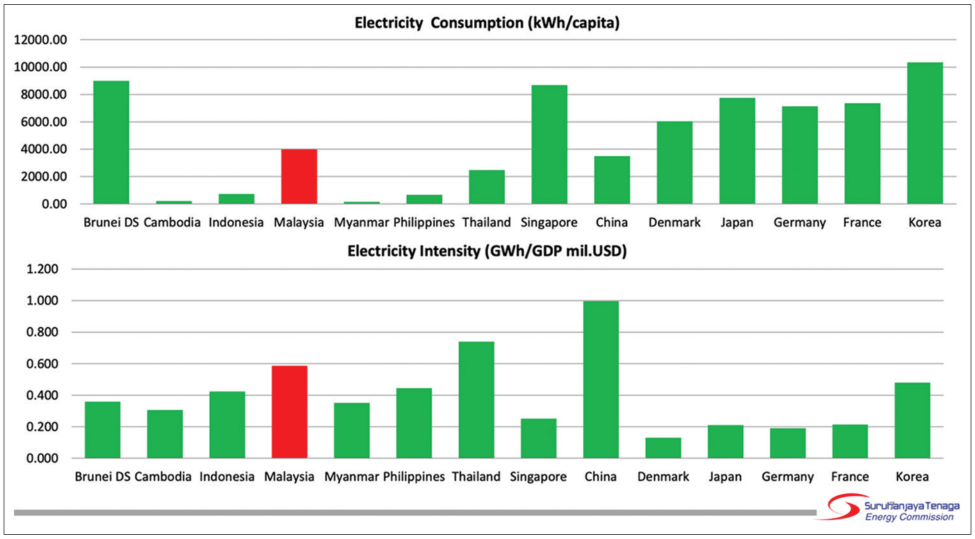
Keywords: Energy Efficiency, Household, Energy Policy, Inflation, Malaysia, Regional Disparities
JEL Classifications: D12, E31, Q48, Q56

1. INTRODUCTION

The imperative to achieve carbon neutrality has emerged as a significant global objective in light of increasing climate change challenges. Within this framework, improving energy efficiency at the household level is identified as an essential strategy for reducing carbon emissions and lowering consumer energy costs. The growing global population and the resulting rise in energy demand further accentuate the urgency of this effort (Galvin, 2024; Zhang and Song, 2023). Consequently, aligning effective policies and economic incentives is crucial to promoting sustainable energy consumption patterns (Jia et al., 2024). The data presented in Figure 1 underscores the critical need for Malaysia to prioritize household energy efficiency. Malaysia's per capita electricity consumption stands at approximately 4000 kWh, which is significantly higher than that of regional neighbors such as Cambodia, Indonesia, Myanmar, and the Philippines, as well as China. Although Malaysia's consumption is lower than that of high-income nations like Singapore, Denmark, and Korea, the disparity with its developing neighbors indicates substantial potential for energy savings. Furthermore, the electricity intensity chart reveals Malaysia's high energy consumption relative to its GDP, exceeding that of Singapore and many developed nations. This suggests that Malaysia is using more energy per unit of economic output, indicating inefficiencies in its energy utilization (Mustapa et al., 2021).

In addition, the residential sector's significant contribution to national electricity consumption further amplifies this urgency (Zen et al., 2022). By focusing on household energy efficiency, Malaysia can reduce its carbon footprint, manage electricity demand more effectively, and align with the sustainability goals of more energy-efficient nations. Understanding the determinants influencing the adoption of energy-efficient appliances (EEAs) by households is crucial for developing effective policies aimed at reducing carbon footprints and promoting sustainable development (Udemba et al., 2022). The adoption of EEAs is

Figure 1: Electricity consumption and intensity by country



Source: (Energy Commission of Malaysia, 2024)

Table 1: Detail of variables

Variable	Symbol	Indicator	Unit	Source
EEA adoption	EA	Household EEA penetration rates	%	(Statista, 2024)
Energy rates	ER	Electricity prices	MYR	(Sabah, 2014; Sarawak, 2015; TNB, 2014; 2024)
Clean energy policy	CE	The share of renewables in electricity production	%	(SEDA, 2024)
Inflation	IN	Consumer Price Index (CPI)	CPI	(DOSM, 2024a)
Productivity	PD	GDP per Capita	MYR	(DOSM, 2024b)
Household income classification	IC	The dummy variable is classified as middle-upper income group (1) and lower income group (0)[a].	DV 1; DV 0	

driven by various household determinants, as outlined in Table 1. This study employs a panel model analysis to investigate these factors and their interactions within Malaysian households. By examining both temporal and cross-sectional variations, the research assesses policy impacts and identifies trends in household adoption behaviors. This comprehensive approach provides valuable insights into the determinants of household decisions regarding EEAs. The findings are expected to aid in policy formulation, reduce environmental impacts, generate economic benefits, and enhance consumer awareness, thereby supporting Malaysia's commitment to international agreements and sustainable development goals (Wong et al., 2024).

