Signifikan: Jurnal Ilmu Ekonomi
Volume 14(2), 2025: 339 - 358
P-ISSN: 2087-2046; E-ISSN: 2476-9223
https://doi.org/10.15408/sjie.v14i2.45828

Undesirable Output in Environmental Efficiency: Evidence from ASEAN Countries

Hapsari Ayu Kusumawardhani
Faculty of Economics and Business, Universitas Diponegoro, Semarang
E-mail: hpsrayu@lecturer.undip.ac.id
*Corresponding author

JEL Classification:
C31
G21
I32
O18

Received: 14 April 2025

Revised: 05 August 2025

Accepted: 09 August 2025

Available online: October 2025

Published regularly: October 2025

ABSTRACT

Research Originality: This study enriches the environmental efficiency literature by applying a DEA model that considers undesirable outputs, to produce more comprehensive and accurate efficiency estimates, especially in the context of the ASEAN region.

Research Objectives: To evaluate and compare the relative environmental efficiency of ASEAN countries using the Data Envelopment Analysis (DEA) method.

Research Methods: This study applies the DEA approach to measure environmental efficiency in ASEAN countries from 2000 to 2022, using population and industry as inputs, and GDP and CO2 emissions as outputs.

Empirical Results: The findings indicate variations in environmental efficiency among ASEAN countries, reflecting differences in industrial policies and levels of economic development. Singapore emerges as the most efficient country, while Indonesia is identified as one of the ASEAN countries that needs to focus on improving its environmental efficiency.

Implications: The research results show significant variation in environmental efficiency across ASEAN countries. This finding emphasizes the importance of formulating development policies that are not solely oriented toward economic growth but also address resource efficiency and emission reduction. Countries with low efficiency, such as Indonesia, need to develop more comprehensive, data-driven green transition strategies.

Keywords:

environmental efficiency; data envelopment analysis; undesirable output; sustainable development; environmental economics

How to Cite:

Kusumawardhani, H. A. (2025). Undesirable Output in Environmental Efficiency: Evidence from ASEAN Countries. *Signifikan: Jurnal Ilmu Ekonomi*, *14*(2), 339-358. https://doi.org/10.15408/sjie.v14i2.45828.

INTRODUCTION

Environmental efficiency in developing countries is crucial in achieving sustainable development. The SDGs emphasize the need for inclusive and sustainable economic growth (SDGs Goal 8) (Kreinin & Aigner, 2022; Rai et al., 2019). In developing countries, economic growth often risks increasing the overexploitation of natural resources (Lampert, 2019). The steadily growing population is applying pressure on natural resources, land, and economic activities. This has resulted in various social and environmental issues for countries, threatening their future survival and development (Galkina & Sorokin, 2020; Sadiq et al., 2022). Energy utilization refers to the increased energy consumption during industrialization and urbanization. Members of the ASEAN countries prioritize energy utilization (Chen & Jia, 2017). The booming economy in the ASEAN region prompts governments to consider social and environmental challenges, as most current development models in the area depend on natural resources (Khoa et al., 2025).

The ecological economy is one of the most studied topics right now. As a result, states focus their recovery plans on improving the economy and quality of life, supporting the economy, and increasing energy use and efficiency (Lacko et al., 2023). Energy consumption is a crucial component in advancing any industry or economy. Sustainable development is a worldwide movement that requires nations to balance environmental effectiveness and economic advancement (Feng et al., 2024). The issue of sustainable energy development has gained prominence due to ASEAN's economic expansion during the past two decades. (Karki, Mann, & Salehfar, 2005) Consequently, economic growth has become an important measure of a nation's progress. Rapid economic progress has generated numerous concerns in various countries in recent years. This is necessitated by balancing economic advancement and environmental protection. Consequently, economic growth has emerged as a significant indicator of a nation's performance. However, the rapid economic expansion has generated considerable concern in certain countries in recent years. This is due to the necessity of balancing environmental safety with economic growth. (Grossman & Krueger, 1995)

While most ASEAN nations empirically witness declining economic growth, environmental challenges have escalated markedly. This is demonstrated by amounts of carbon dioxide (CO2) emissions (Haseeb et al., 2019). The implementation of the fourth industry, along with innovation development and technology utilization, facilitates the economic advancement of ASEAN countries. ASEAN is experiencing growth in industry and population, leading to an increase in GDP. However, this growth is also accompanied by increased CO2 emissions from industrial activities (Feriansyah et al., 2023). Energy consumption and environmental issues are becoming increasingly significant globally as the public becomes more aware and concerned. Numerous methodologies have been implemented to resolve environmental and energy-related concerns. The Data Envelopment Analysis (DEA) method is a non-parametric approach to efficiency evaluation that has garnered significant attention. (Zhou et al., 2008a). DEA, developed by Charnes et al. (1978), is a well-known tool for determining the relative efficiency of a group of comparable entities, commonly known as decision-making units

http://journal.uinjkt.ac.id/index.php/signifikan
https://doi.org/10.15408/sjie.v14i2.45828

(DMUs), each with many inputs and outputs. Since the work of Charnes et al. (1978), Data Envelopment Analysis (DEA) has been extensively studied and gained significant recognition across several application domains. The review by Cook and Seiford (2009) presents an overview of significant methodological advancements in DEA. In the realm of energy and the environment, Meng conducted a study on the application of Data Envelopment Analysis (DEA), identifying environmental performance monitoring as a significant application area. The utilization of DEA to assess ecological performance is predicated on the classification of outputs into desirable and undesirable outputs (Meng et al., 2013; Scheel, 2001).

ASEAN countries face significant pressure to balance economic growth with environmental sustainability. However, conventional approaches often ignore negative impacts such as CO_2 emissions. By including undesirable outputs, this study more fully captures this reality. Several previous studies have discussed how efficiency is related to various factors. Although several studies have examined environmental efficiency using the DEA approach, there is still limited research on environmental efficiency within a country and its comparison (Hosseini et al., 2020; Wang et al., 2021; Zhang et al., 2011), primarily focused on developed countries (Hermoso-Orzáez et al., 2020; Lacko & Hajduová, 2018) or large developing countries such as China, India, or Latin American countries (Anser et al., 2020; Chen & Jia, 2017; Jiang & Xie, 2024).

The research conducted by Yasin (2023) on, this study examined the performance of technical efficiency convergence (Beta and Sigma convergence) in 10 ASEAN countries as well as three main partners from East Asia, namely China, South Korea, and Japan, during the period 1990–2021 using the Stochastic Frontier Analysis approach to estimate technical efficiency, and the research results showed that there was a difference in efficiency among ASEAN countries. While this research measures environmental efficiency by adopting the DEA and time series.

Zhang et al. (2011) studied 23 developing countries from 1980 to 2005, focusing on labor, Capital, and Energy consumption in relation to GDP output. This study uses a time span to see the difference in efficiency levels between developing countries from year to year. Empirical results show that efficiencies vary among the 23 countries; for example, China has experienced the most rapid improvement. Practice in China shows that effective energy policies play an important role in improving energy efficiency. In Zhang's research, undesirable outputs were not considered, and only GDP was used as the measure of efficiency.

