

# Assessing the Impact of Economic Variables on the Energy Demand in Malaysia: A Regression Approach

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## ABSTRACT

The Knowledge of long-term energy demand, is essential for sustainable energy planning, especially in emerging economies. This study examines the relationship between Final Energy Consumption (FEC) and eleven economic variables in Malaysia from 1980 to 2022. The analysis used univariate regressions, feature selection techniques (forward selection, lasso, and recursive feature elimination), and multiple regression with diagnostic checks to systematically evaluate the explanatory power of each predictor. The results reveal that Gross Domestic Product (GDP), manufacturing output, electricity consumption, and urban population are the first factors influencing FEC, while imports, exports, and Foreign Direct Investment (FDI) play secondary roles. Population and trade balance exhibit redundancy and limited predictive value. Diagnostic testing, including the Variance Inflation Factor (VIF), Durbin–Watson statistics, and residual analysis, confirms the reliability of the regression framework. The results show that GDP, manufacturing output, and urban population are the most significant predictors of long-term energy demand ( $R^2 = 0.94$ ,  $p < 0.01$ ), whereas trade-related variables have a moderate impact. These findings underscore the importance of aligning industrial growth, urbanization policies, and trade strategies with sustainable energy planning, highlighting the advantages of using regression with feature selection and diagnostics.

**Keywords**-energy demand forecasting; regression analysis; economic variables; Malaysia; feature selection; long-term forecasting; energy policy

## I. INTRODUCTION

The prediction of energy demand, balanced with sustainable energy transitions and supply and demand

equilibrium, plays a crucial for investments in infrastructure and improves energy security [1]. In Southeast Asia, rapid economic growth and industrialization are causing a significant

increase in energy demand, expecting to have accounted for a quarter of the global rise by 2035. Malaysia, being a country with a large industrial base, and a rapidly expanding urban population, plays a crucial role in global trade, posing global sustainability pressure [2-5]. The National Energy Policy 2022–2040 (NEP) [6] outlines strategies for energy security, affordability, and sustainability, whereas the National Energy Transition Roadmap (NETR) [7] aims to have achieved net-zero emissions by 2050. The connection between energy consumption and economic activity [8-10], varies from country to country reflecting differences in economic structure, resource endowments, and policy frameworks [11, 12]. Authors in [13, 14] examined multidimensional approaches that include trade openness, FDI, industrial output, and urbanization [15]. FDI changes both the type of industries and the adoption of technology used, while urbanization increases household and transportation consumption [16, 17]. In Malaysia, urban growth rose from 34% in 1980 to 75% in 2020, and it is projected to have exceeded 80% by 2030, further highlighting its role as a structural driver of long-term demand. Evidence within ASEAN and adjacent regional blocks highlights the role of external openness and industry in shaping energy demand. Panel results for the East Asian Growth Area show an association between trade openness, energy consumption, and economic growth, emphasizing how exports and industrial activity amplify energy needs in open, manufacturing-oriented economies [17]. Additionally, causality evidence supports a bidirectional energy–growth nexus in developing contexts, which is consistent with the macroeconomic channel through which activity drives long-run energy demand [15]. Machine learning and hybrid models, such as Long Short-Term Memory (LSTM) and ensemble approaches, dominate short- and medium-term forecasting due to their high predictive accuracy [18, 19]. However, regression models remain important for long-term analysis due to their interpretability and transparency, particularly in policy-making contexts [2]. Hybrid statistical–deep learning frameworks outperform standalone models. Authors in [20] reported that ARIMA–LSTM/GRU outperforms single-model baselines for peak and short-term demand prediction. In the energy field, CNN–(Bi)LSTM with attention extracts spatiotemporal features and better captures irregular demand trends than plain LSTM [21]. Attention/Transformer-based hybrids further improve long-term load forecasting by learning long-range dependencies [22]. When hyper-parameters and nonlinearities pose challenges, metaheuristic-optimized hybrid neural networks can enhance the accuracy of energy demand applications [23]. Authors in [24] applied a Temporal Fusion Transformer (TFT) that uses solar irradiance components as exogenous predictors to forecast short-term electricity demand. This study confirmed that including domain-specific variables can significantly improve model accuracy, underscoring the increasing significance of statistical–hybrid–deep learning approaches in improving forecast accuracy while maintaining interpretability. Despite advances, gaps remain in the Malaysian context, because the results rely on predetermined variables and have not systematically applied feature selection to refine predictor sets. Although GDP and population are widely used, less attention has been given to FDI, imports, and exports, despite their key role in Malaysia’s economy [2, 16].