2. LITERATURE REVIEW

The importance of adopting energy-efficient appliances (EEAs) cannot be overstated, particularly in light of the urgent need to reduce the global carbon footprint (Ren et al., 2021). This literature review critically examines various economic theories and empirical studies to understand the factors influencing households' adoption of EEAs. The Rational Choice Theory suggests that consumers make rational decisions to maximize utility. This perspective posits that households will adopt EEAs if they perceive a net benefit in terms of utility, which is often translated into economic terms such as energy savings and cost reduction (Thaler et al., 2014). According to Gillingham et al. (2014) when consumers weigh the upfront costs against long-term savings on energy bills, adopting EEAs can be rationalized as a means of utility maximization. However, this theory operates on the assumption of perfect information and rationality, which may not always hold in real-world scenarios. Neoclassical Economic Theory highlights the significance of accounting for the negative externalities of inefficient energy use. Negative externalities refer to the unintended adverse effects on third parties, such as environmental pollution and health impacts, that are not reflected in the market prices of goods and services. Policies like fiscal incentives or subsidies for EEAs can internalize these externalities, making the cost of inefficient energy use more explicit to consumers. Jaffe and Stavins (1994) argue that such market-based interventions can effectively encourage the use of EEAs and accelerate their adoption by altering the relative costs and benefits perceived by consumers.

Energy rates are a crucial factor in influencing the adoption of EEAs. Higher energy rates prompt consumers to seek more cost-effective ways to lower their energy expenses, including using EEAs. Studies have shown a positive correlation between rising energy rates and adopting EEAs. Zhang and Song (2023) found that higher energy rates create a financial incentive for households to invest in energy-efficient technologies to reduce their utility bills. This price sensitivity underscores the importance of economic

[a] Household income classification is based on average income. Households with an average income > 40,812 MYR /year (average income of M40 Household 3,401 MYR x 12 months) (DOSM, 2023) are classified as middle-upper income (1), while those below this threshold are classified as lower income (0).

incentives in driving adoption. In addition, the rise of clean energy sources also affects the adoption of EEAs. Access to clean energy provides households an additional incentive to use appliances that are more compatible and efficient with these sources. Research indicates that broader access to clean energy influences household decisions to adopt energy-saving technologies. Wang et al. (2017) highlight that supportive policy frameworks, such as subsidies for renewable energy and tax incentives for EEAs, create an enabling environment that fosters adoption. Additionally, integrating clean energy sources with smart grids can further enhance the appeal of EEAs by offering more efficient and reliable energy management solutions.

Inflation affects consumer purchasing power, including investments in EEAs. Higher inflation rates may discourage households from buying new appliances due to reduced disposable income and increased cost of living. However, if households perceive EEAs as a hedge against energy inflation, they may be more likely to invest in such technologies. According to Aidarova et al. (2024), during periods of high inflation, the perceived long-term savings on energy costs can outweigh the immediate financial burden, motivating households to adopt EEAs to manage future expenses. Furthermore, Household productivity often correlated with higher incomes, affects the ability and willingness to invest in EEAs. Higher productivity and income levels enable households to invest in new technologies, including EEAs. Studies have demonstrated a positive correlation between economic prosperity and adopting energy-efficient appliances. Mills and Schleich (2012) found that wealthier households are more likely to invest in EEAs due to their greater financial capacity and higher sensitivity to energy savings. Income classification impacts the adoption of EEAs. Generally, higher-income households are more inclined to adopt EEAs due to their greater financial capacity. Studies have shown that high-income households adopt EEAs quicker than lower-income households. Reaños et al. (2024) argue that financial barriers are a significant impediment for low-income households, which may lack access to credit or face higher opportunity costs. Targeted financial interventions, such as low-interest loans and grants, can help bridge this gap and increase adoption rates among lower-income households.

3. METHODS

3.1. Panel Regression

The study employs the panel data model approach for studying the determinants influencing the adoption of energy-efficient appliances (EEAs) across states in Malaysia from 2014 to 2023. The approach is pivotal due to the nature and complexity of the data collected. Panel data allows for examining multiple variables over time, adding depth to the analysis by focusing on household characteristics and integrating economic factors, regional differences, time effects, and policy impacts (Swamy et al., 2019). This method effectively isolates the individual-specific effects that might influence EEA adoption, ensuring a more nuanced and accurate understanding of the determinants (Sharma et al., 2021). The details of variables can be seen in Table 1.