The research conducted by Xie et al. (2014) focused on analyzing the environmental efficiency of the electricity industry in 26 OECD and BRIC countries (1996–2010). It used the SBM-DEA-based Environmental Malmquist Index, which considers electricity as a desired output and carbon emissions as an undesirable output, with CO2 emissions. The results show that changes in fuel structure and technological advancements are the main drivers of improving the efficiency of dynamic environments. Economic conditions and energy prices also have a significant effect.

The novelty of this research lies in its consideration of undesirable outputs, in addition to desired outputs, for environmental efficiency. Furthermore, it examines all the newest ASEAN countries, including Timor-Leste, in the analysis. Furthermore, this research offers A long-term panel analysis (2000–2022) on ASEAN countries, with environmental DEA being rarely conducted. This research fills this gap by conducting a comprehensive and longitudinal evaluation of environmental efficiency among ASEAN countries and providing relevant policy implications for sustainable development decision-making in the region. Moreover, the Data Envelopment Analysis (DEA) method has been widely used to measure energy and environmental efficiency (Zhou et al., 2008a). Several studies have developed DEA approaches that consider desirable and undesirable outputs (Cámara-Aceituno et al., 2024; Shim & Eo, 2010; Zhou et al., 2008b). However, studies applying this approach in the context of developing countries, particularly in ASEAN, remain limited. Therefore, further analysis is needed to understand how differences in industrial sectors and national policies in ASEAN countries influence the balance between desirable and undesirable outputs in environmental efficiency.

This study aims to evaluate and compare the relative eco-efficiency of ASEAN countries. This method offers a more comprehensive evaluation of environmental efficiency by incorporating both desirable and undesirable outputs, thereby providing valuable insights for sustainable development policies in the region. The unique aspect of our research is the implementation of Data Envelopment Analysis (DEA) to evaluate the eco-efficiency of ASEAN countries from 2000 to 2022. This approach utilizes environmental efficiency indicators derived from various input variables and distinguishes between desirable outputs (maximized) and undesirable outputs (minimized). Furthermore, our investigation improves objectivity by employing graphical analysis to present the findings, which enables a more thorough and data-driven classification of eco-efficiency in ASEAN countries.

METHODS

We found that the most used method for evaluating environmental efficiency is the data envelopment analysis (DEA) (Mardani et al., 2017). The data source used in this research consists of secondary data obtained from the World Development Indicators from 2000 to 2022., Due to the absence of recently reported data from certain governments, particularly regarding CO2 emissions. The selection of inputs and outputs is a crucial aspect in evaluating environmental efficiency (Cooper et al., 2006; C. Feng & Wang, 2017; Wu et al., 2016).

The data in this research includes several variables grouped into input, desired output, and undesirable output variables, as shown in Table 2. The data in Table 1 are extracted from reliable resources, namely the World Bank's online database (World Bank, 2023) and "Our World in Data".

http://journal.uinjkt.ac.id/index.php/signifikan
https://doi.org/10.15408/sjie.v14i2.45828

Table 1. Names of Countries and Decision-Making Units (Dmus)

No.	DMUs	Country	GDP Average (2000 - 2022)	GDP 2022
1	DMU1	Indonesia	6.97776E+11	1.32E+12
2	DMU2	Malaysia	2.49935E+11	4.08E+11
3	DMU3	Filipina	2.30474E+11	4.04E+11
4	DMU4	Singapore	2.51266E+11	4.98E+11
5	DMU5	Thailand	3.35415E+11	4.96E+11
6	DMU6	Laos	9576140334	1.55E+10
7	DMU7	Vietnam	1.782E+11	4.1E+11
8	DMU8	Brunei	12691798246	1.67E+10
9	DMU9	Myanmar	43190500236	6.23E+10
10	DMU10	Cambodia	18457818875	4E+10
11	DMU11	Timor Leste	1235125235	3.21E+09

Source: World Bank processed, 2025

Table 2. Input Variable, Desirable Output, and Undesirable Output

Input	Desirable Output	Undesirable Output
- Population (People) - Industry (Constan)	GDP (current US$)	CO_2 Emission (Million Ton)

The study was divided into four parts to reach our objectives, as illustrated in Figure 1. This research adopts the Seiford and Zhu (2002) DEA undesirable model to evaluate countries' productivity in Asia:

$$\begin{bmatrix} Y \\ -X \end{bmatrix} = \begin{bmatrix} Y^g \\ Y^b \\ -X \end{bmatrix}$$

Y^g : Desirable output, Y^b: Undesirable Output, $Y = Y^g + Y^b$

The DEA model assumes that $Y(Y^g + Y^b)$ increases, indicating improved efficiency, but the increase in undesirable output Y^b causes efficiency to decrease. Here, -x is the input. Therefore, after putting a minus sign on the undesirable production and finding out a proper transaction vector ω, the minus undesirable will become a plus sign, such as $\bar{Y}_j^b = -Y_j^b + \omega > 0$, and $\omega = \max \{Y_j^b\} + 1$, such that model becomes

$$\begin{aligned} \max \quad & h \\ \text{s.t} \quad & \sum_{j=1}^{n} Z_j Y_j^g \geq h Y_0^g \\ & \sum_{j=1}^{n} Z_j \bar{Y}_j^b \geq h \bar{Y}_0^b \\ & \sum_{j=1}^{n} Z_j X_j \leq X_0 \\ & \sum_{j=1}^{n} Z_j = 1 \\ & Z_j \geq 0 \end{aligned}$$

Here, inputs X_j (j = 1,…., m), $\sum_{j-1}^{n} z_j$ = 1 indicates that the DMU must represent the effective elasticity set of the production function, h denotes the relative efficiency value, and Zj signifies the input and output weights.

We assume that there are 11 DMUs Where they are the 11 ASEAN countries. The value of k ranges from 1 to 11. For each of the DMU_k, this research has N inputs $X_{k\,=}\,(X_{1k,}\,X_{2k,}\,X_{3k,....}\,X_{nk})$, M desirable outputs $Y_{k\,=}\,(Y_{1k,}\,Y_{2k,}\,Y_{3k,....}\,Y_{mk})$, and J undesirable outputs $U_{k\,=}\,(U_{1k,}\,U_{2k,}\,U_{3k,....}\,U_{jk})$. With the data, we proceed to operate by Tyteca's process (1997) :

