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Research Article

Estimation of Primary Energy Consumption for a Panel of Five ASEAN Countries by Models Derived from Trend Analysis

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Abstract

Compared to other approaches like artificial intelligence (AI), which involve numerous parameters and greater complexity, trend analysis (TA) is simpler and founded on the idea that future developments can be predicted by studying patterns from past events. Thus, this work employed TA as a simple and practical modeling technique to derive estimating models for the primary energy consumption (PEC). A panel of five ASEAN countries, known as the ASEAN – 5 (Indonesia, the Philippines, Malaysia, Singapore and Thailand) were selected as the study's case. Various statistical indices were then employed to test the validity and robustness of the derived models. In addition, the PECs of the ASEAN – 5 countries were estimated by the derived models from 2025 to 2035. The results showed that all of the derived models could achieve up to 97% accuracy in their estimations. Additionally, the projected results revealed that the ASEAN – 5 countries' total PEC would increase at a rate of 1.82% annually and 20.33% overall by 2035, when compared to the data in 2023. In summary, this paper concludes that models for estimating the PEC may be derived efficiently using the trend analysis.

Keywords: Primary energy consumption, Trend analysis, Modelling, Estimation

Trend Analizinden Türetilen Modeller ile Beş ASEAN Ülkesinin Birincil Enerji Tüketiminin Tahmini

Öz

Trend analizi (TA), yapay zekâ gibi çok sayıda parametre içeren ve daha karmaşık olan diğer yaklaşımlarla karşılaştırıldığında, daha basittir ve geçmiş olaylardaki örüntüleri inceleyerek gelecekteki gelişmelerin tahmin edilmesine imkân tanır. Bu nedenle, bu çalışmada, birincil enerji tüketimine (PEC) yönelik tahmin modelleri türetmek amacıyla basit ve pratik bir modelleme tekniği olarak trend analizi kullanılmıştır. ASEAN – 5 (Endonezya, Filipinler, Malezya, Singapur ve Tayland) olarak bilinen beş ASEAN ülkesinden oluşan bir grup ülke, çalışmanın örneklemi olarak seçilmiştir. Ayrıca, türetilen modellerin geçerliliğini ve sağlamlığını test etmek için de çeşitli istatistiksel endeksler kullanılmıştır. Ek olarak, ASEAN – 5 ülkelerinin PEC'leri türetilen modeller tarafından 2025'ten 2035'e kadar tahmin edilmiştir. Sonuçlar, türetilen tüm modellerin tahminlerinde %97'ye varan doğruluk elde edebileceğini göstermiştir. Tahmin sonuçları, ASEAN – 5 ülkelerinin toplam PEC'nin 2023'teki verilerle karşılaştırıldığında 2035 yılına kadar yıllık %1,82 ve genel olarak %20,33 oranında artacağını ortaya koymuştur. Özetle, bu çalışma, PEC'ni tahmin etmek için trend analizi kullanılarak modellerin verimli bir şekilde türetilebileceği sonucuna varmıştır.

Anahtar Kelimeler: Birincil enerji tüketimi, Trend analizi, Modelleme, Tahmin

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1. Introduction

Energy is undoubtedly indispensable for the economic ecosystems of all countries, but it is particularly vital for those at the forefront of sustainable development goals and plans. Over the past few decades, the world's economy has grown rapidly due to the enormous increase in the world's energy consumption (particularly fossil fuels). Until inefficiencies arise, energy will be the fundamental component of economic growth and development, as it drives global economies [1].

Energy can be normally utilized in a variety of ways and extracted from several sources. These sources that are either found or stored in nature are referred to as primary energy sources. The major common energy sources are coal, oil, natural gas, renewables, nuclear and hydropower. These sources can be either used directly as the primary energy and/or converted in industrial utilities into secondary energy sources. Among these sources, the FFs account for the majority of the primary energy resources that are currently widely and regularly used. In 2023, almost 81.5 percent of the world's PEC came from these resources, (roughly 32%, 27% and 24% of which result from oil, coal and natural gas respectively), followed by renewable energy resources at 8.16%, hydroelectric at 6.40% and nuclear energy at 4%. In spite of the numerous initiatives and regulations that promote the adoption of sustainable energy resources, it is anticipated that the proportion of the FFs in the world's energy mix will keep rising in the coming years [2,3]. On the other hand; the PEC of the world reached to 620 exajoule (EJ) in 2023. China, United States, India, the Russian Federation and Japan were the top five consumers in 2022. As shown in the Fig.1, together, a total of 58.4% of the world's PEC was consumed by these top five countries [2].

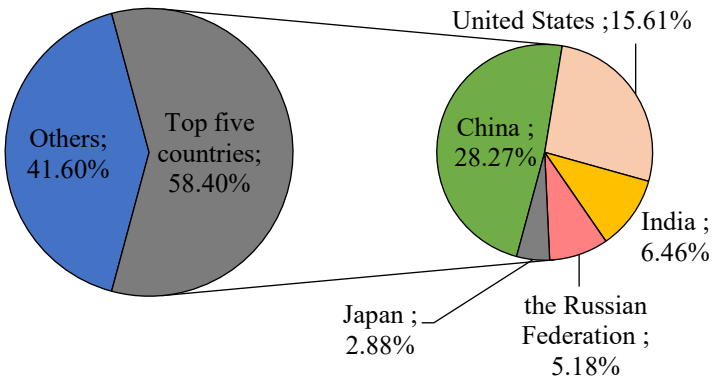


Figure 1. Top five primary energy consumers in the world [2]

Owing to the significance of energy for the countries' economic developments and the rise in energy demand in recent years, there have been numerous debates among all relevant parties, including academics, over how to meet this demand. Therefore, both academics and other stakeholders (e.g. policy makers, energy investors) are stepping up their efforts to ensure that the development of the energy sector is more secure, more affordable and more sustainable. In order to achieve these goals, future projections need to be much more effective. This will enable

countries to rigorously plan their energy projections. A significant contribution can be made to overcome the aforementioned problem by deriving sound, reliable and consistent predictive models on a regional or national scale. In this framework, the current study aims at developing models for estimating the population-based PECs of Indonesia, the Philippines, Malaysia, Singapore and Thailand, which are known as the founding countries of ASEAN or ASEAN – 5 (Association of South East Asian Nations, an intergovernmental group with ten members in the region - Indonesia, Malaysia, the Philippines, Singapore, Thailand, Vietnam, Myanmar, Cambodia, Lao People's Democratic Republic and Brunei Darussalam) [4]. Trend analysis (TA) is employed to develop the population-based estimating models using data spanning the years 1980 to 2022 for the PECs and TPs of the relevant countries. Actually, the current study's main objective is based on two-fold as to derive predictive models and estimate the future PECs of the ASEAN – 5. In this regard, the following summarizes the importance of our study and what distinguishes it from earlier studies in terms of methodology and scope.