3.2. Regression Model Estimation

The Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM) are three common approaches used for estimating panel data regression models. The parameters for both the CEM and FEM are estimated using Ordinary Least Squares (OLS). In contrast, the REM parameters are estimated using Generalized Least Squares (GLS), where a dummy variable represents the FEM intercept (Eibinger et al., 2024; Huang et al., 2019).

(1) Common Effect Model (Pooled OLS)

$$Y_{it} = \alpha + \beta X_{it} + \epsilon_{it}$$

with:
Y_{it}: EEA adoption rate for household (i) at time (t).
X_{it}: Vector of explanatory variables for household (i) at time (t).
α: Intercept.
β: Coefficient vector.
ϵ_{it}: Error term.

(2) Fixed Effect Model (FEM)

$$Y_{it} = \alpha_i + \beta X_{it} + \epsilon_{it}$$

With:
Y_{it}: EEA adoption rate for household (i) at time (t).
X_{it}: Vector of explanatory variables for household (i) at time (t).
α_i: Individual-specific intercept for household (i).
β: Coefficient vector.
ϵ_{it}: Error term.

(3) Random Effect Model (REM)

$$Y_{it} = \alpha + \beta X_{it} + u_i + \epsilon_{it}$$

With:
Y_{it}: EEA adoption rate for household (i) at time (t).
X_{it}: Vector of explanatory variables for household (i) at time (t).
α: Intercept.
β: Coefficient vector.
u_i: Random error term specific to the household (i).
ϵ_{it}: Error term.

3.3. Best Model Selection

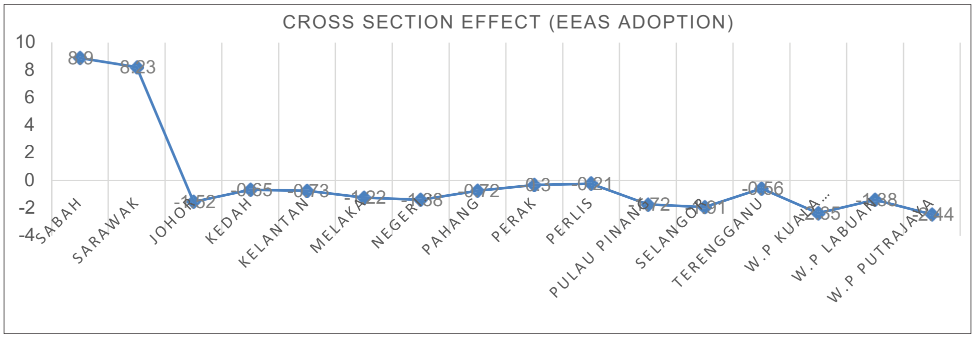
Several tests were conducted to determine the appropriate estimation method for the panel data regression, including:

(1) Chow Test
The Chow test is used to decide between the Common Effect Model (CEM) and the Fixed Effect Model (FEM) (Huang et al., 2019). The hypothesis for this test is formulated as follows:
Hypothesis:
H_0: CEM is appropriate (no firm or time-specific effects).
H_1: FEM is more appropriate (individual-specific intercepts).
Test statistics:

$$F = \frac{(RSS_C - RSS_F)/(N-1)}{RSS_F/[N(T-1)-K]}$$

With:
RSS_C: Residual sum of squares for the CEM.
RSS_F: Residual sum of squares for the FEM.
N: Number of cross-sectional units.

Figure 2: Cross-sectional effect analysis



T: Number of time periods.
K: Number of parameters estimated.

If the calculated *F* value is greater than the critical *F* value from the F-distribution table, reject the null hypothesis favouring the Fixed Effect Model.

Based on the output value above, the Prob Cross Section F value is 0.0001 <alpha 5%, which means that the study reject H0; thus, the best model is the Fixed Effect Model (FEM).

Table 2: Chow test result

Effect test	Statistic	d.f	Prob.
Cross-section F	3.420283	(15,139)	0.0001
Cross-section Chi-square	50.264030	15	0.0000

(2) Breusch-Pagan Lagrange Multiplier (LM) Test
The Breusch-Pagan Lagrange Multiplier (LM) Test is employed to determine whether the Random Effect Model (REM) is more appropriate than the Common Effect Model (CEM) (Coetzee and Kleynhans, 2021; Wooldridge, 2018).
Hypothesis:
H_0: The variance of random effects is zero (CEM is appropriate).
H_1: Variance of random effects is greater than zero (REM is appropriate).
Test statistics:

$$LM = \frac{NT}{2(T-1)}\left[\frac{\sum_{i=1}^{N}\sum_{t=1}^{T}(Y_{it}-\bar{Y}_i-\bar{Y}_t+\bar{Y})^2}{\sum_{i=1}^{N}\sum_{t=1}^{T}(Y_{it}-\bar{Y})^2 / NT}\right]$$

If the LM statistic is greater than the critical value from the chi-squared distribution table with 1 degree of freedom, reject the null hypothesis in favour of the Random Effect Model.