$$\text{EEI} = \text{Min } \lambda$$

$$s.t \sum_{1}^{k} Z_k X_{nk} \leq X_{n,}, n = 1,2,..N$$

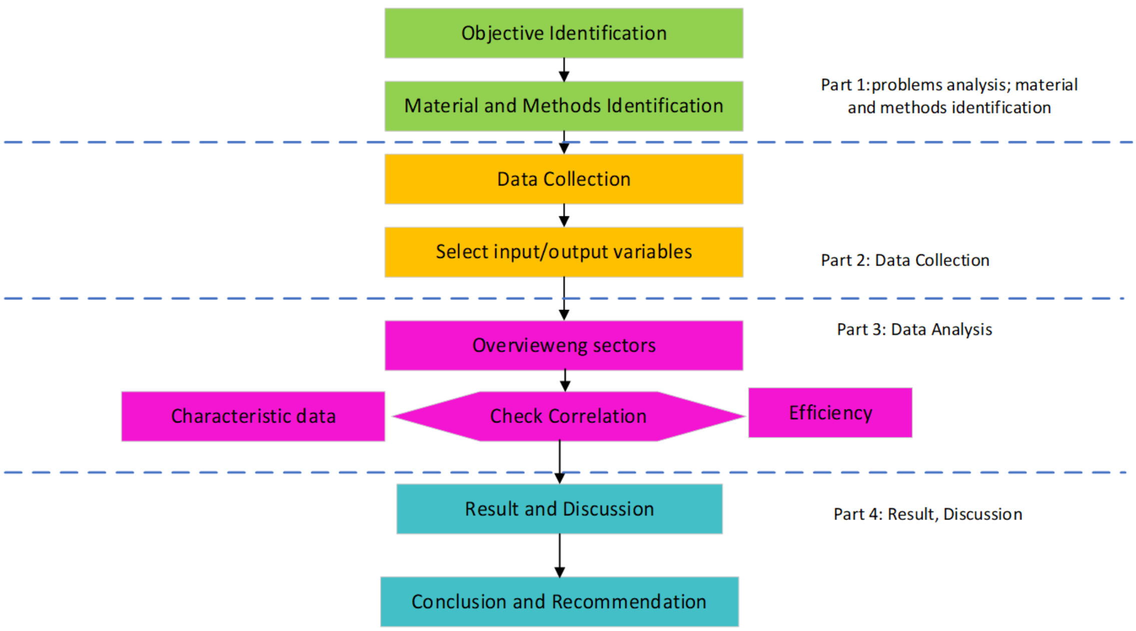
$$\sum_{1}^{k} Z_k X_{mk} \geq y_{m,}, m = 1,2,..M$$

$$\sum_{1}^{k} Z_k U_{jk} = \lambda u_j = 1,2,..$$

$$Z_k \geq 0, k = 1,2,\ldots,K$$

Where k = number of DMUs (ASEAN countries), n = number of inputs, x = inputs, y =desirable outputs, M = number of desirable outputs, z = undesirable outputs, and j= = number of outputs.

Figure 1. Step of Research Process



http://journal.uinjkt.ac.id/index.php/signifikan
https://doi.org/10.15408/sjie.v14i2.45828

RESULT AND DISCUSSION

This research's main results explain that environmental efficiency levels vary widely across ASEAN countries. Singapore and Brunei show consistently high efficiency, whereas Myanmar and Cambodia have low efficiency due to high emission intensity and low economic output. Another finding is that average environmental efficiency in the ASEAN region increased slowly throughout 2000–2022, but with uneven progress across countries. It was also found that industrial and population growth are negatively correlated with environmental efficiency, especially in countries that have not widely adopted clean technologies or strict environmental policies. The use of a DEA approach with undesirable outputs (CO_2 emissions) significantly changes the country efficiency rankings, compared to traditional DEA models, and reveals hidden inefficiencies in high-emission countries.

To improve the precision of the final evaluation process, a comprehensive statistical description was employed, as illustrated in Table 3. Concurrently, environmental efficiency is assessed for each country annually. This is the case with the energy from the industry process during the period 2000-2022. When reviewed based on population, Indonesia had the highest average population from 2000 to 2022, including 2022. Meanwhile, the country with the lowest average population in ASEAN in 2022 is Brunei. Indonesia occupies the highest position in industry compared to 10 other Southeast Asian countries (ASEAN). In Hamilton and Waters' research (Hamilton & Waters, 2018), it is stated that the Indonesian industry is one of the highest in the ASEAN region.

Regarding CO2 emissions, it can be seen that the country with the highest CO2 emissions in 2022 is Vietnam, but when considering the average emissions from 2000 to 2022, the highest is Indonesia. Chairiawan (2019) and data from IEA (2018) indicate that Indonesia contributed 1.41% of global CO2 emissions and was the largest emitter in the ASEAN region, with 454.9 MtCO2 in 2016. The research of Kusumawardhani et al. (2022) also strengthens this by discussing the relationship between economic growth and energy consumption. Meanwhile, Timor-Leste is the country with the average CO2 emissions in 2022 in ASEAN.

Table 3. Maximum, Minimum, and Average Values for Input and Output.

	Indicator	Unit	Maximum	Minimum	Average
Inputs	Population	People	278830529	326424	55449532
	Industry	Constant	4.51E+15	44213900	3.97E+14
Desirable output	GDP	(*current* US$)	1.32E+12	3.67E+08	1.84E+11
Undesirable output	CO2 Emission	Million Tons	54.619	0.002	11.374

Source: Data processed (2025)

Pearson correlation is a statistical method used to measure linear relationships between variables. A positive correlation value indicates a positive and unidirectional relationship, whereas a negative correlation value indicates an opposite relationship. Currently, this investigation employs a straightforward Pearson correlation test to assess the correlation between input and output. The coefficient value is between -1 (perfect negative) and 1 (perfect positive). A crucial requirement of applying DEA analysis is a positive correlation. The Pearson correlation calculation based on data with the variables Population, Industry, GDP, and CO2 emissions from industry is shown in Table 4.

Table 4. Pearson Correlation Value between Input & Output

Input & Output	Population	Industry	GDP	CO_2 Emission
Population	1			
Industry	0.885	1		
GDP	0.768	0.755	1	
CO2 Emission	**0.782**	0.764	0.81	1

Source: Data processed (2025)

Pearson's correlation value is 0.71 – 0.90, which shows a strong correlation (Akoglu, 2018). For example, we pay attention to the Pearson correlation value between population and CO2, which is 0.782; this shows a strong direct proportional relationship, indicating that as the population increases, CO2 emissions will rise accordingly. There have been several previous studies that have discussed this connection further. One of the research findings is that population density impedes CO2 emissions in high and lower-middle-income countries but enhances them in lower-income nations (Pickson et al., 2024). However, an empirical investigation by Cahyo et al. (2023) found that CO2 and population have a negative relationship.

The results of DEA modeling produce efficiency values. Efficiency values are divided into four categories based on the Environmental Efficiency Indicator (EEI) value grouping method by Hermoso-Orzáez et al. (Hermoso-Orzáez et al., 2020).

1. Excellent Environmental Efficiency (0.99 to 1 Value)
2. Good Environmental Efficiency (0.80 to 0.98 Value)
3. Average Environmental Efficiency (0.5 to 0.79 Value)
4. Environmental Efficiency Can Be Improved (0.0 to 0.49 Value)

The efficiency value for each Decision-Making Unit *(DMU),* specifically 11 ASEAN countries from 2000 to 2022, is shown in Table 5.

Table 5 and Figure 2 show that from year to year (2000 to 2022), the environmental efficiency value for each DMU (11 ASEAN countries) fluctuates significantly from year to year. It can be seen that Singapore is the only country with a stable and superior efficiency value compared to other countries, with a value of 1 from 2000 to 2022. The results from Table 5 and Figure 2 are then calculated on average from 2000 to 2022, as shown in Table 6.