Diagnostic testing, residual autocorrelation, and structural stability, are often missing, raising concerns about the reliability of the results. Addressing these limitations is critical for producing reliable regression-based forecasts to guide effective energy policies. This study systematically analyzes the relationship between FEC and eleven economic variables in Malaysia from 1980 to 2022, aiming to identify the most influential factors of energy demand while maintaining methodologically accurate. First, it provides updated empirical evidence on the energy demand in Malaysia by including recent data and accounting for structural changes in the economy. Second, the benefits of combining traditional econometric methods with modern feature selection techniques for improved model specification are shown and third, it offers practical insights for developing energy policies, particularly in aligning industrial, urban, and trade strategies with sustainable energy planning.

## II. METHODOLOGY

### A. Data Collection and Preprocessing

This study uses secondary data from multiple authoritative sources to ensure the quality and depth of the data. MyEnergyStats, Malaysia's official energy database under the Energy Commission [25], is the primary data source for energy statistics. Economic and demographic data are sourced from Macrotrends [26] and the World Bank [27]. The dependent variable is FEC, measured in thousands of tons of oil equivalent (ktoe). FEC represents the total energy consumed by end users across all sectors, excluding transformation losses and the energy industry's own use. This measure provides a comprehensive view of actual energy demand in the economy. The independent variables comprise eleven economic indicators that were selected based on their theoretical relevance and the availability of data:

- Electricity consumption (in billions of kWh): Total electricity consumption across all sectors.
- GDP (USD billions): Total economic output.
- Population (millions): Total population.
- Imports (USD billions): Total value of goods and services imported.
- Exports (USD billions): Total value of goods and services exported.
- FDI (USD billions): Net inflows of foreign investment.
- Manufacturing output (USD billions): Value added by the manufacturing sector.
- Urban population (millions): The population residing in urban areas.
- Population growth rate (%): Annual population growth rate.
- Trade balance (USD billions): The difference between exports and imports.
- Inflation Rate (%): Annual consumer price inflation.

The study period extends from 1980 to 2022, offering 43 data points for analysis. This timeframe captures Malaysia's transformation from a commodity-based economy to a diversified, industrialized nation, providing sufficient historical coverage for robust statistical testing. Several steps were taken during data preprocessing to ensure analytical validity. Missing values were addressed through interpolation as needed, and all variables were examined for abnormalities using the interquartile range method. Variables were transformed as required to achieve normality and homoscedasticity.

**B. Analytical Framework**

As shown in Figure 1, the analytical framework follows a systematic approach designed to maximize methodological rigor and policy relevance. The analysis proceeds through four main stages:

**1) Univariate Regression Analysis**

To examine the individual relationships between FEC and each economic variable, simple linear regression is used:

$$FEC = \alpha + \beta X_i + \varepsilon \tag{1}$$

where FEC is the final energy consumption,  $X_i$  represents each economic variable,  $\alpha$  is the intercept,  $\beta$  is the slope coefficient, and  $\varepsilon$  is the error term. The coefficient of determination ( $R^2$ ) measures the explanatory power of each variable individually.

**2) Feature Selection**

Three techniques for selecting features are used to identify the most relevant predictors:

- Forward Selection: adds variables iteratively based on statistical significance.
- Lasso Regression: uses  $L_1$  regularization to minimize less important variables.
- Recursive Feature Elimination (RFE): systematically removes the least important variables.