- A report by the IEA [5] indicated that the ASEAN region's portion of the world's energy demand grew from 30% to 40% between 2000 and 2017, and it will reach 45% by 2040. That is, this organization is poised to become the world's most rapidly expanding and dynamic hub for energy consumption. Besides, a significant development following COP26 and COP27 was the introduction of a new global program known as the JETPs. They are essentially a tool for mobilizing climate finance. In this regard, their goal is the acceleration of the just transition to a low-carbon economy [6]. Included two members of the ASEAN (Indonesia and Vietnam), there are several countries that have been supported for developing a JETPs. This shows that ASEAN will be among the regions where energy investments will expand fastest in the world.
- Although the ASEAN has 10 members formally, the current study adopts only a panel of five ASEAN nations (ASEAN – 5) due to their fast rate of urbanization, increased energy consumption, electrification, and improved living standards [7]. For instance, the ASEAN – 5 includes more than 6% of all people worldwide and govern 3% of the global economy with their over half billion people and over 3 trillion US dollars' gross domestic products (GDPs) respectively. Hence, accurate forecasts are required for such countries' future energy strategies.
- It is fact that the majority of artificial intelligence-based computing techniques have the benefits of precisely representing long-term trends phenomenon. However, they have certain drawbacks (e.g. black box in it) in the development of the models and applied in real-world scenarios due to their complex structures. Simpler and less accurate modeling strategies may be, therefore, more suitable to overcome the relevant challenges. This is precisely the goal of the chosen methodology of the current study.
- The TA is less complex than other methods that require more parameters and are significantly more complex. It puts out the notion that readers may predict what's going to occur in the future by examining prior events that have already occurred. In other words; the TA is a branch of study that uses historical data to attempt to forecast future movements [8]. The primary focus is on identifying and quantifying patterns that can be represented by lines or surfaces [9]. Hence, the predictive models in the current study are derived using the TA.

- As fa as the authors are aware, there isn't a published study addressing the TA's capacity to model PECs of the ASEAN – 5. Thus, the current study is the first study that applies the TA for testing its capacity to model the PECs of the relevant countries.

2. Association of Southeast Asian Nations (ASEAN)

2.1. Geographic, Demographic and Economic Profiles

As an emerging power in the world economy, the Association of Southeast Asian Nations is a ten-member regional intergovernmental organization within the Southeast Asia region. It was officially founded in 1967 in Bangkok, Thailand as the founding countries (Indonesia, Malaysia, the Philippines, Singapore and Thailand) signed the ASEAN Declaration (Bangkok Declaration). In 1984, 1995, and 1997, successively, Brunei Darussalam, Viet Nam, Lao PDR and Myanmar took part in the organization respectively. Following the admission of Cambodia in 1999, ASEAN today serves as a ten-member organization. It mainly aims at promoting economic growth, regional peace and stability and cooperation in social, cultural, technical, educational and other fields [10,11]. As one of the largest economic alliances, the ASEAN countries are known by their distinctive stage of development, industrial output, politics, history, demographic and geography. A wide range of socio-economic conditions, from low-income to middle-income economies, exist in ASEAN member countries. Although several nations are seeing swift economic expansion and industrialization, others are confronted with issues including disparities in income and unequal progress. Geographically, the ASEAN nations are sandwiched between two continents with generally humid and tropical climates; only Myanmar has subtropical climate (Fig.2). As reported by the World Bank [12], ASEAN is home to 8.6% of the world's population with 685 million people, and the region's total land area is 4409572 square kilometers or 3.4% of world land surface geographically. In addition, the region’s cumulative gross domestic products (GDP) exceeded 3.5 trillion US dollars as of July 2024. That means, the ASEAN governs 3.5% of the world economy. In the event that ASEAN is regarded as a single economic unit, it will already be one of the top six largest economies in the world [13]. Nevertheless, comparatively, the organization’s economy is larger than the most countries such as UK. Moreover, the ASEAN countries have shown a growing trend recently as well. Again as of July 2024, six members of the ASEAN has higher annual growth rates than the world’s average that is 2.72%. the Philippines, Cambodia, Viet Nam and Indonesia have the largest annual growth rates of 5.54%, 5.40%, 5.04% and 5.04% respectively among the members. Additionally, four members of the ASEAN, Indonesia, the Philippines, Malaysia, Thailand and Viet Nam are projected to advance their current GDP positions in a high place by 2050. For instance, Indonesia is predicted to be the fourth largest world economy surpassing Japan by 2050. Moreover, Brunei Darussalam, Singapore and Malaysia were classified as countries of “Very High Human Development”, Indonesia, the Philippines and Viet Nam fell into the category “High Human Development”, Cambodia, the Lao PDR and Myanmar were countries of “Medium Human Development” as of March 2025. It should be noted that five ASEAN members (Indonesia, Malaysia, Philippines, Singapore, and Thailand), as mentioned above, also known as ASEAN – 5, account for the majority of the group's economic dominance. Despite having the largest economies and the most populous of the

ASEAN nations, the fastest-growing urbanization and electrification rates, there are also a number of differences among ASEAN – 5, including the size of their economies, living standards, endowments in natural resources, and the industrials promoting economic growths. As of March 2025, almost 3.1 trillion US dollars GDP came from ASEAN – 5. They occupy 3 million square kilometers of the ASEAN total as well and they home 6.38% of all people worldwide while ASEAN total is almost 8.62%. In other words; the ASEAN – 5 occupies 2.34% of the world land surface while the ASEAN total is 3.4%. Similarly, the ASEAN – 5 contributed 3.06% to the world economy, whereas the ASEAN's total contribution was 3.58%.