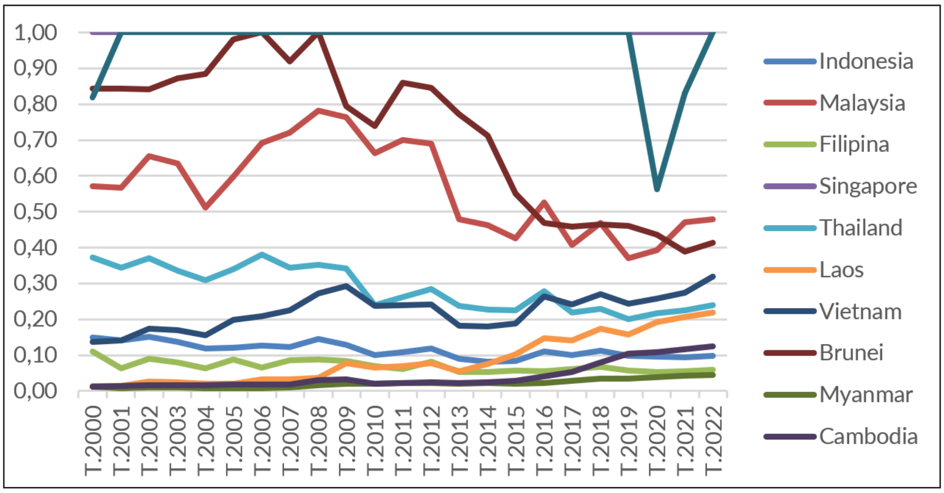
Based on Table 6, Singapore is noted to have excellent environmental efficiency. Meanwhile, Timor-Leste is included in the category of countries with good environmental

http://journal.uinjkt.ac.id/index.php/signifikan
https://doi.org/10.15408/sjie.v14i2.45828

efficiency. Malaysia and Brunei are classified as countries with average environmental efficiency. Countries such as Indonesia, the Philippines, Thailand, Laos, Vietnam, Myanmar, and Cambodia show improvements in environmental efficiency compared to the previous period, although they are still in the suboptimal category. These findings reflect the diverse dynamics and developments in environmental management in the ASEAN region.

The more advanced a country is, the more efficient its environment will be (Barra & Falcone, 2023; Chiu et al., 2012). The Environmental Kuznets Curve (EKC) theory posits an inverted U-shaped relationship between economic growth and environmental degradation (Adhikary & Hajra, 2021; Hoang et al., 2024; Zilio, 2012). The research conducted on ASEAN countries is related to the EKC theory, which suggests that more developed countries aim to be more efficient in resource use and environmental management. This condition occurs because they have moved beyond the phase of high resource exploitation and have adopted more environmentally friendly policies and technologies. Additionally, a factor is that Singapore is a small country, whereas Indonesia has low efficiency in certain areas. The countries that have average efficiency are Malaysia and Brunei.

Figure 2. Line Chart *Visualization* of Efficiency Values of Decision-Making Units (DMUs) in 2000 – 2022



Source: Data processed (2025)

Table 5. Efficiency Value of Decision-Making Units (DMUs) in 2000 – 2022

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Indonesia	0.15	0.14	0.15	0.14	0.12	0.12	0.13	0.12	0.14	0.13	0.10	0.11	0.12	0.09	0.08	0.08	0.11	0.10	0.11	0.10	0.10	0.09	0.10
Malaysia	0.57	0.57	0.66	0.64	0.51	0.60	0.69	0.72	0.78	0.76	0.66	0.70	0.69	0.48	0.46	0.43	0.53	0.41	0.47	0.37	0.39	0.47	0.48
Philippiness	0.11	0.06	0.09	0.08	0.06	0.09	0.07	0.09	0.09	0.08	0.07	0.06	0.08	0.05	0.05	0.06	0.06	0.06	0.07	0.06	0.05	0.05	0.06
Singapore	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Thailand	0.37	0.34	0.37	0.34	0.31	0.34	0.38	0.34	0.35	0.34	0.24	0.26	0.28	0.24	0.23	0.23	0.28	0.22	0.23	0.20	0.22	0.22	0.24
Laos	0.01	0.01	0.03	0.02	0.02	0.02	0.03	0.03	0.04	0.08	0.07	0.07	0.08	0.06	0.08	0.10	0.15	0.14	0.17	0.16	0.19	0.21	0.22
Vietnam	0.14	0.14	0.17	0.17	0.16	0.20	0.21	0.22	0.27	0.29	0.24	0.24	0.24	0.18	0.18	0.19	0.26	0.24	0.27	0.24	0.26	0.27	0.32
Brunei	0.84	0.84	0.84	0.87	0.88	0.98	1.00	0.92	1.00	0.79	0.74	0.86	0.85	0.77	0.71	0.55	0.47	0.46	0.46	0.46	0.44	0.39	0.41
Myanmar	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.03	0.04	0.04	0.04
Cambodia	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.05	0.08	0.10	0.11	0.12	0.12
Timor Leste	0.82	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.56	0.83	1.00

http://journal.uinjkt.ac.id/index.php/signifikan
https://doi.org/10.15408/sjie.v14i2.45828

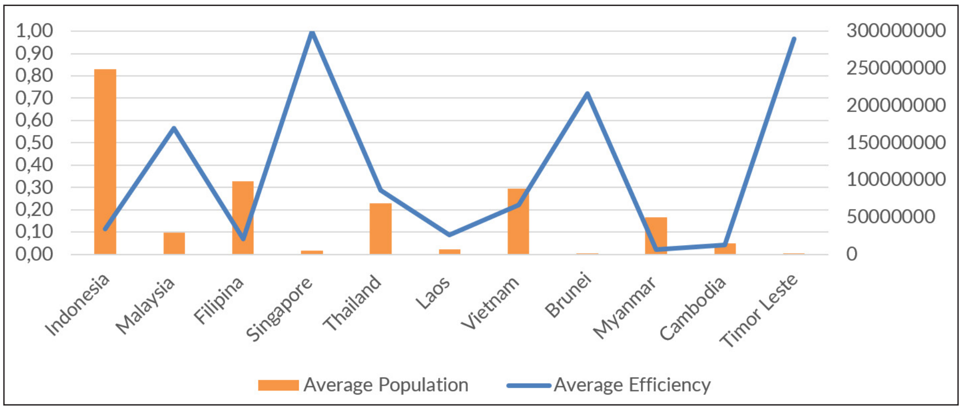
Table 6. Average Efficiency of Each DMU

DMU Name	Average Efficiency
Indonesia	0.11
Malaysia	0.57
Filipina	0.07
Singapore	1.00
Thailand	0.29
Laos	0.09
Vietnam	0.22
Brunei	0.72
Myanmar	0.02
Cambodia	0.04
Timor Leste	0.97