Convergence of the results across these methods enhances confidence in variable selection.

**3) Multiple Regression Analysis**

A multiple regression model is built using a selected group of variables:

$$FEC = \alpha + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k + \varepsilon \tag{2}$$

where k represents the number of selected variables. The model is estimated using Ordinary Least Squares (OLS) with robust standard errors.

**4) Diagnostic Testing**

Comprehensive diagnostic tests ensure model validity:

- Multicollinearity: assessed using the VIF.
- Autocorrelation: tested using Durbin-Watson statistics.
- Heteroscedasticity: evaluated through residual analysis
- Normality: checked using the Shapiro-Wilk test.
- Model stability: assessed through out-of-sample forecasting (2016–2022).

This framework ensures the statistically valid and practical identification of the key drivers of energy demand.

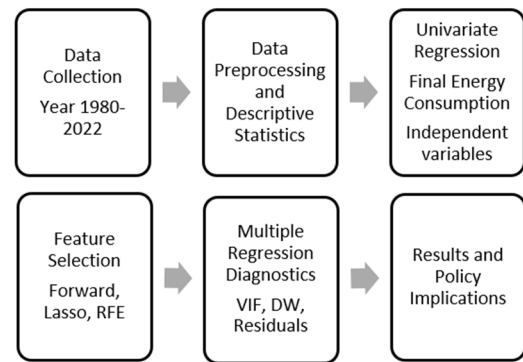


Fig. 1. Workflow diagram.

**III. RESULTS AND DISCUSSION**

**A. Descriptive Statistics**

Table I provides descriptive statistics for all variables throughout the study period (1980-2022). The data reveal significant variation across all indicators, reflecting Malaysia's economic and demographic shifts over the past four decades.

TABLE I. DESCRIPTIVE STATISTICS OF VARIABLES (N=43)

Var.	mean	std	min	25%	50%	75%	max
FEC	3.197e+04	1.89e+04	6385	1.383e+04	3.151e+04	4.637e+04	6.648e+04
EC	6152	4461	747	1820	5593	9624	1.466e+04
PES	5.337e+04	3.105e+04	1.066e+04	2.403e+04	5.116e+04	8.17e+04	1.046e+05
GDP	1.579e+11	1.259e+11	2.449e+10	4.658e+10	1.008e+11	2.996e+11	4.076e+11
FDI	5.599e+09	4.758e+09	1.147e+08	1.533e+09	4.178e+09	8.984e+09	2.025e+10
Manufacturing output	3.789e+10	2.798e+10	5.2e+09	1.161e+10	2.895e+10	6.642e+10	9.51e+10
Urban population	1.532e+07	6.846e+06	5.459e+06	9.078e+06	1.48e+07	2.116e+07	2.714e+07
Population	2.372e+07	6.675e+06	1.298e+07	1.809e+07	2.353e+07	2.941e+07	3.47e+07
Population growth rate	2.35	0.6074	1.15	1.765	2.39	2.8	3.29
Imports	1.121e+11	7.963e+10	1.348e+10	3.596e+10	9.238e+10	1.837e+11	2.839e+11
Exports	1.287e+11	9.28e+10	1.309e+10	3.551e+10	1.092e+11	2.155e+11	3.132e+11
Trade balance	1.659e+10	1.576e+10	3.49e+09	9.068e+08	1.802e+10	2.754e+10	5.154e+10