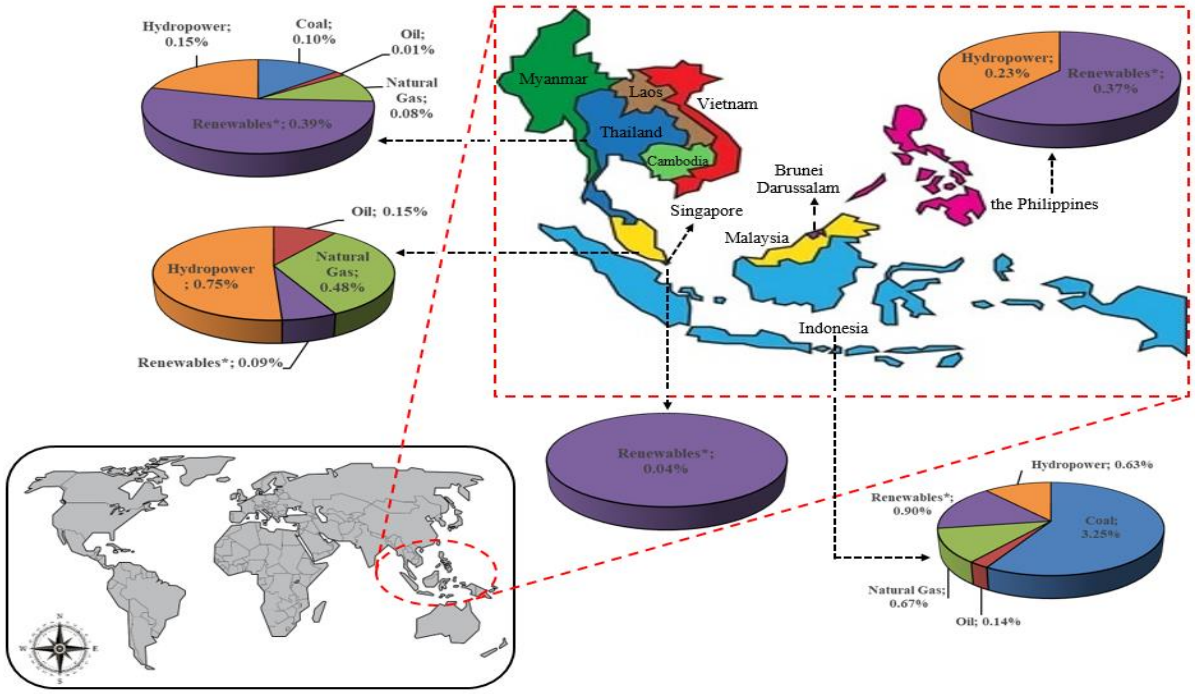


Figure 2. Geographical location and energy reserves of the ASEAN – 5 [2,14]

2.2.Energy Profile

Southeast Asia's energy sector future is now firmly in the global spotlight due to the region's rising economy and population. Despite their patchy distribution throughout the region, the region has abundant and diverse energy resources from the FFs to RE and hydro. As reported by [2] in 2023, together, all ten member states held almost 0.5%, 2% and 4% of oil, natural gas, and coal reserves worldwide respectively. In addition to the FFs such as oil, natural gas and coal, the region held roughly 4% of global hydroelectric energy resources and 3% of renewable energy resources. The so-called as ASEAN – 5 have a remarkable share in terms of the FFs and renewable energy reserves within the region. The remaining ones have considerable hydroelectric resources. In other words; the ASEAN – 5 has 3.35%, 1.79%, 1.77%, 1.22%, 0.3% and of the world coal, renewables, hydropower, natural gas, and oil reserves respectively. The region's coal and hydropower resources are remarkably shared by Indonesia and Vietnam (Fig.2). Although they have significant energy resources, these resources cannot meet the energy needs of the region. Based on the underlying statistics, the ASEAN region's TPES is mostly derived from the FFs, biomass, and modern renewable energy sources. During the past

20 years, the region's total PEC has increased dramatically. Notable increases have been seen in the use of sustainable energy sources in addition to coal, oil, and natural gas as the FFs. In other words; the historical development of PECs in the ASEAN region reflects an increasing trend. In 2023, total PECs of the ASEAN reached to 30.48 EJ, 25.59 EJ of which resulted from ASEAN – 5, while the world primary PECs was 619.63 EJ, pretty much to 5 percent of all PECs globally. Indonesia, Malaysia and Thailand among the ASEAN – 5, they were particularly noticeable among the main countries impacting these amount (Fig.3). In 2023, with 27.25 EJ or almost 90% of total PECs of the organization, the FFs fulfilled a significant portion of PECs in the ASEAN – 5 countries. Among these fuels, oil accounted the majority of FFs, (11.12 EJ). Following the FFs, the renewable and hydroelectric were the next energy sources in terms of the PECs. By the way, there is no nuclear energy consumption within the organization so far [2].

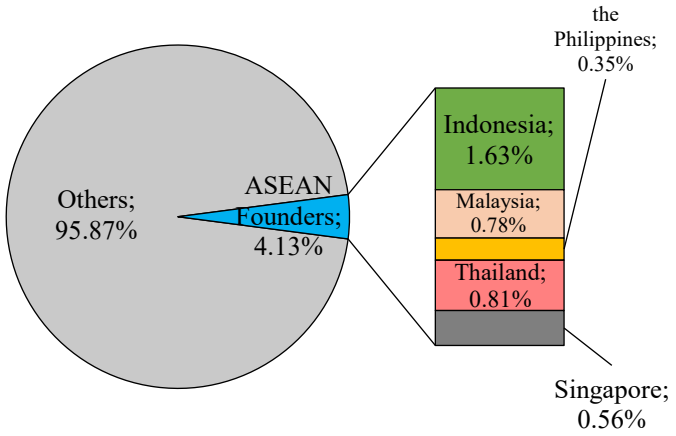


Figure 3. Shares of the PECs of the ASEAN – 5 in the world [2]

3. Data and Methodology

3.1. Dataset and Variable Description

This study used the PEC and TP of the ASEAN – 5 countries as dependent and independent variables respectively. Kavaklioglu et al. [15] and Kankal et al. [16] revealed that an increasing number of people means that there is a greater need for energy resources because of various human activities. Additionally, the TP and energy requirements have a strong correlation, and their time series are readily accessible in a variety of statistical databases. In the current study, the TP was, therefore, used as an independent variable. Both data for the PEC and TP were taken from the officially and freely available on line sources [2,12], spanning the years 1980 to 2023 for the PECs and TP of the relevant countries respectively.

3.2. Descriptive Statistics

Prior to training the data for model deriving, an analysis was done for the variables' descriptive statistics and the results are presented in Table 1. The figures in Table 1 indicates that for practically all ASEAN – 5 nations as well as the ASEAN – 5 as a whole, the mean values of

PEC and TP are larger than the standard deviations (SDs). The PEC and TP, for example, have mean values of 10.712 and 365.220 for the ASEAN – 5 as a whole, with respective variability of 5.739 and 63.927. Based on the CV, the difference is notably substantial and exhibits the most associated variation as well. This speaks well for the homogeneity and consistency of the data set. Additionally, in the context of statistical analysis, uneven probability distributions around mean values are measured by their skewness, while the kurtosis measures how peaked the distribution is [17]. The fundamental assumption is that the kurtosis and skewness values should be zero for an observed data set in order for it to be symmetrical or regularly distributed. However, a considerable number of researchers reports that the observed series can also be considered to have a normal distribution if both values were within ±1.5 [18-19]. In particular, the PEC data series for almost each of the ASEAN – 5 nations show positive skewness, with a thicker tail on the right side. Only the PEC of the Philippines presents negative skewness, indicating the thicker tail on the left side. Additionally; other than the TPs of the Philippines, Malaysia and Singapore, the TPs of the remaining ASEAN – 5 nations exhibit a negative skewness. Moreover, it can be observed that every data series in the group, including the global and ASEAN – 5 total, confirm that the kurtosis curve is platykurtic since they are all below the typical value. We may, therefore, conclude that the skewness and kurtosis values in Table 1 support a normal distribution of the series. The Jarque-Bera (JB) test for normalcy, which provides strong proof that all observed series have a normal distribution because of the highest p-values ($p > 0.05$), yields results that are compatible with the skewness and kurtosis. Therefore, it can be concluded that the data mainly confirms one of the fundamental assumptions of the regression model, as forward by Ostrom [20].