Table 3 shows that the Breusch Pagan Prob is 0.0000 <5% alpha, which means that it rejects H_0, suggesting that the Random Effect Model is appropriate. However, it must perform the Hausman Test to definitively choose between the Random Effect Model (REM) and the Fixed Effect Model (FEM) for the best fit in this study.

(3) Hausman Test
The Hausman Test is utilized to determine the suitability between the Fixed Effect Model (FEM) and the Random Effect Model (REM).
Hypothesis:
H_0: Random effects are uncorrelated with the predictors (REM is appropriate).
H_1: Random effects are correlated with the predictors (FEM is appropriate).
Test statistics:

$$H = (\beta_{FE}-\beta_{RE})'\,[Var(\beta_{FE})-Var(\beta_{RE})]^{-1}\,(\beta_{FE}-\beta_{RE})$$

Where:
- β_{FE}: Coefficient vector from the Fixed Effect Model.
- β_{RE}: Coefficient vector from the Random Effect Model.
- $Var(\beta_{FE})$: Variance-covariance matrix of the Fixed Effect coefficients.
- $Var(\beta_{RE})$: Variance-covariance matrix of the Random Effect coefficients.

If the Hausman statistic is larger than the critical value from the chi-squared distribution table with *K* degrees of freedom, reject the null hypothesis in favour of the Fixed Effect Model.

As shown in Table 4, the random cross-section prob value of 0.0000 <alpha 5% was obtained, which means the study rejects H_0. Thus, the best model is the Fixed Effect Model.

4. FINDINGS

4.1. Simultaneous Impact of Independent Variables

Hypothesis:
H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = D = 0$,
(All independent variables simultaneously do not affect EA)
H_1: $\beta_1 \neq \beta_1 \neq \beta_1 \neq \beta_1 \neq D \neq 0$
(All independent variables simultaneously affect EA)

Referring to Table 5, the probability value of the F-statistic is 0.0000, which is more significant than the significance level (α = 5%). It indicates that all independent variables collectively significantly affect the dependent variable. The results of the F-test demonstrate that the overall model has a statistically significant impact on adopting EEAs This finding implies that when considered together, independent variables like energy rates, clean energy policy, inflation, productivity, and household average income classification collectively influence the adoption of energy-efficient actions. It is consistent with the multifaceted nature of energy efficiency adoption, which is often influenced by various economic, policy-related, and socio-economic factors. Ehrhardt-Martinez et al. (2022) supports this integrated approach, highlighting that green policies, economic incentives, and market conditions often interact to encourage or discourage adoption.

4.2. Individual Variable Analysis: Partial t-tests

4.2.1. Energy rates impacting the adoption of energy-efficient appliances

The relationship between energy rates (electricity prices) and consumer behaviour in the context of adopting energy-efficient appliances is a critical area of study in energy economics. An increase in electricity prices often catalyzes consumers to seek out energy-efficient solutions. The recent t-test analysis on the energy rates variable yielded a probability value of 0.0067, underscoring a statistically significant impact on adopting energy-efficient appliances (Table 6). This finding aligns with the hypothesis that escalating or fluctuating energy rates incentivize consumers to adopt energy efficiency measures, enabling them to manage and potentially reduce their energy expenses.

Table 3: LM test result

Test Summary	Cross-section	Test hypothesis time	Both
Breusch-Pagan	0.444962 (0.5047)	656.2505 (0.0000)	656.6954 (0.0000)
Honda	0.667054 (0.2524)	25.61739 (0.0000)	18.58591 (0.0000)
King-Wu	0.667054 (0.2524)	25.61739 (0.0000)	20.66081 (0.0000)
Standardized Honda	1.475634 (0.0700)	29.19407 (0.0000)	18.05676 (0.0000)
Standardized King-Wu	1.475634 (0.0700)	29.19407 (0.0000)	20.49628 (0.0000)
Gourieroux et al.	--	--	656.6954 (0.0000)

Table 4: Hausman test result

Test summary	Chi-square statistic	Chi-square d.f.	Prob.
Cross-section random	51.304252	5	0.0000

Table 5: Panel model estimation result

Variables	Coefficient
EA	−31.44181***
ER	0.443591***
CE	0.194834***
IN	0.127341***
PD	1.19E-05
IC	0.271568
Effect specification	
Cross-section fixed (dummy var.)	
Observation number	160
R-square	0.884457
AR^2 Test	0.867832
Akaike info criter.	1.823757
Bayesian info criter.	2.227374
Hannan-Quinn criter.	1.987652
The F-test	53.20074
Prob (F-statistic)	0.000000