FEC shows a consistent upward trend, growing from around 15,000 ktoe in 1980 to over 65,000 ktoe by 2022. This growth pattern aligns with Malaysia's economic expansion and industrialization. Similarly, GDP expanded from USD 24.5 billion in 1980 to USD 432.3 billion in 2022, representing a compound annual growth rate of approximately 7.2%. Manufacturing output demonstrates particularly strong growth, reflecting Malaysia's successful industrialization strategy. Throughout the period, the sector's contribution to GDP has remained substantial, underscoring its importance as a key driver of energy demand. Electricity demand has grown exponentially, increasing from 4.8 billion kWh in 1980 to 184.2 billion kWh in 2022. The urban population grew steadily from 9.8 million in 1980 to 26.4 million in 2022, reflecting an increase in the urbanization rate from 42% to 78%. This demographic shift significantly impacts energy consumption patterns because urban areas typically have higher per capita energy use. Trade variables (imports, exports, and FDI) exhibit high variability, reflecting Malaysia's integration into global markets and its susceptibility to external economic shocks. The Asian Financial Crisis (1997–1998) and the Global Financial Crisis (2008–2009) are evident in the data, demonstrating the sensitivity of the Malaysian economy to international crises.

**B. Univariate Regression Analysis and Scatterplots**

The results of the univariate regressions are presented in Table II, with GDP, manufacturing output, electricity consumption, and urban population being the strongest individual predictors of FEC, each with a high coefficient of determination ( $R^2$ ). Figure 2 presents these relationships, showing the clear linear relationships between FEC and these four variables. In contrast, the population growth rate and the trade balance show weak associations with FEC, as reflected by their low  $R^2$  values and dispersed scatter patterns. These results establish GDP, manufacturing output, electricity consumption, and urban population as the most promising factors to include in the multivariate model.

TABLE II. SIMPLE REGRESSION RESULTS FOR FEC VS EACH VARIABLE (N = 43)

Var.	Coef	StdErr	p_value	R <sup>2</sup>	RMSE
PES	0.6039	0.01177	7.911e-39	0.9847	2312
EC	4.199	0.08635	6.932e-38	0.983	2438
Urban population	0.002736	5.687e-05	1.079e-37	0.9826	2464
Population	0.0028	6.524e-05	1.064e-35	0.9782	2756
Manufacturing output	6.542e-07	2.61e-08	1.742e-26	0.9388	4621
Imports	2.285e-07	1.002e-08	6.506e-25	0.9269	5047
GDP	1.435e-07	6.853e-09	1.641e-23	0.9145	5460
Exports	1.947e-07	9.304e-09	1.693e-23	0.9144	5464
Population growth rate	-2.964e+04	1473	7.302e-23	0.9081	5662
Trade_Bal	9.18e-07	1.204e-07	2.182e-09	0.5865	1.201e+04
FDI	3.034e-06	4.002e-07	2.521e-09	0.5837	1.205e+04

Scatterplot analysis reveals linear relationships between FEC and the key predictors, which supports the use of linear regression techniques. However, some variables exhibit slight nonlinearities, particularly in recent years. This suggests potential structural changes in the economy's energy intensity.

**C. Feature Selection Results**

Table III compares the results of three feature selection techniques: forward selection, lasso regression, and RFE. Although the exact sets of variables are slightly different, the methods converge on a common core of predictors: GDP, manufacturing output, and urban population. Lasso also emphasizes electricity consumption, which is consistent with the univariate analysis. Imports and FDI are occasionally selected, though less consistently among the methods. These results highlight the redundancy of total population when urban population is included, as well as the limited predictive value of trade balance.