Table 1. Descriptive statistics for the PECs in the ASEAN – 5 countries

Country	Variables	Mean	Min	Max	SD	CV(%)	Skewness	Kurtosis	JB test
Indonesia	PEC	3.751	1.100	6.820	1.921	51.209	0.150	-1.176	0.331
	TP	206.767	148.177	259.091	33.159	16.156	-0.065	-1.175	0.351
the Philippines	PEC	0.937	0.490	1.160	0.318	33.686	-0.003	-1.133	0.382
	TP	74.331	48.419	103.031	16.775	22.569	0.113	-1.255	0.295
Malaysia	PEC	1.971	0.460	4.010	1.196	60.702	0.285	-1.380	0.188
	TP	21.787	13.215	31.068	5.630	25.841	0.090	-1.306	0.272
Singapore	PEC	1.556	0.400	3.360	0.861	55.252	0.362	-1.031	0.304
	TP	3.825	2.413	5.535	0.963	25.182	0.286	-1.132	0.299
Thailand	PEC	2.494	0.520	4.960	1.473	59.076	0.123	-1.341	0.248
	TP	60.038	45.737	70.294	7.512	12.512	-0.392	-1.097	0.256
ASEAN – 5 total	PEC	10.712	3.010	20.450	5.739	53.575	0.184	-1.321	0.244
	TP	365.220	257.961	469.019	63.927	17.504	-0.035	-1.218	0.327

3.3. Methodology

For the purpose of estimating the population-based PECs in the ASEAN – 5, this study used the TA to derive predictive models. By using the dependent variable's past trend, the TA can

derive models that estimate the variable's future values. The study, therefore, assumes that the PECs will continue to follow its historical trend. As reported in previous sections, the main benefit of this method is that it is easy to use and allows estimating using any available data. [21-23]. The annual PEC data were split into two sets. For the modelling studies, as well – known that the data sets are often split into two categories as training and testing/validation. Thus, in the current study, almost 82% of the total (from 1980 to 2015) was utilized to train the model, and 18% of the total data (from 2016 to 2023) was utilized to test/validate the model respectively. Based on the functions that are linear, logarithmic, power, exponential, inverse, growth and S, all predictive models were derived by SPSS statistical software, providing a choice of regression. An important step in the entire modelling process is to verify the effectiveness of a predictive model once it has been derived. The goodness of a fit can be verified using a variety of statistical tests. It is highly advised to employ them in order to validate the derived models [24]. In the current study, a number of statistical tests are used for the verification of the derived models, among which the R^2, the t-test, the F-test and the predicted versus the observed data. The R^2 is frequently utilized in statistics to validate and evaluate model performance. It is a measure of the precision of the model and indicates the percentage of variance in one variable that can be predicted from another. In other words; the R^2 has a value in the range of 0 to 1. The model's high prediction performance is indicated by the R^2's proximity to 1. That is, high values of R^2 indicate more reliability of the model [25-27]. In statistical inference, the F - and t tests are important since they have a direct impact on model coefficients, confidence intervals, and, in the end, hypothesis testing findings. In the t-test, the computed and tabulated t-values are compared with the null hypothesis. If the calculated t-value exceeds the tabulated value, the correlation is considered significant. At the 95% confidence level, an analysis of variance was also performed to assess the significance of the proposed models. When performing the variance analysis, In the event that the calculated F-value exceeds the tabulated F-value, the proposed models are deemed verified [25,28]. As with any conventional approach, it is critical to specify the measures that will allow us to evaluate the models' ability to forecast. In the relevant field, numerous widely-used forecast error metrics are available [29]. Seven of them that are recorded in Table 3 were employed in order to assess each model's forecasting accuracy objectively in the current study. Regardless of performance criteria, generally, The smaller the metrics' value, the better the model [30,31]. In other words; the proposed model is more precise when the indicators are smaller. On the other hands; representing the errors associated with the models, the MAD and MSE are two measures for the absolute projected error's average size [32], while the RMSE represents a degree of dispersion rather than a precise error. It calculates how far the observed value deviates from the actual ones. Found by dividing the observed data's average value by RMSE, the RRMSE is a measure of a model's total relative accuracy. Additionally, the U_{95} is employed to display additional details regarding the model deviance. Moreover, a flowchart of the current study is shown in Fig.4.

4. Results and Discussion

4.1. Derived Models and Verification

Table 4 reports the derived models for estimating population-based PECs. First, individual models for each of the ASEAN – 5 countries were derived for all equation forms. The models were also derived for the ASEAN – 5 total using the similar process.

Table 3. Statistical indices for assessing the models' efficacy

Mean absolute deviation	$MAD = \left(\frac{1}{n}\sum_{i=}^{n}\lvert X_i - Y_i\rvert\right)$
Mean square error	$MSE = \frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2$
Root mean square error	$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2}$
Relative root mean square error	$RRMSE = \frac{RMSE}{\bar{O}}.100$
Maximum absolute relative error	$erMAX = max\left(\left\lvert\frac{X_i - Y_i}{Y_i}\right\rvert\right)$
Mean absolute percentage error (%)	$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{\lvert X_i - Y_i)\rvert}{Y_i}\right).100$
Uncertainty at 95%	$U_{95} = (1.96)\sqrt{SD^2 + RMSE^2}$

where; n is the total number of data, X_i is the predicted PEC, Y_i is the actual PEC, $\bar{O}$ is the mean value of observed data