Significance levels are marked as *** for 1%, ** for 5%, and * for 10%

This observation is further supported by the work of Park and Woo (2023);who identified energy pricing reform as a potent mechanism for encouraging energy efficiency. Their research indicates that when energy prices rise, consumers are more likely to invest in appliances that consume less energy, decreasing their overall expenditure. This behaviour not only aids individual households in balancing their budgets but also contributes to wider environmental and economic benefits by reducing energy demand and the associated environmental impact (Xu et al., 2023). Consequently, strategic adjustments in energy pricing can play a pivotal role in driving the adoption of energy-efficient technologies, reinforcing the importance of energy policy in shaping consumer behaviour and advancing energy sustainability in Malaysia.

4.2.2. Clean energy policies on the EEAs adoption in Malaysia

The significant influence of clean energy policy on the adoption of energy efficiency applications (EEAs) in Malaysia is significant, as reflected by the probability value of 0.0000. It underscores the critical role that governmental support plays in advancing sustainable energy solutions within the country. Malaysia's clean energy policies establish a regulatory framework that encourages developing and deploying energy efficiency technologies (Priyadi et al., 2022). By setting clear objectives and guidelines, these policies provide a roadmap for energy transition, which can stimulate private sector investment and innovation in energy-efficient technologies. Effective policies often include incentives such as tax credits, rebates, and grants, making energy-efficient technologies more affordable and attractive to businesses and consumers (Maulud and Saidi, 2012; Zou and Mishra, 2020).

Supporting studies further highlight the importance of such policies. For instance, Wang et al. (2017) illustrate how targeted policy interventions have led to significant energy savings and reduced carbon emissions in different regions. Similarly, the Kuriakose et al. (2022) provides evidence that countries with comprehensive clean energy policies achieve higher rates of energy efficiency adoption. The effective policies create an environment conducive to innovation and the adoption of advanced energy technologies, contributing to sustainable economic growth and environmental benefits. Specifically in Malaysia, the government's commitment to promoting energy efficiency is seen in various initiatives and frameworks that align with global standards. Thus, the clean energy policy is integral to achieving substantial energy efficiency improvements in Malaysia, driving the energy transition forward while ensuring economic and environmental goals are attained (Mustapa et al., 2021).

4.2.3. Inflation on the EEAs adoption

As measured by the Consumer Price Index (CPI), inflation significantly impacts the adoption of energy-efficient appliances (EEAs) in Malaysia. With a probability value of 0.0000, statistical analysis indicates that inflation strongly influences households' and businesses' decisions to invest in EEAs. Higher inflation escalates the cost of living and operational expenses, prompting consumers and businesses to seek cost-saving measures (Aidarova et al., 2024). Consequently, energy-efficient technologies become more attractive due to their potential to reduce long-term energy

Table 6: Partial t-test interpretations

Variable	Hypothesis	P-value	Sig. level	Result
Energy rates (ER)	H0: β=0 (ER does not affect EA) H1: $\beta_1 \neq 0$ (ER affects EA)	0.0067	0.01	Significant Effect (Reject H_0)
Clean Energy Policy (CE)	H0: $\beta_2=0$ (CE does not affect EA) H1: $\beta_2 \neq 0$ (CE affects EA)	0.0000	0.01	Significant Effect (Reject H_0)
Inflation (IN)	H0: $\beta_3=0$ (IN does not affect EA) H1: $\beta_3 \neq 0$ (IN affects EA)	0.0000	0.01	Significant Effect (Reject H_0)
Productivity (PD)	H0: $\beta_4=0$ (PD does not affect EA) H1: $\beta_4 \neq 0$ (PD affects EA)	0.1909	0.05	No Significant Effect (Fail to Reject H_0)
Dummy Variable (Household Income Classification, IC)	H0: $\beta_5=0$ (IC does not affect EA) H1: $\beta_5 \neq 0$ (IC affects EA)	0.2290	0.05	No Significant Effect (Fail to Reject H_0)

costs. The economic pressures induced by inflation necessitate strategies for mitigating increased expenses. As (Caballero et al., 2024) demonstrated, inflationary conditions often drive greater energy efficiency as a cost-saving measure.

4.2.4. Productivity

The productivity variable, with a probability value of 0.1909, does not significantly affect EEA adoption. This suggests that while productivity improvements might be linked to efficiency within production systems, they do not necessarily translate to energy efficiency adoption in a broader sense. Jones and Kammen (2011) state that productivity gains do not automatically lead to energy efficiency unless specifically targeted.

4.2.5. Household average income classification

The household average income classification variable had a probability value of 0.2290, showing no significant impact on EEA adoption. This may indicate that energy efficiency actions are adopted across various income levels, potentially due to widespread awareness or universally applicable incentives. This aligns with findings from (Kumar et al., 2023) who noted that energy efficiency is not limited to high-income households but is increasingly seen as beneficial across different socio-economic groups.