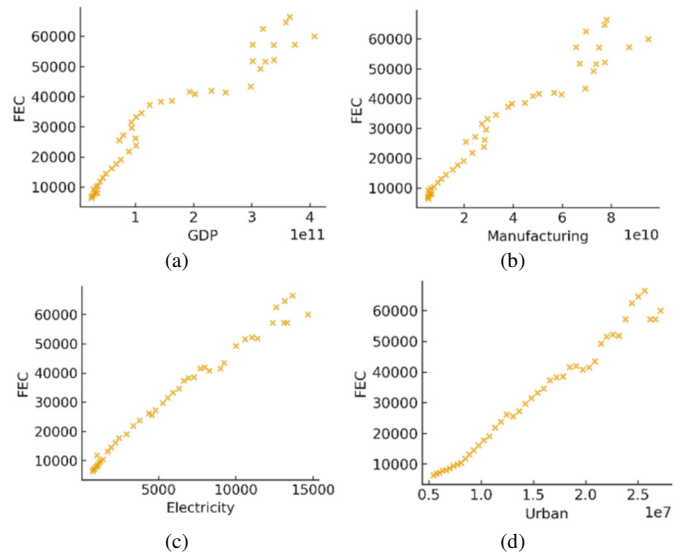


Fig. 2. Scatterplots linear relationships: (a) GDP, (b) manufacturing, (c) electricity, (d) urban.

TABLE III. FEATURE SELECTION RESULTS (FORWARD, LASSO, RFE)

Variable	Forward	Lasso	RFE	Selected_Count
Electricity consumption	1	1	1	3
Primary energy supply	1	1	1	3
Manufacturing output	1	1	0	2
Population	0	1	1	2
Population growth rate	0	1	1	2
Trade balance	0	1	1	2
FDI	0	1	0	1
Urban population	0	0	1	1
Imports	0	0	1	1
Exports	0	0	1	1
GDP	0	0	0	0

As shown in Figure 3, the Lasso regression results indicate that GDP, electricity consumption, and urban population have non-zero coefficients, confirming their influence on final energy consumption. In contrast, the coefficients for manufacturing output and several trade-related variables were reduced to zero, implying high correlation and limited independent contribution once GDP and electricity consumption were included.

D. Multiple Regression Analysis and Diagnostics

The coefficients of the multiple regression model with all eleven independent variables are presented in Table IV. GDP and manufacturing output remain statistically significant, along with urban population and electricity consumption. Imports, exports, and FDI have positive but less significant effects, suggesting that their influence is partially mediated by domestic industrial and demographic dynamics.

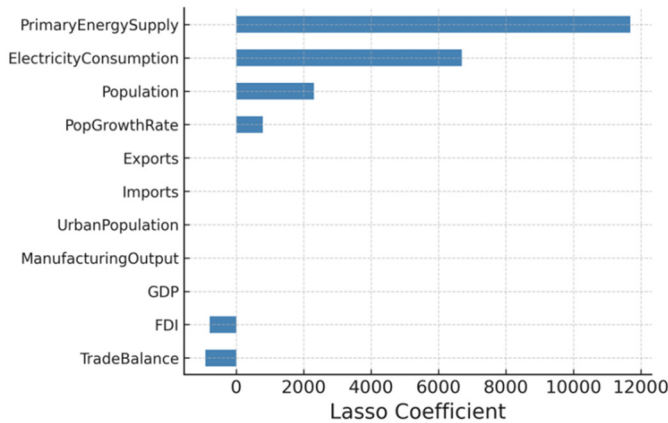


Fig. 3. Lasso coefficients for eleven economic variables.

TABLE IV. MULTIPLE REGRESSION OLS COEFFICIENTS

Variable	Coefficient	Std Err	p_value
Const	-3189	5629	0.5764
Electricity consumption	0.8517	0.9008	0.3538
Primary energy supply	0.2893	0.07982	0.001351
GDP	-8.166e-08	1.761e-08	0.0001045
FDI	-1.68e-07	7.07e-08	0.02579
Manufacturing output	4.158e-07	1.577e-07	0.01443
Urban population	0.0009533	0.001444	0.5156
Population	-0.0002606	0.0008877	0.7716
Population growth rate	1282	862.9	0.1503
Imports	-2.88e+04	2.004e+04	0.1636
Exports	2.88e+04	2.004e+04	0.1636
Trade balance	-2.88e+04	2.004e+04	0.1636