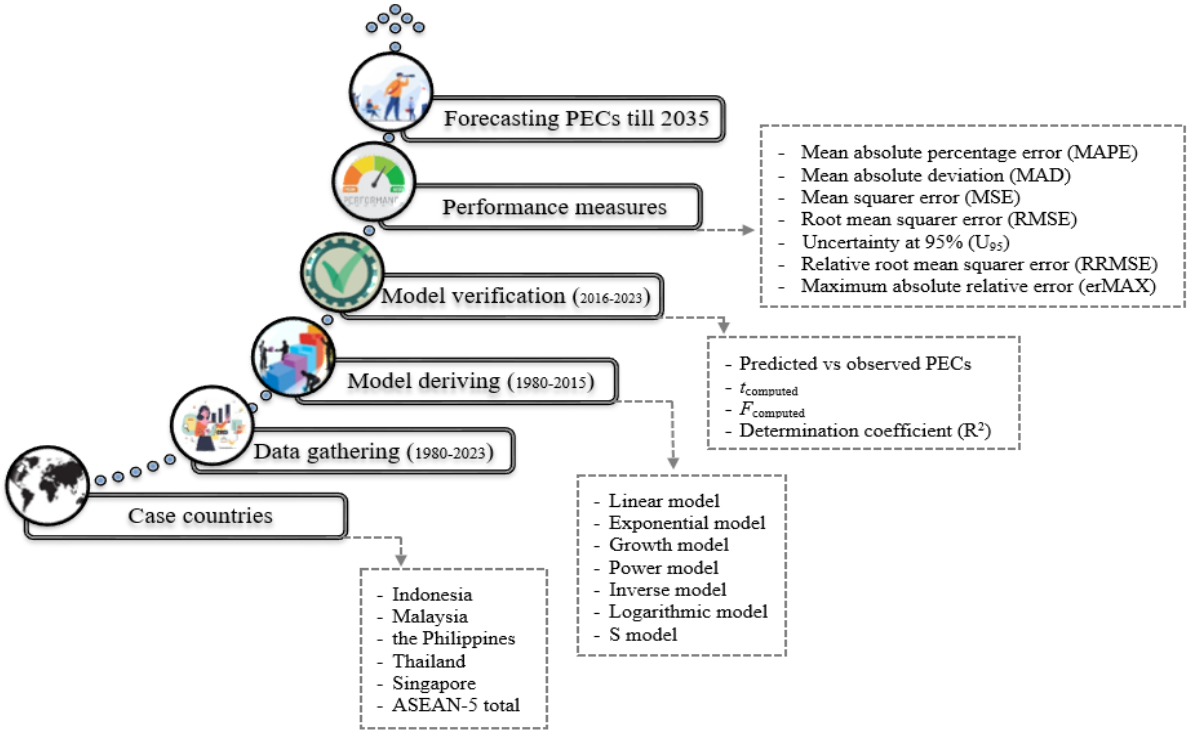


Figure 4. A framework of the study

Considering the values of the highest R^2, which proves a substantial correlation between the variables and lowest MAPE values that enable the evaluation of the relative error as a percentage, the best model for each of the ASENAN – 5 nations and the ASEAN – 5 as a whole was chosen upon all model forms were derived. The mathematical equations in Table 4 indicate that the models for Indonesia, Malaysia, Singapore, Thailand and ASEAN – 5 total are described by S regression function, while the model for the Philippines is based on growth function. Table 5 displays the statistically verified findings of the derived models using the t- and F-tests and R^2.

Table 4. Derived models

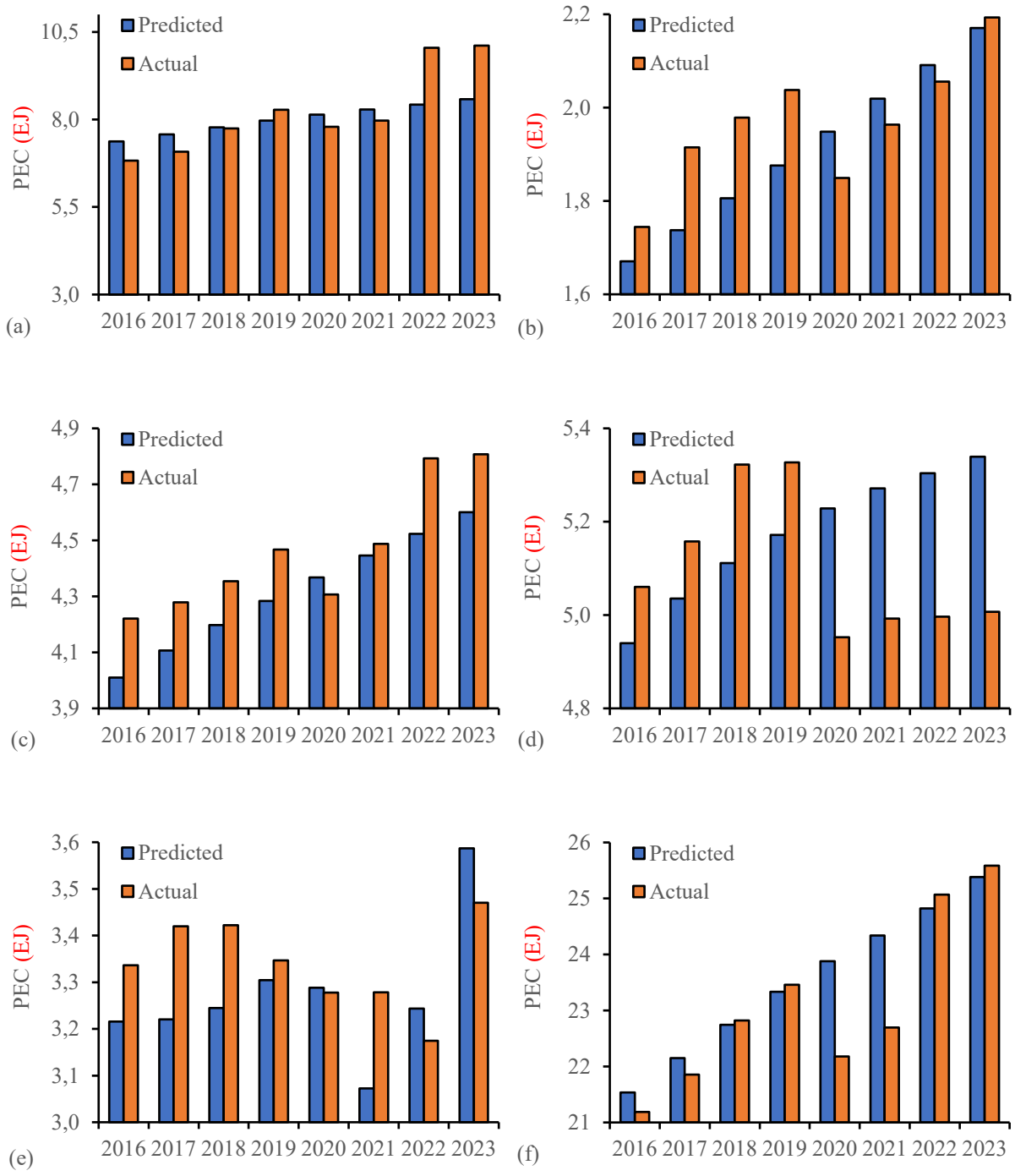
Countries	**Derived models**	
Indonesia	S	$y = e^{[(4.679) - (701.925) / (TP)]}$
the Philippines	Growth	$y = e^{(-1.689) + (0.021).(TP)}$
Malaysia	S	$y = e^{[(3.084) - (53.445) / (TP)]}$
Singapore	S	$y = e^{[(2.782) - (9.049) / (TP)]}$
Thailand	S	$y = e^{[(6.280) - (330.635) / (TP)]}$
ASEAN – 5 total	S	$y = e^{[(5.629) - (1214.248) / (TP)]}$