Source: Data processed, 2025

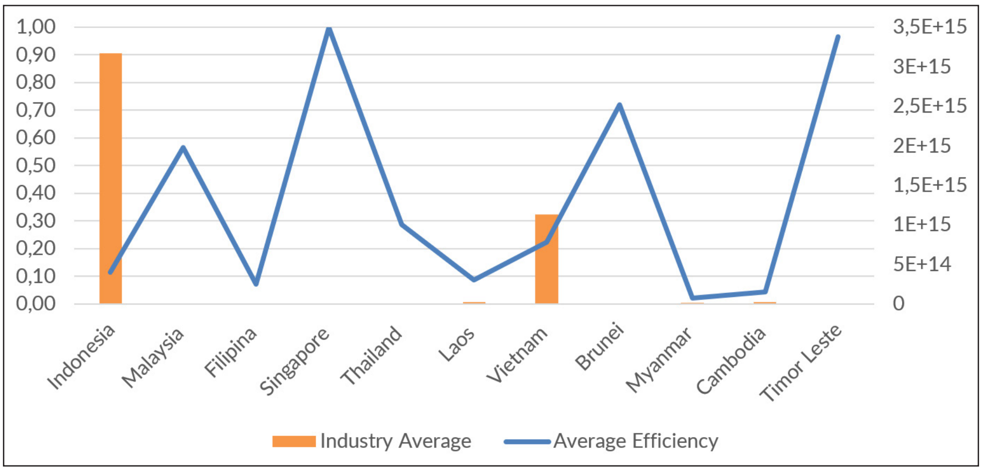
Research related to DEA, as explained earlier, explains that inputs in the form of Population and Industry are used. In this case, a deeper review of the relationship between each input and the average efficiency value is provided in Figures 3 and 4. Figure 3 shows the results, indicating that the country with the highest average population, Indonesia, has the lowest average efficiency compared to other ASEAN countries. On the contrary, countries with low average populations, such as Singapore, Timor-Leste, and Brunei, have a relatively high average efficiency. Indonesia has the largest population in ASEAN, which means that domestic energy demand is significantly higher to support economic activities and household consumption (Prasetyanto et al., 2025; Pattiruhu & Kriekhoff, 2022). Singapore, Malaysia, and Brunei have significantly smaller populations, which means that the pressure on the environment is relatively lower in terms of energy consumption and CO2 emissions (Islam & Ghani, 2018).

Figure 3. Comparison Chart of Input (Average Population) and Average Efficiency



Source: Data processed (2025)

Figure 4. Comparison Chart of Inputs (Industry Average) and Average Efficiency

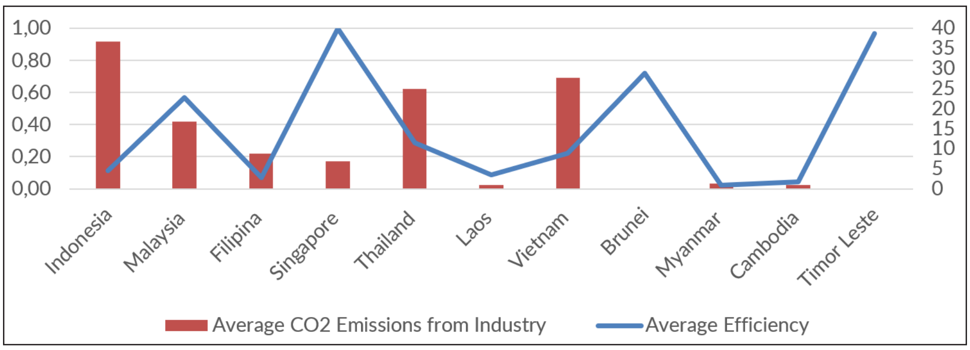


Source: Data processed (2025)

Based on Figure 4, the country with the highest industrial average is Indonesia, which has a low average efficiency. However, other countries, such as Myanmar and Cambodia, have low average efficiency despite a fairly low average industrial input. Indonesia has a relatively large industrial sector within its national economic structure; however, this sector still heavily relies on environmentally unfriendly energy sources (e.g., coal-based industries and energy-intensive manufacturing) (Hariyanto, 2021; Ramadanti et al., 2024; Yohanes Handoko & Loisa, 2023). Meanwhile, Singapore and Brunei have industrial sectors that are more focused on high-value-added industries such as technology, finance, and service-based industries, which are more energy-efficient compared to heavy manufacturing sectors (Asgari et al., 2024; Holloway, 1971; Shi, 2015; Su et al., 2021)

This study uses outputs in the form of Gross Domestic Product (GDP) and CO2 emissions. In this, the relationship between each output and the average efficiency values depicted in Figures 5 and 6 is reviewed in depth. The results of Figure 5 show that Singapore, the country with the highest efficiency in ASEAN, has a GDP that is not significantly higher than that of its nearest country, Indonesia. However, in terms of GDP, Singapore can be far superior to Timor-Leste, which has the lowest GDP despite having a high average efficiency value.

Figure 5. Comparison Chart of Output (Average CO2 emissions) and Average Efficiency

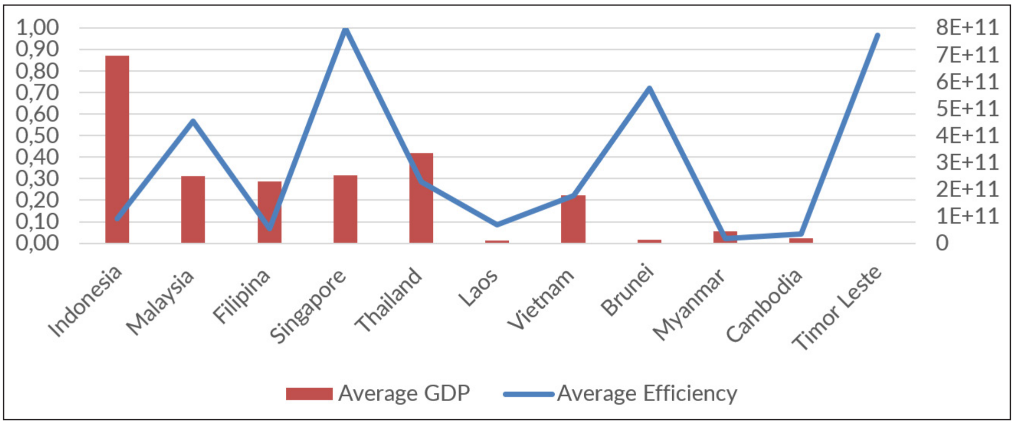


Source: Data processed (2025)

http://journal.uinjkt.ac.id/index.php/signifikan
https://doi.org/10.15408/sjie.v14i2.45828

Indonesia produces greater CO2 emissions due to its reliance on fossil fuels and the ongoing large-scale deforestation (Chairiawan, 2019). Countries like Singapore, despite having large-scale economic activities, apply much higher energy efficiency and utilize more modern technology, resulting in lower CO2 emissions per unit of output (Koh et al., 2012; Meirun et al., 2021). For example, Singapore's power generation sector emphasizes high energy efficiency (Ali & Weller, 2014). Emphasizing efficiency is also important to reduce the "decoupling gap" between economic growth and environmental pressures, which remains a challenge in many developing countries (Zhang et al., 2019).

Figure 6. Comparison Chart of Output (Average GDP) and Average Efficiency



Source: Data processed (2025)

Based on Figure 6, the results show that the three countries with low average CO2 emissions and low average efficiency are Singapore, Timor-Leste, and Brunei. When compared, Indonesia's economic output (GDP per capita) is still lower than that of Singapore and Brunei. These results are in line with research conducted by Hill (2018), which suggests that an equivalent level of economic output does not match the high CO2 emissions. Singapore and Brunei have a much higher GDP per capita with relatively more controlled CO2 emissions, making them technically more efficient in generating GDP per ton of CO2.

The closeness of the relationship between the average efficiency value generated by Data Envelopment Analysis (DEA) and Input and Output can be measured using Pearson correlation. The results of Pearson's correlation calculation show that overall, the average input and output (population, industry, GDP, and CO2 emissions) have a negative correlation with the average efficiency value. Negative correlation values indicate opposite relationships. Some studies show a negative correlation between specific inputs (such as population, industry, and GDP) and efficiency. For example, higher population density and energy consumption per unit of GDP negatively impact environmental efficiency (Wang et al., 2013). CO2 emissions are often used as an undesirable output in efficiency models. According to studies, higher CO2 emissions correlate with poorer efficiency ratings. For example, increasing CO2 emissions has a detrimental influence on regions' environmental efficiency (Iqbal et al., 2019; Wang et al., 2012).