4.3. Coefficient of Determination

The analysis reveals that the coefficient of determination (R^2) is an impressive 0.8844, indicating that 88.44% of the variance in the adoption of energy-efficient appliances (EEAs) within Malaysian households is accounted for by the variables such as exchange rate, clean energy policy, inflation, productivity, and household income classification. This high R^2 underscores the model's robustness in capturing the essential dynamics that drive EEA adoption. At the same time, the remaining 11.56% variance is left unexplained by the model, suggesting the presence of other latent factors or stochastic noise. The regression model, specified as

$$EA_{it} = -31.44 + 0.271IC_{it} + 0.4435ER_{it} + 0.1948CE_{it} + 0.1273IN_{it} + 1191E\text{-}05PD_{it} + \varepsilon_{it}.$$

Table 5 reveals that household income classification (IC) and productivity (PD) are not statistically significant. However, the model highlights that exchange rate (ER), clean energy policy (CE), and inflation (IN) play significant roles in influencing the adoption of energy-efficient appliances. The positive coefficient for exchange rate (ER) indicates that fluctuations in currency values significantly impact the cost of imported energy-efficient appliances, making them more or less affordable for consumers. The coefficient for clean enery policy (CE) suggests that increased investments in infrastructure and technological advancements create an environment conducive to higher EEA adoption. Subsequently, the positive coefficient for inflation (IN) implies that as consumer prices increase, households may be driven to adopt EEAs to achieve longer-term cost savings on energy consumption. These findings underscore the multifaceted economic mechanisms that affect EEA adoption rates, providing valuable insights for policymakers who aim to design effective strategies to promote energy efficiency and sustainable consumption. By understanding how these economic variables interact, targeted interventions can be developed to encourage the widespread adoption of energy-efficient technologies, fostering a more sustainable future.

4.4. Cross-sectional Effect Analysis on The EEA Adoption Across States in Malaysia

The cross-sectional effect analysis of Energy-Efficient Appliances (EEA) adoption across various states in Malaysia delineates a fascinating spectrum of adoption rates. Sabah has the highest adoption rate, at 8.906213, while W.P. Putrajaya records the lowest, at −2.443520. This disparity manifests a sizable gap of 11.34% between the two regions, underlining pronounced regional variations in EEA adoption as outlined in Figure 2.

The findings on Sabah reflect regional policies such as Sabah Energy Roadmap and Master Plan 2040 and consumer awareness programs that promote energy efficiency, which could be attributed to targeted incentives, subsidies, and education campaigns that have heightened consumer acceptance of energy-efficient technologies. Chen et al. (2024) study supports these insights, suggesting that regions with proactive governmental policies and consumer education programs witness higher rates of energy-efficient technology adoption. Conversely, the low adoption rate in W.P. Putrajaya may raise questions about the barriers to adoption. These could include high initial costs, lack of awareness, or insufficient incentives for consumers and businesses. Mustaffa and Kudus (2022) echo these challenges, highlighting factors inhibiting the adoption of green technologies in developing regions, including financial constraints, lack of consumer awareness, and the absence of robust regulatory frameworks. Critically, the analysis implies the necessity for a nuanced, region-specific approach to promoting EEA adoption. Targeted policy measures, such as subsidies for energy-efficient appliances, consumer financing options, and educational campaigns, could bridge the adoption gap. The variance in adoption rates also emphasizes the need for policymakers to address structural and socio-economic challenges distinct to each region, which could involve collaboration with local governments, private enterprises, and non-governmental organizations to create a comprehensive strategy that encourages the widespread adoption of energy-efficient appliances. In conclusion, the cross-sectional effect analysis underscores the successes and challenges of promoting EEA adoption across Malaysia. By identifying and addressing the diverse factors influencing adoption rates in different regions, Malaysia can advance towards its energy efficiency and sustainability goals more effectively.

5. CONCLUSION

The analysis of ten years of panel data from Malaysian states identifies key factors influencing household adoption of energy-efficient appliances (EEAs). Important determinants include energy tariffs, clean energy policies, and inflation, suggesting that specific policy and price interventions are essential for encouraging the adoption of EEAs. Targeted measures could promote a shift toward more sustainable energy consumption patterns. However, the study also notes regional disparities, indicating that a one-size-fits-all approach may not be appropriate. Instead, location-specific strategies should be developed to address these differences and improve the effectiveness of policy initiatives, ensuring a more balanced transition to energy efficiency across various regions. These findings offer useful insights for policymakers aiming to design initiatives that promote energy efficiency and support sustainable development goals. By understanding the interactions between economic and policy factors, decision-makers can create more effective programs to increase household adoption of EEAs. This, in turn, can contribute to reducing overall energy consumption and achieving Malaysia's sustainability targets. The research provides a foundation for developing policies that promote energy efficiency while also supporting economic and environmental objectives at a national level.