Table 5. Statistical results of the derived models indicating the verification

Country	**Model function**	**Variable**	$t_{computed}$	t_{table}	$F_{computed}$	F_{table}	R^2
Indonesia	S	Constant	82.054	1.690	3897.394	4.125	0.99
		TP	-62.429				
the Philippines	Growth	Constant	-19.644	1.690	346.181	4.125	0.91
		TP	18.605				
Malaysia	S	Constant	61.393	1.690	2932.349	4.125	0.98
		TP	-54.151				
Singapore	S	Constant	47.305	1.690	1945.851	4.125	0.98
		TP	-44.111				
Thailand	S	Constant	53.451	1.690	2309.144	4.125	0.98
		TP	-48.053				
ASEAN – 5 total	S	Constant	98.863	1.690	3745.707	4.125	0.99
		TP	-61.202				

It can be seen that all of the proposed models have R^2 values greater than 0.90, indicating a robust correlation between TP and PEC. Of course, fitting a model based on R^2 alone is insufficient to complete the regression analysis; neither is it sufficient to offer confidence

intervals or run tests. These steps just offer the statistical inferences, which tell us half of the story. Thus, additional tests are required for robust verification. For this reason, the F-and t-values are listed in Table 5. At the 95% confidence level, the computed F- and t-values for each model are both larger than the tabular values, confirming the accuracy of the equations and the model's coefficients, respectively. Additionally, the graphs representing the predicted and actual data demonstrate how closely the two sets of data match, demonstrating the statistical validity of the suggested models (Fig.5).



(a): Indonesia, (b): the Philippines, (c): Malaysia, (d): Thailand, (e): Singapore, (f): ASEAN – 5 total

Figure 5. Predicted vs actual values of the PECs

In conclusion, the verification results confirm whether the derived models may be used to estimate the PECs of the ASEAN – 5 countries separately and ASEAN – 5 as a total, taking into account the conditions of the current study.

4.2. Estimating Abilities of the Derived Models

As noted previously, the derived models' applicability or forecasting performances were demonstrated by putting them through seven statistical criteria. Due to the varying scales of pre-processed, raw and input data utilized for model estimate, the MAPE is the most appropriate tool for evaluating relative error among these criteria. Its benefits of scale independence and interpretability make it one of the most popular measures for predicting accuracy. In addition, its scale independence and ease of understanding make it favored by industry professionals [33-35]. Also, the value of the RRMSE can be also chosen, offering the decisive index on the performance metrics together with the MAPE values as advised by earlier forecasting studies [32, 35-37]. As a result, in addition to other statistical measures, the prediction accuracies of the derived models were primarily assessed using both the MAPE and RRMSE. The reference tables for the MAPE and RRMSE levels as well as the performance metrics results of the derived models are given in Tables 6 and 7, respectively.

Table 6. Reference table of the MAPE and RRMSE for the model accuracies [37,38]

MAPE (%)	**RRMSE (%)**	**Forecasting ability**
MAPE ≤ 10	RRMSE < 10	Excellent
11 ≤ MAPE ≤ 20	10 < RRMSE < 20	Good
21 ≤ MAPE ≤ 51	20 < RRMSE < 30	Qualified
MAPE > 51	RRMSE ≥ 30	Unqualified

Table 7. Performance metrics for the derived models

Nations	**Function**	**MAPE**	**MAD**	**MSE**	**RMSE**	**U_{95}**	**RRMSE**	**erMAX**
Indonesia	S	6.26	0.53	0.05	0.23	1.10	2.84	0.16
the Philippines	Growth	5.73	0.11	0.01	0.09	0.21	4.51	0.09
Malaysia	S	3.52	0.16	0.01	0.09	0.23	1.84	0.06
Singapore	S	3.52	0.12	0.01	0.09	0.21	2.27	0.06
Thailand	S	4.13	0.21	0.01	0.09	0.25	1.94	0.06
ASEAN – 5 total	S	2.83	0.63	0.04	0.19	1.45	0.84	0.08

It is evident from their error indicators that all models have excellent forecasting accuracies given that their RRMSE and MAPE values are both less than 10%. Since their values are close proximity to the ideal value of 0, the derived models have also been validated by other statistical indicators. In summary, the derived models exhibit superior accuracies with less relative errors, as verified by the performance measurement criteria.

4.3. Estimating of the PECs from 2025 to 2035

Using the derived models, the PECs for the economies of the ASEAN – 5 were estimated from 2025 to 2035 using the TP estimations data of the United Nations [39] and the results are displayed in Fig.6.