Table 7. Pearson Efficiency Value Average Correlation Value between Input & Output

Input & Output	Average Efficiency	Population Average	Industry average	GDP Average	Average CO2 Emissions
Average Efficiency	1				
Population Average	-0.463	1			
Industry average	-0.275	0.903	1		
GDP Average	-0.15	0.869	0.785	1	
Average CO2 Emissions	-0.241	0.814	0.765	0.869	1

Source: Data processed (2025)

Based on the results of the previously carried out Data Envelopment Analysis (DEA), an efficiency value is obtained. In this case, these efficiency values can be optimized by reviewing Slack results in the DEA. Slack in Data Envelopment Analysis is an indicator that shows inefficiencies in the use of inputs or outputs in a Decision-Making Unit (DMU). Slack describes how much input can be reduced or how much output can be increased without changing overall efficiency. Table 8 shows information indicating that countries such as Singapore and Timor-Leste have input and output slack values of 0. This result suggests that the inputs and outputs in these two countries do not need optimization by adding or decreasing values, as their conditions are efficient and ideal. It is different from Indonesia, where there is still a value of 446169818783442 for input slacks and 1122749409806.93000 for output slacks. Therefore, to optimize efficiency in the future, the Government of Indonesia is advised to reduce industrial inputs or increase output.

Table 8. Slacks Values for Input & Output for Each DMU in 2022

DMU Name	*Input Slacks*		Output Slacks	
	Population	*Industry*	GDP	CO2
Indonesia	0.00000	446169818783442.00000	1122749409806.93000	0.00000
Malaysia	5889664.40154	0.00000	538431530439.88300	0.00000
Filipina	0.00000	0.00000	185702654968.65600	0.00000
Singapore	0.00000	0.00000	0.00000	0.00000
Thailand	0.00000	0.00000	1024847736778.44000	0.00000
Laos	0.00000	0.00000	81798578513.44700	0.00000
Vietnam	0.00000	645630941652965.00000	2395110493642.80000	0.00000
Brunei	0.00000	5412223.93229	0.00000	0.22087
Myanmar	0.00000	0.00000	145604856805.31300	0.00000
Cambodia	0.00000	0.00000	119071948772.07800	0.00000
Timor Leste	0.00000	0.00000	0.00000	0.00000

Source: Data processed (2025)

http://journal.uinjkt.ac.id/index.php/signifikan
https://doi.org/10.15408/sjie.v14i2.45828

CONCLUSION

This study evaluates and compares the relative environmental efficiency levels of 11 ASEAN countries over the period 2000–2022. The results show significant variations in environmental efficiency across the region. Singapore and Brunei consistently rank among the highest environmentally efficient countries, driven by their high economic output and relatively low emissions intensity. In contrast, Myanmar, Cambodia, and Laos show lower environmental efficiency scores, primarily due to their high emissions relative to their economic performance and low adoption of clean technologies. Some countries, such as Vietnam and Indonesia, show step-by-step improvements in environmental efficiency over time, reflecting the positive impacts of economic restructuring and the implementation of environmental regulations. Meanwhile, countries that rely heavily on extractive industries and coal, such as Thailand and the Philippines, show fluctuating efficiency levels. This comparison emphasizes the importance of sustainable industrial policies, energy diversification, and investment in environmentally friendly technologies as key factors influencing environmental efficiency performance in the ASEAN region.

The study focuses only on ASEAN countries, so its findings may not be generalized to other developing countries outside the region. In future research, it is expected to calculate economic efficiency with a broader coverage of countries in Asia, or conduct comparative studies with developing countries in the Americas or Africa. This study also supports Sustainable Development by providing data-driven analysis that can be used to design policies balancing economic growth with environmental protection. These findings emphasize the importance of formulating development policies that focus not only on economic growth but also on resource efficiency and emissions reduction. Countries with low efficiency levels, such as Indonesia, need to develop more comprehensive, data-driven green transition strategies.

REFERENCES

Adhikary, M., & Hajra, C. (2021). Environmental Kuznets Curve: A Revisit in the Case of SAARC. In. Kateja, A., & Jain, R. (Eds). *Urban Growth and Environmental Issues in India*. Singapore: Springer.

Alam, A., Biswas, S., & Satpati, L. (2023). Population Dynamics and Economic Growth in Southeast Asia. In. Alam, A., Rukhsana, Islam, N., Sarkar, B., & Roy, R. (Eds). *Population, Sanitation and Health* (pp. 17–27). Cham: Springer.

Ali, H., & Weller, S. R. (2014). Carbon Dioxide Mitigation Strategies for the Singapore Power Generation Sector. *World Congress on Sustainable Technologies (WCST-2014)*, 42–47.

Anser, M. K., Iqbal, W., Ahmad, U. S., Fatima, A., & Chaudhry, I. S. (2020). Environmental Efficiency and the Role of Energy Innovation in Emissions Reduction. *Environmental Science and Pollution Research*, *27*(23), 29451–29463. https://doi.org/10.1007/s11356-020-09129-w.

Asgari, B., Majumdar, S., & Amoah, C. (2024). Efficiency Analysis of Manufacturing Industries in Singapore Using the DEA-Malmquist Productivity Index. *Journal of*

Infrastructure, Policy and Development, *8*(10), 5746. https://doi.org/10.24294/jipd.v8i10.5746.

Barra, C., & Falcone, P. M. (2023). Cross-Country Comparisons of Environmental Efficiency Under Institutional Quality. Evidence from European Economies. *Journal of Economic Studies*, *51*(9), 75-111. https://doi.org/10.1108/JES-05-2023-0264.

Cahyo, H., Purnomo, S. D., Octisari, S. K., Surveyandini, M., Sundari, S., & Purwendah, E. K. (2023). Environment, Population, and Economy on CO2 Emission in Indonesia. *International Journal of Energy Economics and Policy*, *13*(6), 295-303. https://doi.org/10.32479/ijeep.14938.

Cámara-Aceituno, J., Hermoso-Orzáez, M. J., Terrados-Cepeda, J., Mena-Nieto, Á., & García-Ramos, J. E. (2024). Application of the Data Envelopment Analysis Technique to Measure The Environmental Efficiency of the 27 Countries of the European Union During the Period 2012–2020. *Clean Technologies and Environmental Policy*, *26*(5), 1477–1505. https://doi.org/10.1007/s10098-023-02553-9.

Chairiawan, M. A. (2019). Indonesia Opportunity to Accelerate Energy Transition. *2019 International Conference on Technologies and Policies in Electric Power and Energy, TPEPE 2019*. https://doi.org/10.1109/IEEECONF48524.2019.9102598.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the Efficiency of Decision Making Units. *European Journal of Operational Research*, *2*(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138–8.

Chen, L., & Jia, G. (2017). Environmental Efficiency Analysis of China's Regional Industry: A Data Envelopment Analysis (DEA) Based Approach. *Journal of Cleaner Production*, *142*(2), 846–853. https://doi.org/10.1016/j.jclepro.2016.01.045.