Model diagnostics confirm the adequacy of the regression framework. The VIF values in Table V show acceptable levels of multicollinearity, except for population and urban population, which exhibit redundancy. The Durbin–Watson statistic, shown in Table VI, indicates no major autocorrelation in the residuals, whereas the plots in Figure 4, suggest random dispersion around zero, with minor deviations in the later years. The residual Autocorrelation Function (ACF) in Figure 5 shows no significant spikes as well, which further validates the OLS assumptions. A comparison of the actual and predicted values, shown in Figure 6, indicates a strong alignment during the training period (1980–2015), demonstrating a good in-sample fit. However, during the testing period (2016–2022), the model underperforms slightly, suggesting reduced predictive power. This decline may reflect structural changes in Malaysia’s energy sector, including the gradual integration of renewable energy and efficiency improvements, as well as outside influences, which create nonlinearities that are beyond the scope of linear regression.

TABLE V. VIF VALUES FOR MULTICOLLINEARITY CHECK

Variable	VIF
Const	3059
Electricity consumption	889.6
Primary energy supply	423.3
GDP	285.6
FDI	6.753
Manufacturing output	1239
Urban population	5957
Population	2296
Population growth rate	18.05
Imports	inf
Exports	inf
Trade balance	inf

TABLE VI. MODEL PERFORMANCE METRICS (TRAIN/TEST)

Metric	R <sup>2</sup> _train	AdjR <sup>2</sup> _train	RMSE_train	MAE_train
Values	0.9989	0.9984	498.5	393.1
Metric	R <sup>2</sup> _test	RMSE_test	MAE_test	Durbin Watson in_sample
Values	-1.724	5893	4872	1.862

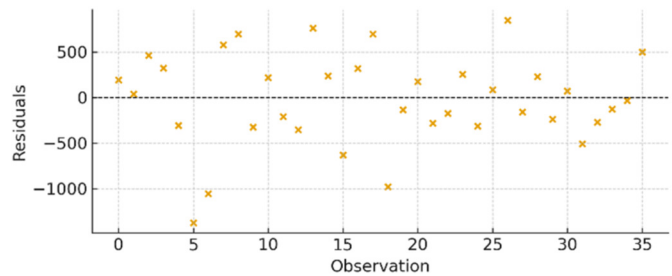


Fig. 4. Residuals plot.

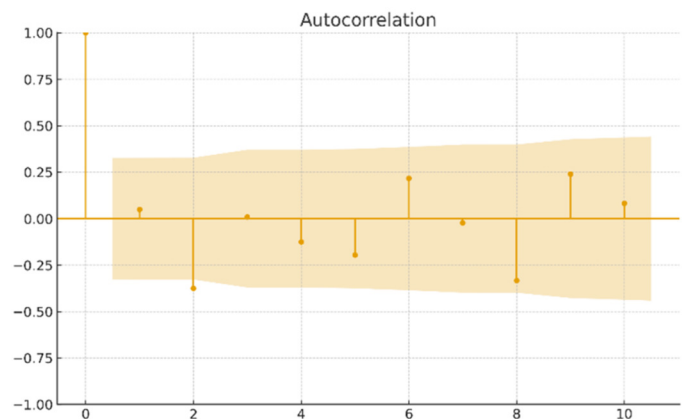


Fig. 5. Residual ACF plot.

E. Policy Implications

The strong correlation between FEC and GDP indicates that energy demand is closely tied to economic growth, underscoring the importance of energy policies that align with industrial growth trajectories. Manufacturing output is a key driver, indicating that efficiency improvements and energy diversification in the industrial sector are central to sustainable energy management. The importance of the urban population underscores the necessity of demand-side management policies in urban centers, especially regarding transportation and

residential energy use. Finally, the role of imports, exports, and FDI suggests that Malaysia's energy demand is sensitive to global economic integration, requiring continuous monitoring of trade and investment flows. Together, these implications provide actionable insights for balancing energy security with sustainable growth.