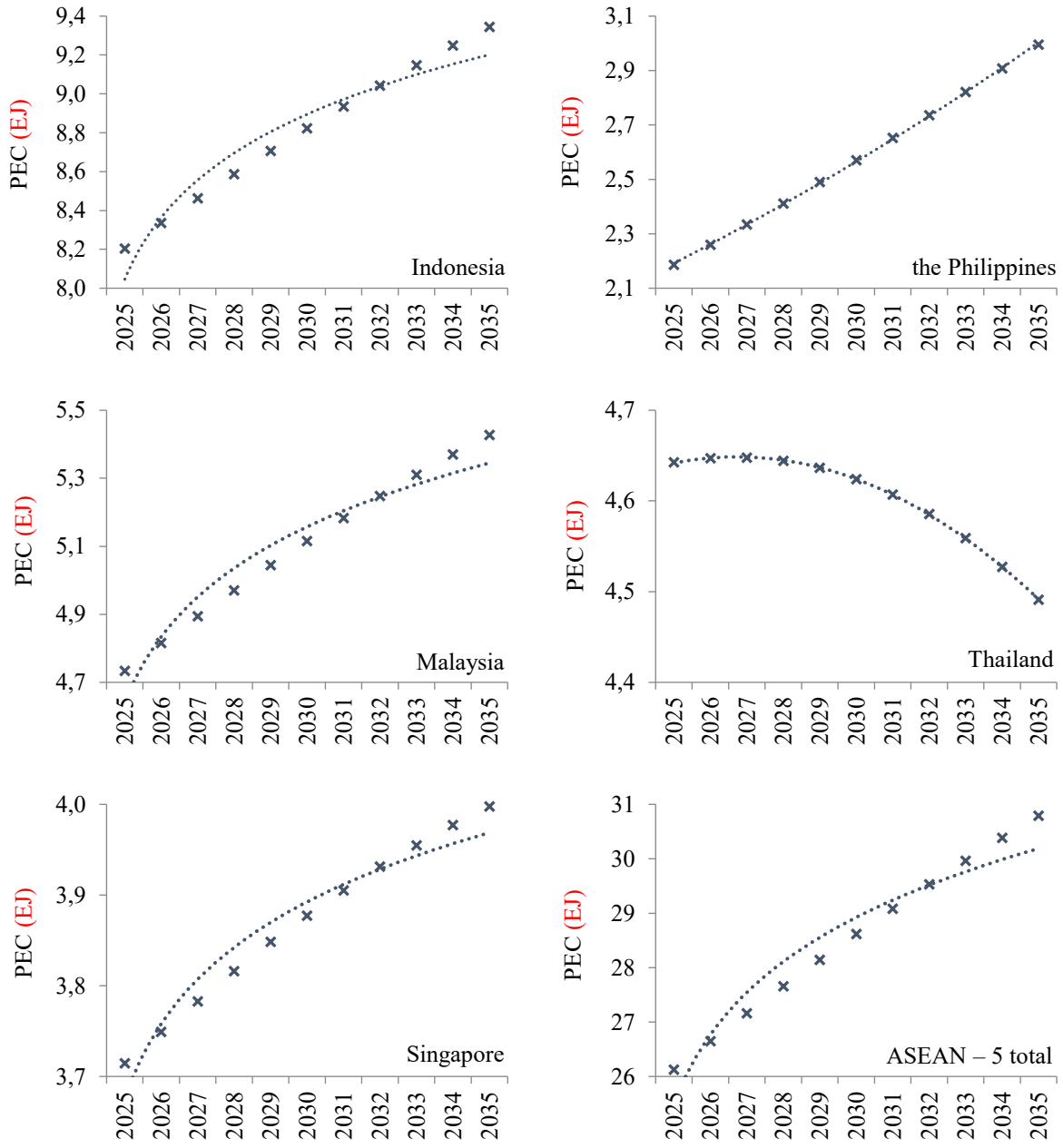


Figure 6. Estimated the PECs in the ASEAN – 5 from 2025 to 2035

The results indicate that the PECs for all nations except Thailand are estimated to increase. ASEAN - 5's total PEC is projected to increase from 25.59 EJ in 2023 to almost 31 EJ in 2035. That means, there will be 20.33% growth in the PEC overall between 2025 and 2035, growing at a slower annual rate of 1.82% (Fig.7).

When considered country-by-country, Indonesia and the Philippines are estimated to see the lowest and largest PEC increases, respectively. In other words; with a 36.77% growth rate, the PEC of the Philippines is expected to rise from 2.19 EJ in 2023 to 3 EJ in 2035, whereas Indonesia's PEC will rise by 6.42%, from 10.11 EJ in 2023 to 10.76 EJ in 2035. In addition, two other countries that will see substantial increases in the PECs of around 13% and 15%, respectively by 2035 are Malaysia and Singapore as compared to 2023's data. Thailand is the only one of the ASEAN – 5 nations where a decline in the PEC is anticipated. It is estimated that the nation's PEC will decline by around 10% in 2035, with an average annual decline of 0.3%, in comparison to 2023 data. It is worth noting that, despite the downward trend, the overall rate of change is not remarkably high. The estimation results of the current paper corroborate the claim found in the energy literature that the TP significantly affects countries' PECs. In other words; it confirms the findings of researches in the body of current literature that show that the population density and energy use are positively correlated [40-44]. For instance, Indonesia has developed into a rising middle-income country which is currently the fourth most populated nation in the world. That is, the middle class makes up one-fifth of high-density Indonesians. On the other hand, it is anticipated that Indonesia would continue to have rapid population expansion for the upcoming 25 years [12,45]. As noted in the current and related studies, the country's rise to middle-income status is accompanied by an increase in energy consumption because of the positive impact of population density on energy use. Thus, it may be inferred from the current indicators that an increase in the PEC in Indonesia would be projected in the upcoming years. In another study [46], it was discovered that population increase and urbanization, respectively, have favorable and statistically significant impacts on energy consumption for Malaysia and Thailand as well. In addition to population growth, the scholars indicated the significance of the urbanization on the energy consumption in their study given that urbanization's increased energy consumption promotes economic growth as described by [15,47,48]. Thus, it can be concluded that the urbanization is directly related to population growth too. These results should cause the current study's estimations and those found in the literature to overlap for Malaysia and Thailand as well as other countries of ASEAN – 5. It is evident from Fig.7 that the outcomes of the current study for the Malaysian and Thai cases align with the findings reported in previous studies. It is vital to include a particular parenthesis for Thailand here because a decline in the nation's population is anticipated in the upcoming years by a report of UN [39], and that's why, it is reasonable to expect a decline in the PEC for Thailand case. As the most prosperous country in the ASEAN – 5 and an economy heavily dependent on energy, both the land area and population of Singapore are the smallest. It is well-known for its engineering, information, and communications industries, as well as for producing electronics [7]. That is why, Singapore is also seeing a rise in energy consumption as a result of the use of several sophisticated technological products and services [49]. Therefore, a rise in energy consumption rather than population growth or population density may be attributed to using numerous cutting-edge

technology products and services for Singapore. This implies that labor and capital are being replaced by energy in the industrial process. It can also be argued that this situation has been prompted by the low rate of population growth and the population-based estimate of energy consumption for Singapore. As for the Philippines, as mentioned above, the country is projected to experience the largest PEC increases among the ASEAN – 5. As of July 2024, there were around 117 million people living in the Philippines. Even if the average annual population growth rate is expected to slow down, the country's population is anticipated to rise in the near future, surpassing 138 million by 2050 [50-52].