This study relies on secondary data from 2014 to 2023 (Table 1), which may introduce biases, lack primary validation, and limit generalizability beyond Malaysia. Rapid technological and market changes during this period may also affect the consistency of the findings.

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REFERENCES

Aidarova, A.B., Ramashova, A.N., Baisholanova, K., Jaxybekova, G., Imanbayev, A., Kenzhebekova, I., Kelesbayev, D. (2024), Relationship between oil price, inflation, and economic growth in BRICS countries: Panel cointegration analysis. International Journal of Energy Economics and Policy, 14(6), 24-31.

Caballero, M.D., Vandenbergh, M.P., Gilligan, J.M., Currier, E.O. (2024), Incentivizing household action: Exploring the behavioral wedge in the 2021 infrastructure investment and jobs act and the 2022 inflation reduction act. Energy Policy, 186, 113992.

Chen, A., Rafiz Azuan, N.B., Harun, N.M., Ooi, Y.B.H., Khor, B.H. (2024), Nutritional status and dietary fatty acid intake among children from low-income households in Sabah: A cross-sectional study. Human Nutrition and Metabolism, 36, 200260.

Coetzee, C.E., Kleynhans, E.P.J. (2021), Estimating economic activity of South African provinces using satellite technology: An econometric panel data application. Remote Sensing Applications: Society and Environment, 23, 100564.

DOSM. (2023), Household Income Malaysia. Malaysia: Department of Statistics Malaysia.

DOSM. (2024a), CPI Inflation by State. Malaysia: Department of Statistics Malaysia.

DOSM. (2024b), Gross Domestic Product per Capita by state in Malaysia. Malaysia: Department of Statistics Malaysia.

Ehrhardt-Martinez, K., Hollis, N., Hillman, T. (2022), The Determinants of Household Energy Burdens and their Influence on Participation in Energy-efficiency Programs. In: Eceee Summer Study Proceedings. p33-42.

Eibinger, T., Deixelberger, B., Manner, H. (2024), Panel data in environmental economics: Econometric issues and applications to IPAT models. Journal of Environmental Economics and Management, 125, 102941.

Energy Commission of Malaysia. (2024), Kecekapan Tenaga Sebagai Alat Pemerkasaan Untuk Pengguna Yang Merangkumi Domestik, Komersial, Dan Perindustrian - Kerangka Dasar and Perundangan. Malaysia: Energy Commission of Malaysia

Galvin, R. (2024), The economic losses of energy-efficiency renovation of Germany's older dwellings: The size of the problem and the financial challenge it presents. Energy Policy, 184, 113905.

Gillingham, K., Palmer, K., Gillingham, K., Palmer, K. (2014), Bridging the energy efficiency gap: Policy insights from economic theory and empirical evidence. Review of Environmental Economics and Policy, 8(1), 18-38.

Huang, B., Lee, T.H., Ullah, A. (2019), A combined random effect and fixed effect forecast for panel data models. Journal of Management Science and Engineering, 4(1), 28-44.

Jaffe, A.B., Stavins, R.N. (1994), The energy-efficiency gap What does it mean? Energy Policy, 22(10), 804-810.

Jia, Y., Nadeem, M., Hameed, I., Waris, I., Akram, U. (2024), Towards sustainable consumption: Factors influencing energy-efficient appliance adoption in haze-affected environments. Energy Strategy Reviews, 53, 101416.

Jones, C.M., Kammen, D.M. (2011), Quantifying carbon footprint reduction opportunities for U.S. households and communities. Environmental Science and Technology, 45(9), 4088-4095.

Kumar, P., Caggiano, H., Shwom, R., Felder, F.A., Andrews, C.J. (2023), Saving from home! How income, efficiency, and curtailment behaviors shape energy consumption dynamics in US households? Energy, 27, 126988.

Kuriakose, J., Jones, C., Anderson, K., McLachlan, C., Broderick, J. (2022), What does the Paris climate change agreement mean for local policy? Downscaling the remaining global carbon budget to sub-national areas. Renewable and Sustainable Energy Transition, 2, 100030.

Maulud, A.L., Saidi, H. (2012), The Malaysian fifth fuel policy: Re-strategising the Malaysian renewable energy initiatives. Energy Policy, 48, 88-92.

Mills, B., Schleich, J. (2012), Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries. Energy Policy, 49, 616-628.

Mustaffa, N.K., Kudus, S.A. (2022), Challenges and way forward towards best practices of energy efficient building in Malaysia. Energy, 259, 124839.