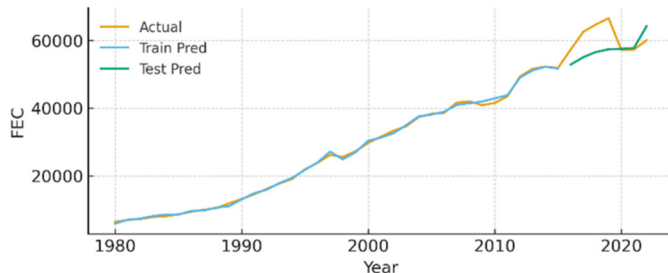


Fig. 6. Actual versus predicted plot.

#### IV. COMPARATIVE ANALYSIS OF RESULTS

The results of this study align with previous literature on the relationship between energy demand and economic activity. However, they also expand on existing knowledge by using a broader set of variables, applying systematic feature selection, and conducting diagnostic testing. Authors in [16] analyzed Malaysian energy consumption using regression methods and identified GDP and electricity demand as dominant drivers. While their findings align with the present study in highlighting GDP and electricity consumption as dominant drivers, their dataset was restricted to fewer variables and did not include trade or FDI. Authors in [28] showed that export intensity (medium/high-tech exports) and energy consumption are nonlinearly linked across ASEAN, indicating that trade-driven industrial dynamics can amplify energy needs. Similarly, authors in [13] emphasized the importance of trade and FDI in shaping energy consumption across developing Asian economies. These findings corroborate the present results, in which imports, exports, and FDI help explain variations in final energy consumption, though with less reliability than GDP and manufacturing output. Comparative evidence suggests that, although trade-related variables are important, domestic economic expansion and urbanization are the primary structural factors driving energy consumption in Malaysia. Authors [18] used machine learning with Boruta-Lasso feature selection to identify GDP, industrial activity, and urbanization as the strongest predictors of energy demand. Authors in [21] also found that deep learning approaches, particularly CNN-BiLSTM with attention, consistently emphasize economic growth and population-related factors as the main determinants. This study supports these findings using regression analysis and shows that, even within traditional econometric frameworks, GDP, manufacturing output, and urbanization are reliable predictors. Previous studies often used shorter time spans or fewer predictors, limiting their ability to detect structural changes, such as trade liberalization, demographic transitions, and investment inflows. By covering the period from 1980 to 2022 and applying systematic diagnostics, the current analysis provides stronger evidence of redundancy between the population and the urban population, as well as the

limited explanatory power of the trade balance. This comparative perspective highlights the value of the study in improving the set of relevant predictors and establishing a stronger empirical foundation for policy and future model development.

#### V. CONCLUSIONS

This study examined the long-term relationship between energy consumption and various economic factors in Malaysia from 1980 to 2022. Regression-based modeling and systematic feature selection techniques were used, showing that primary energy supply, electricity consumption, and manufacturing output are the strongest determinants of Malaysia's energy demand, followed by exports and Foreign Direct Investment (FDI). Variables such as Gross Domestic Product (GDP), urban population, and imports exhibit limited explanatory power once collinearity effects are considered. These findings confirm that industrial expansion and trade activities are central to Malaysia's long-term energy dynamics, while urbanization indirectly influences demand through manufacturing and service growth. Diagnostic testing, such as Variance Inflation Factor (VIF), Durbin-Watson, and residual analyses, verified the regression model's reliability, while Lasso feature selection reinforced the dominance of energy supply and industrial variables. Overall, the results underscore the necessity of coordinated policies that align economic diversification, industrial growth, and energy efficiency initiatives to ensure sustainable energy development. Future studies should use time-series analysis to capture nonlinear and dynamic behavior in energy demand, by combining ARIMAX, RNN, LSTM, and hybrid deep-learning frameworks. Incorporating renewable energy indicators, carbon emission targets, and energy price elasticity would strengthen the models' interpretability and policy relevance. Comparative assessments between econometric and data-driven models across ASEAN economies are encouraged to identify cross-regional drivers of demand. Additionally, scenario-based modeling aligned with Malaysia's National Energy Transition Roadmap (NETR) could evaluate the long-term impact of decarbonization strategies on energy consumption.

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