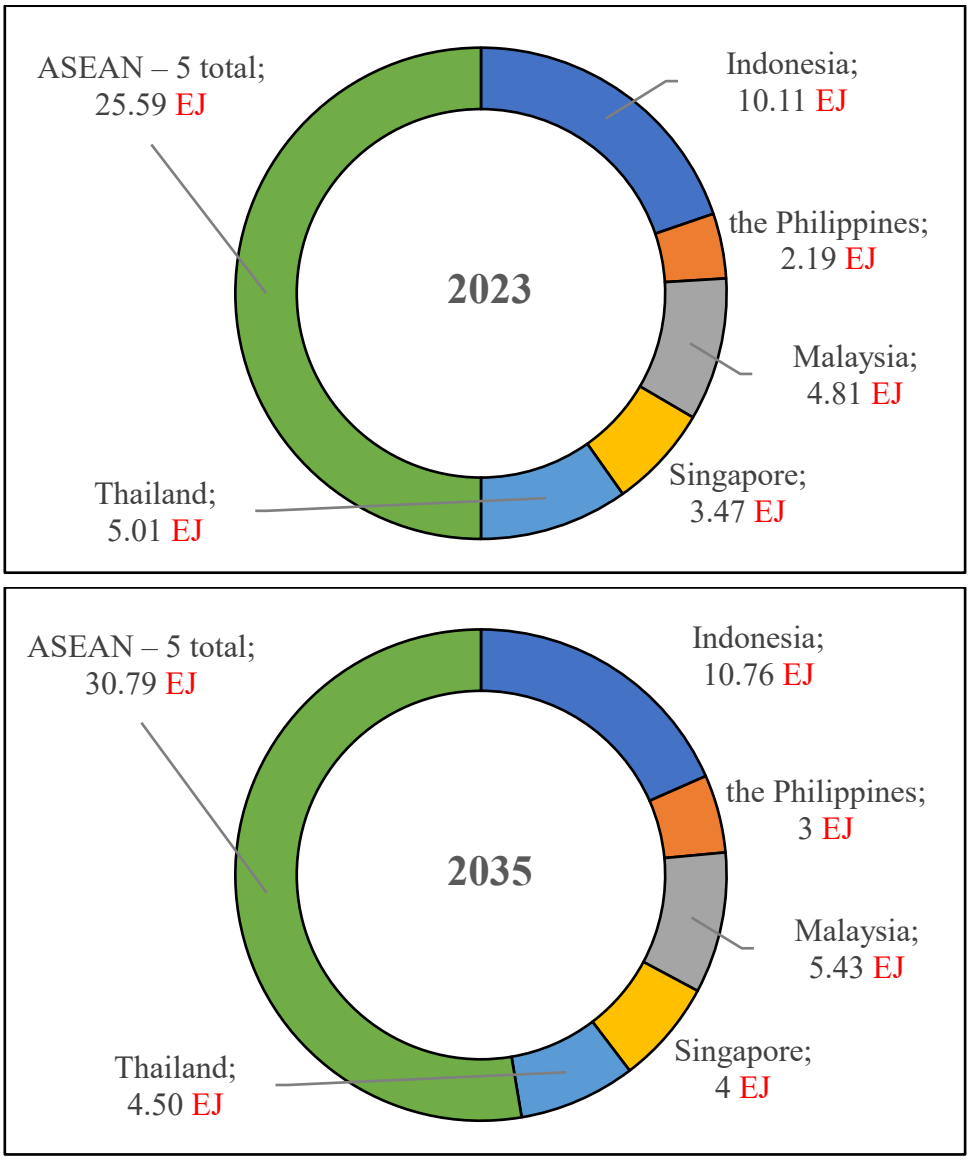


Figure 7. Total PECs of the ASEAN – 5 countries in 2023 and 2035

This suggests that throughout a 30-year period, the population of 2024 will increase by almost 22 million people. In other words; an increase of almost one fifth of the current population is expected in the foreseeable future. This projected increase in population will entail a rise in the sectors, such as infrastructure investments, urbanization, and industries, all of which are heavily

reliant on energy usage as identified by [53,54]. As determined in the current study, therefore, increases in energy consumption can be expected in the near future for the Philippines. It can be finally concluded that the ASEAN and therefore ASEAN – 5 has grown significantly over the last few decades. This current economic growth witnessed by ASEAN, and consequently by ASEAN – 5, is anticipated to persist for an extended period [55]. The ASEAN – 5's energy demand and consumption, which currently primarily rely on FFs, will rise as a result of this economic growth. As a result, all five ASEAN nations ought to put up great effort in addressing pertinent concerns by establishing appropriate goals for their energy requirements.

5. Conclusions

Principal conclusions drawn from this paper, which used the TA to derive estimating models for the PECs of the five major ASEAN nations, with population serving as the independent variable are outlined as. Firstly, it was discovered that the models derived for Indonesia, Malaysia, Singapore, Thailand and ASEAN – 5 total were described by S regression function, while the model for the Philippines was defined by growth function. Secondly, the verification results demonstrated that the derived models may be used to estimate the PEC of each of the ASEAN – 5 countries individually and the ASEAN – 5 as a whole successfully. Thirdly, the performance measurement criteria affirmed that the derived models have excellent estimating accuracies and less relative errors. Fourthly, the performance measure results showed that all of the derived models achieve up to 96% accuracy in their estimations. Fifthly, it was disclosed that the ASEAN – 5 countries' total PEC will reach around 31 EJ, growing at a rate of 1.82% annually and by 20.33% overall by 2035. Sixthly, it was concluded that, with the exception of Thailand, all countries' PECs will rise by 2035. Seventhly, it was estimated that Indonesia and the Philippines will experience the lowest and largest PEC increases, with a total of 6.42% and 36.77% growth rates by 2035 respectively. Finally, overall results showed that the TA can be used to derive models for the estimation of the PEC.

6. Future Works

Recently, the development of a sound sustainable development plan including the energy strategies has become a new challenge for all those responsible for managing the nations, including ASEAN – 5. Of course, there are a number of actions that can help steer the sustainable development plan in this direction, such as projections or estimations suggested in the current study. In light of the derived models' predictive efficiencies in the current study, further actions, including but not limited to, may be listed as i) if the key variables affecting the ASEAN – 5 countries' energy production and consumption could be precisely defined, all parties involved, including politicians, might more efficiently plan their future energy requirements. To this end, further studies on the critical factors that influencing the ASEAN – 5 countries' energy production and consumption are recommended, ii) above all, this study carries significance since it draws the conclusion that the energy consumption should be assessed in relation to population density as in similar studies. Accordingly, the paper urges governments to incorporate population growth into their national energy plans as a part of sound sustainable development, iii) based on the findings from this paper, the PEC of ASEAN – 5 with the exception of Thailand, will exhibit an increasing tendency during the next ten years.

To promote sustainable development and fulfill the growing demand for energy, the ASEAN – 5 countries should increase the rate of energy production, iv) FFs are currently the dominant energy sources in the ASEAN – 5 countries (more than 90% of total), with the rate of around 43%, 22% and 27% oil, natural gas and coal respectively. In order to meet the future energy requirements, the usage of renewable energy sources should be heavily encouraged as FFs are not environmentally friendly and rapidly running out, v) the current results show that the TA can be effectively applied to PEC modeling. Thus, encouragement should be given to the application of TA in especially PEC modeling and the energy-related researches. In addition, the TP was considered an independent factor in this study. It is strongly recommended that estimating models may be derived by the TA, taking into account a variety of variables, such as GDP and UP for various nations and associations besides the ASEAN – 5.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

Author Contributions

All authors planned and designed the study in addition to the data collection and analysis. Moreover, the initial draft of the manuscript was mainly written by second and third authors. Furthermore, all authors commented on, read and approved the final version of the manuscript.

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