Mustapa, S.I., Rasiah, R., Jaaffar, A.H., Abu Bakar, A., Kaman, Z.K. (2021), Implications of COVID-19 pandemic for energy-use and energy saving household electrical appliances consumption behaviour in Malaysia. Energy Strategy Reviews, 38, 100765.

Park, J., Woo, J.R. (2023), Analyzing consumers' willingness to purchase energy-efficient appliances in response to energy price changes: Case study of South Korea. Energy Economics, 127, 107088.

Priyadi, U., Atmadji, E., Artiani, L.E., Nordin, S.M., Abdullah, M.R.T.L., Imron, M.A., Wildan, M.A., Omar, R.C. (2022), Sustainable energy economic policy: Population, energy consumption, and macroeconomic conditions. International Journal of Energy Economics and Policy, 12(6), 80-85.

Reaños, M.A.T., Curtis, J., Meier, D., Pillai, A. (2024), Looking beyond energy efficiency and the role of financial literacy in experiencing fuel poverty: Evidence from Irish homeowners. Energy Research and Social Science, 112, 103515.

Ren, Y.S., Ma, C.Q., Apergis, N., Sharp, B. (2021), Responses of carbon emissions to corruption across Chinese provinces. Energy Economics, 98, 105241.

Sabah. (2014), Sabah Electricity Tariffs. Available from: https://www.sesb.com.my/services/tariff-rates

Sarawak. (2015), Sarawak Electricity Tariffs. Available from: https://lawnet.sarawak.gov.my/lawnet_file/subsidiary/sub_issue%20no.%2041_%20l.n.%20215%20doc.pdf%20(watermark)fro.pdf

SEDA. (2024), Malaysia Renewable in % Electricity Production. Available from: https://www.enerdata.net/estore/energy-market/malaysia

Sharma, G.D., Tiwari, A.K., Erkut, B., Mundi, H.S. (2021), Exploring the nexus between non-renewable and renewable energy consumptions and economic development: Evidence from panel estimations. Renewable and Sustainable Energy Reviews, 146, 111152.

Statista. (2024), Household Penetration Rate. Available from: https://www.statista.com/outlook/cmo/smart-home/smart-appliances/malaysia#product-types

Swamy, P.A.V.B., Von Zur Muehlen, P., Mehta, J.S., Chang, I.L. (2019), Alternative approaches to the econometrics of panel data. In: Panel Data Econometrics: Theory. United States: Academic Press. p289-344.

Thaler, R.H., Sunstein, C.R., Balz, J.P. (2014), Choice Architecture. SSRN Electronic Journal. Available from: http://dx.doi.org/10.2139/ssrn.2536504

TNB. (2014), Peninsular Electricity Tariffs. Available from: https://www.tnb.com.my/assets/files/tariff_rate_final_01.jan.2014.pdf

TNB. (2024), TNB Pricing and Tariffs. Available from: https://www.tnb.com.my/residential/pricing-tariffs

Udemba, E.N., Philip, L.D., Emir, F. (2022), Performance and sustainability of environment under entrepreneurial activities, urbanization and renewable energy policies: A dual study of Malaysian climate goal. Renewable Energy, 189, 734-743.

Wang, Z., Wang, X., Guo, D. (2017), Policy implications of the purchasing intentions towards energy-efficient appliances among China's urban residents: Do subsidies work? Energy Policy, 102, 430-439.

Wong, G.Z., Wong, K.H., Lau, T.C., Lee, J.H., Kok, Y.H. (2024), Study of intention to use renewable energy technology in Malaysia using TAM and TPB. Renewable Energy, 221, 119787.

Wooldridge, J.M. (2018), The Econometric Analysis of Crosssection and Panel Data. Veronica Forrest-Thompson and Language Poetry. United Kingdom: Liverpool University Press. pi-vi.

Xu, Q., Li, S., Shen, L., Chang, R., Wang, Q.C., Liu, X., Chen, Y. (2023), Pricing strategy for household energy-saving option (HESO): A novel option-based intervention for promoting household energy efficiency. Environmental Impact Assessment Review, 98, 106969.

Zen, I.S., Uddin, M.S., Al-Amin, A.Q., Majid, M.R.B., Almulhim, A.I., Doberstein, B. (2022), Socioeconomics determinants of household carbon footprint in Iskandar Malaysia. Journal of Cleaner Production, 347, 131256.

Zhang, Y., Song, B. (2023), Does energy-efficiency label affect appliance price? Empirical analysis of the new national standard air conditioners in China. Energy, 269, 126847.

Zou, B., Mishra, A.K. (2020), Appliance usage and choice of energy-efficient appliances: Evidence from rural Chinese households. Energy Policy, 146, 111800.