Chiu, C. R., Liou, J. L., Wu, P. I., & Fang, C. L. (2012). Decomposition of the Environmental Inefficiency of the Meta-Frontier with Undesirable Output. *Energy Economics*, *34*(5), 1392-1399. https://doi.org/10.1016/j.eneco.2012.06.003.

Cook, W. D., & Seiford, L. M. (2009). Data Envelopment Analysis (DEA) - Thirty Years On. *European Journal of Operational Research*, *192*(1), 1-17.

Cooper, W. W., Seiford, L. M., & Tone, K. (2006). *Introduction to Data Envelopment Analysis and Its Uses: With DEA-Solver Software and References*. Berlin: Springer.

Feng, C., & Wang, M. (2017). Analysis of Energy Efficiency and Energy Savings Potential in China's Provincial Industrial Sectors. *Journal of Cleaner Production*, *164,* 1531–1541. https://doi.org/10.1016/j.jclepro.2017.07.081.

Feng, S., Mohd Shafiei, M. W., Ng, T. F., Ren, J., & Jiang, Y. (2024). The Intersection of Economic Growth and Environmental Sustainability in China: Pathways to achieving SDG. *Energy Strategy Reviews*, *55*, 101530. https://doi.org/10.1016/j.esr.2024.101530.

Feriansyah, F., Nugroho, H., Larre, A. A., Septiavin, Q., & Nisa, C. K. (2023). Economic Growth and CO2 Emission in ASEAN: Panel-ARDL Approach. *Economics and Finance in Indonesia*, *69*(1), 102–113. https://doi.org/10.47291/efi.2022.04.

Galkina, E. E., & Sorokin, A. E. (2020). Quality Management and Sustainable Economic Development. *Russian Engineering Research*, *40*(7), 577–578. https://doi.org/10.3103/S1068798X2007014X.

Grossman, G. M., & Krueger, A. B. (1995). Economic Growth and the Environment. *The Quarterly Journal of Economics*, *110*(2), 353–377. https://doi.org/10.2307/2118443.

Hamilton, G. G., & Waters, T. (2018). Chinese Capitalism in Thailand: Embedded Networks and Industrial Structure. In. Chen, E. K. Y. (Ed.). *Corporate Links and Foreign Direct Investment in Asia and the Pacific*. New York: Routledge.

Hariyanto, B. (2021). Energy Efficiency: The Manufacturing Sector in Indonesia. *JEJAK*, *14*(2), 200–217. https://doi.org/10.15294/jejak.v14i2.28850.

Haseeb, M., Kot, S., Hussain, H., & Jermsittiparsert, K. (2019). Impact of Economic Growth, Environmental Pollution, and Energy Consumption on Health Expenditure and Expenditure of ASEAN Countries. *Energies*, *12*(19), 3598. https://doi.org/10.3390/en12193598.

Hermoso-Orzáez, M. J., García-Alguacil, M., Terrados-Cepeda, J., & Brito, P. (2020). Measurement of Environmental Efficiency in the Countries of the European Union with the Enhanced Data Envelopment Analysis Method (DEA) During the Period 2005–2012. *Environmental Science and Pollution Research*, *27*(13), 15691-15715. https://doi.org/10.1007/s11356-020-08029-3.

Hill, H. (2018). Asia's Third Giant: A Survey of the Indonesian Economy. *Economic Record*, *94*(307), 469–499. https://doi.org/10.1111/1475-4932.12439.

Hoang, T.-H., Le, B.-T., Mai, T.-T.-X., & Pham, T.-L. (2024). Green Governance and the EKC hypothesis: Evidence from Vietnamese Provinces. *Edelweiss Applied Science and Technology*, *8*(6), 3218–3229. https://doi.org/10.55214/25768484.v8i6.2686.

Holloway, R. (1971). Singapore—An Asian Economic Miracle. *Intereconomics*, *6*(10), 317–318. https://doi.org/10.1007/BF02929133.

Hosseini, H., Fanati Rashidi, S., & Hamzehee, A. (2020). Study of the Impact of Environmental Pollution on Efficiency and Sustainable Development using Data Envelopment Analysis. *MATEMATIKA*, *36*(2), 157–179.

IEA. (2018). *World Energy Outlook*. Singapore: International Energy Agency.

Iqbal, W., Altalbe, A., Fatima, A., Ali, A., & Hou, Y. (2019). A DEA Approach for Assessing the Energy, Environmental, and Economic Performance of Top 20 Industrial Countries. *Processes*, *7*(12), 902. https://doi.org/10.3390/PR7120902.

Islam, R., & Abdul Ghani, A. B. (2018). Link among Energy Consumption, Carbon Dioxide Emission, Economic Growth, Population, Poverty, and Forest Area. *International Journal of Social Economics*, *45*(2), 275–285. https://doi.org/10.1108/IJSE-12-2016-0351.

Jiang, J., & Xie, B.-C. (2024). Environmental Efficiency Evaluation of China's Power System Considering Factor's Spatial Dependence: A Dynamic Spatial Network DEA Approach. *Environmental Impact Assessment Review*, *104*, 107329. https://doi.org/10.1016/j.eiar.2023.107329.

Khoa, B. Q., Nguyen, T. T. H., Tu, Y.-T., Diep, G. L., Tran, T. K., Tien, N. H., & Chien, F. S. (2025). Effects of Energy Use and the Extraction of Natural Resources on the Sustainability of the Environment in ASEAN Nations. *International Journal of Multidisciplinary Research and Growth Evaluation*, *6*(1), 475–488. https://doi.org/10.54660/.IJMRGE.2025.6.1.475-488.

Kreinin, H., & Aigner, E. (2022). From "Decent Work and Economic Growth" to "Sustainable Work and Economic Degrowth": A New Framework for SDG 8. *Empirica*, *49*, 281-311. https://doi.org/10.1007/s10663-021-09526-5.

Kusuma Prasetyanto, P., Gravitiani, E., Suryanto, Mulyanto, & Shohibul Manshur Al Ahmad, A. (2025). The Impact of Economic Growth on Energy Consumption: An Error Correction Approach in Indonesia. *IOP Conference Series: Earth and Environmental Science*, *1438*(1), 012050. https://doi.org/10.1088/1755-1315/1438/1/012050.

Kusumawardhani, H. A., Susilowati, I., Hadiyanto, & Melati, F. C. (2022). Analysis of Environmental Degradation in Indonesia Based on Value Added Industry, Economic Growth, and Energy Consumption. *International Journal of Sustainable Development and Planning*, *17*(6), 1721-1726. https://doi.org/10.18280/ijsdp.170605.

Lacko, R., & Hajduová, Z. (2018). Determinants of Environmental Efficiency of the EU Countries Using Two-Step DEA Approach. *Sustainability*, *10*(10), 3525. https://doi.org/10.3390/su10103525.

Lacko, R., Hajduová, Z., & Markovič, P. (2023). Socioeconomic Determinants of Environmental Efficiency: the Case of the European Union. *Environmental Science and Pollution Research*, *30*, 31320-31331. https://doi.org/10.1007/s11356-022-24435-1.

Lampert, A. (2019). Over-Exploitation of Natural Resources is Followed by Inevitable Declines in Economic Growth and Discount Rate. *Nature Communications*, *10*, 1419. https://doi.org/10.1038/s41467-019-09246-2

Leong Hai Koh, Yen Kheng Tan, Peng Wang, & King Jet Tseng. (2012). Renewable Energy Integration Into Smart Grids: Problems and Solutions- Singapore experience. *2012 IEEE Power and Energy Society General Meeting*, 1–7.

Long, N. T., & Ngoc, B. H. (2023). Is Financial Development Good for Ecological Footprint A Bayesian Multilevel Mixed-Effects Analysis in ASEAN Countries. *International Journal of Environment and Sustainable Development*, *22*(4), 409–424. https://doi.org/10.1504/IJESD.2023.133824.

Mardani, A., Zavadskas, E. K., Streimikiene, D., Jusoh, A., & Khoshnoudi, M. (2017). A Comprehensive Review of Data Envelopment Analysis (DEA) Approach in Energy Efficiency. *Renewable and Sustainable Energy Reviews*, *70*, 1298–1322. https://doi.org/10.1016/j.rser.2016.12.030.

Meirun, T., Mihardjo, L. W., Haseeb, M., Khan, S. A. R., & Jermsittiparsert, K. (2021). The Dynamics Effect of Green Technology Innovation on Economic Growth and CO2 Emission in Singapore: New Evidence from Bootstrap ARDL Approach. *Environmental Science and Pollution Research*, *28*(4), 4184–4194. https://doi.org/10.1007/s11356-020-10760-w.

Meng, F. Y., Fan, L. W., Zhou, P., & Zhou, D. Q. (2013). Measuring Environmental Performance in China's Industrial Sectors with Non-Radial DEA. *Mathematical and Computer Modelling*, *58*(5–6), 1047–1056. https://doi.org/10.1016/j.mcm.2012.08.009

Pattiruhu, J. R., & Kriekhoff, S. (2022). Energy Consumption Impact on Economic Management: Evidence from Indonesian Economy. *International Journal of Energy Economics and Policy*, *12*(3), 270–279. https://doi.org/10.32479/ijeep.13035.

Peng, T. N. (2017). Southeast Asia's Demographic Situation, Regional Variations, and National Challenges. *Southeast Asian Affairs*, *SEAA17*(1), 55–82. https://doi.org/10.1355/aa17-1d.

Pickson, R. B., Gui, P., Jian, L., & Boateng, E. (2024). Do Population-Related Factors Matter for Carbon Emissions? Lessons from Different Income Groups of Countries. *Urban Climate*, *55*, 101934. https://doi.org/10.1016/j.uclim.2024.101934.

Rai, S. M., Brown, B. D., & Ruwanpura, K. N. (2019). SDG 8: Decent Work and Economic Growth – A Gendered Analysis. *World Development*, *113,* 368-380. https://doi.org/10.1016/j.worlddev.2018.09.006.

Ramadanti, S. S., Azwardi, A., & Subardin, M. (2024). Economic Growth and Environmental Quality: A Study on Mineral-Rich Provinces in Indonesia. *Signifikan: Jurnal Ilmu Ekonomi*, *13*(1), 85–96. https://doi.org/10.15408/sjie.v13i1.40285.

Sadiq, M., Alajlani, S., Hussain, M. S., Ahmad, R., Bashir, F., & Chupradit, S. (2022). Impact of Credit, Liquidity, and Systematic Risk on Financial Structure: Comparative Investigation from Sustainable Production. *Environmental Science and Pollution Research*, *29*, 20975. https://doi.org/10.1007/s11356-021-17276-x.

Scheel, H. (2001). Undesirable Outputs in Efficiency Valuations. *European Journal of Operational Research*, *132*(2), 400-410. https://doi.org/10.1016/S0377-2217(00)00160-0.

Shi, X. (2015). Energy Efficiencies in ASEAN Region. In. Yan, J (Ed.) *Handbook of Clean Energy Systems* (pp. 1–19). New York: Wiley.

Shim, H. S., & Eo, S. Y. (2010). An Analysis of Eco-Efficiency in Korean Fossil-Fueled Power Plants Using DEA. In. Yao, T (Ed.) *Zero-Carbon Energy Kyoto 2009. Green Energy and Technology.* Tokyo: Springer.

Su, B., Goh, T., Ang, B. W., & Ng, T. S. (2021). Energy Consumption and Energy Efficiency Trends in Singapore: The Case of a Meticulously Planned City. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3881485.

Tan, S. Y. L., & Kamaruddin, H. (2019). Environmental Challenges Within ASEAN: Contemporary Legal Issues and Future Considerations. In. Idris, A., & Kamaruddin, N. (Eds). *ASEAN Post-50*. Singapore: Springer.

Wang, C. N., Nguyen, H. P., & Chang, C. W. (2021). Environmental Efficiency Evaluation in the Top Asian Economies: An Application of DEA. *Mathematics*, *9*(8), 889. https://doi.org/10.3390/math9080889.

Wang, L. F., Sun, P. P., & Zhu, J. J. (2013). Research on the Causes of China's Industrial Environmental Efficiency. *Advanced Materials Research*, *869–870*, 698–701.

Wang, Q., Zhou, P., & Zhou, D. (2012). Efficiency Measurement with Carbon Dioxide Emissions: The Case of China. *Applied Energy*, *90*(1), 161-166. https://doi.org/10.1016/j.apenergy.2011.02.022.

Wu, L. J., Gao, S., & Bai, T. (2016). Review on the Migration Mechanisms of Large Jellyfish and Techniques of the Monitoring, Forecasting, and Warning of Jellyfish Disaster. *Shengtai Xuebao*, *36*(10), 3103–3107. https://doi.org/10.5846/stxb201409251898.

Yohanes Handoko, A., & Loisa, P. (2023, September). The Systemic Risks of Indonesian Energy Sector Transition Pathways (A Case Study of Energy Transition in Indonesia). *SPE Offshore Europe Conference & Exhibition*. https://doi.org/10.2118/215513-MS.

Zhang, H., Hewings, G. J. D., & Zheng, X. (2019). The Effects of Carbon Taxation in China: An Analysis based on Energy Input-Output Model in Hybrid Units. *Energy Policy*, *128*, 223–234. https://doi.org/10.1016/j.enpol.2018.12.045.

Zhang, X. P., Cheng, X. M., Yuan, J. H., & Gao, X. J. (2011). Total-Factor Energy Efficiency in Developing Countries. *Energy Policy*, *39*(2), 644-650. https://doi.org/10.1016/j.enpol.2010.10.037.

Zhou, P., Ang, B. W., & Poh, K. L. (2008a). A Survey of Data Envelopment Analysis in Energy and Environmental Studies. *European Journal of Operational Research*, *189*(1), 1–18. https://doi.org/10.1016/j.ejor.2007.04.042.

Zhou, P., Ang, B. W., & Poh, K. L. (2008b). Measuring Environmental Performance under Different Environmental DEA Technologies. *Energy Economics*, *30*(1), 1-14. https://doi.org/10.1016/j.eneco.2006.05.001.

Zilio, M. I. (2012). The Environmental Kuznets Curve: The Validity of Its Foundations in Developing Countries. *Cuadernos de Economia*, *35*(97), 43-54. https://doi.org/10.1016/S0210-0266(12)70022-5.