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Can Renewable Energy and Industrialization Work Together to Improve Environmental Sustainability? Case of Association of Southeast Asian Nations (ASEAN) Countries

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ABSTRACT

Sustainable Development Goals (SDGs) offer a global plan to tackle urgent environmental issues like climate change. They align with ASEAN's goal to cut greenhouse gas emissions by using more renewable energy, aiming for 23 percent, and promoting sustainable industrial practices. This study aims to investigate the relationship between renewable energy and industrialization on environmental sustainability in the Association of Southeast Asian Nations (ASEAN). Using panel data from ASEAN countries from 1996 to 2021, we utilize the Generalized Method of Moments (GMM) method to understand both short and long-term effects. The study shows that renewable energy and industrialization affect sustainability in the short term. In the long term, renewable energy improves the environment, but industrialization does not. This highlights the need for ASEAN countries to adopt greener industrialization. The results suggest policy changes to help ASEAN balance economic growth with environmental goals that align with the SDGs.

1. INTRODUCTION

Sustainable Development Goals (SDGs) is a global framework to address a range of complex challenges, including climate change and economic concerns. Industrialization, a key driver of economic growth, has a crucial role in the realization of the SDGs [1]. The United Nations has developed the 2030 Agenda for Sustainable Development framework, meaning that sustainable development has been a universal objective for both developed and developing countries [2]. The agenda represents a significant milestone in acknowledging the global nature of social, economic, and environmental challenges. The framework comprises 17 SDGs that address critical issues such as poverty eradication, quality education, climate action, and sustainable economic growth [3].

Renewable energy ensures access to sustainable and greener energy. Research shows that renewable energy contributes positively to economic development by fostering job creation in the clean energy sector [4]. Additionally, renewable energy policies contribute to SDGs by encouraging infrastructure development and innovation, particularly in energy sectors, which are critical for building sustainable industries [5]. Renewable energy also plays a role in addressing environmental challenges by reducing carbon emissions, which is vital for climate action and boosts energy security, aligning with the broader environmental goals [6, 7]. However, some renewable energy projects may hinder progress towards specific SDGs if not managed carefully, such as through the unsustainable use of resources or unintended social impacts, underscoring the need for careful integration and policy support [8].

Industrialization plays a crucial role in aligning with the SDGs [9]. Industries are increasingly motivated to adopt greener practices due to a combination of technological innovation, governmental policies, and market pressures. The development of green technologies, including sustainable manufacturing processes, enables industries to reduce their carbon footprints [10, 11]. Stricter environmental regulations compel industries to innovate and comply with sustainability standards [12]. Lastly, investors are increasingly considering environmental, social, and governance (ESG) factors in their decision-making processes. This trend encourages companies to adopt sustainable practices to attract investment and enhance their brand reputation [13].

However, challenges arise in the alignment of industrialization processes with environmental goals, as economic priorities often overshadow sustainable resource use [14]. To address these challenges, strategic and operational alignment across diverse sectors, including public, private, and civil society, is necessary to increase the likelihood of achieving the SDGs [15]. Furthermore, industries need to conduct practices, including reducing carbon footprints, conserving water, and enhancing social equity, that will contribute to advancing the global sustainability agenda [16].

The Association of Southeast Asian Nations (ASEAN) Plan of Action for Energy Cooperation (APAEC) is an initiative by ASEAN, aimed at fostering cooperation in the energy sector among its member countries. It explains ASEAN's role in fostering regional economic and geopolitical integration through various agreements and institutions [17]. Through the APAEC, ASEAN aims to reduce greenhouse gas emissions

and promote sustainable development, and promoting 23% renewable energy usage [18]. APAEC's framework encourages the integration of renewable energy within industrial sectors, which not only mitigates the environmental impact of industrial development but also alters the turning point of emissions per capita during industrialization phases in several ASEAN nations [19, 20]. APAEC drives ASEAN into a sustainable future by combining economic growth strategies with climate action, supporting the attainment of SDGs related to clean energy, sustainable industrialization, and climate readiness [21].

Previous research on renewable energy towards environmental sustainability also provides diverse perspectives, leading to several conclusions. A study found that renewable energy significantly reduces the ecological footprint, contributing positively to environmental sustainability [1]. Conversely, another research highlights the complex nature of renewable energy's impact. While increasing renewable energy usage can mitigate the ecological burden, economic shifts and policy changes may negatively impact renewable energy progress, thus affecting environmental sustainability unfavorably [22]. In a different study focused on the MENA region, it was found that investment in renewable energy has a positive relationship with environmental sustainability [23]. Additionally, empirical analysis from top remittance-receiving countries found that renewable energy has a negative impact on emissions and ecological footprint when assessed alongside non-renewable energy and economic growth. This highlights the beneficial role of renewable energy in decreasing environmental degradation, especially when replacing non-renewable sources [24].

Previous studies show that industrialization has a mixed impact on environmental sustainability, with studies revealing both negative and positive outcomes, as well as instances of no significant impact. In Asian countries, industrialization has been found to adversely impact environmental sustainability in the long run due to increased emissions [25]. Similarly, in Ghana, industrialization was reported to have a negative impact on ecological footprint, thus contributing positively to environmental sustainability under certain conditions [3]. Conversely, in Sub-Saharan Africa, industrialization is generally detrimental to the environment, as it increases the ecological footprint. However, the adoption of renewable energy in industrial processes can mitigate this negative impact, underscoring a nuanced relationship between industrialization and environmental sustainability [1]. In some scenarios, the transformation of industries into eco-industrial networks has been suggested as a sustainable solution to preserve natural resources, particularly in regions with booming industrial growth like South India [26]. In Somalia, industrialization and urbanization have been found to reduce environmental pollution both in the short and long term. This suggests that industrialization may have mixed effects, contingent on the regional context and the synergistic effects with other factors like energy consumption [27].

Based on mixed results on both variables, this study seeks to address gaps in understanding the relationship between renewable energy, industrialization, and environmental sustainability in the ASEAN region, using panel data from 1996 to 2021. The chosen timeframe aligns with significant global shifts in energy policies and industrial development, making it particularly relevant for policymakers and researchers alike. By exploring how renewable energy adoption and industrial growth impact environmental indicators, the study promises to offer valuable insights for shaping sustainable development strategies in the region. The findings could inform policy decisions aimed at balancing economic growth with environmental preservation, a critical challenge facing nations in Southeast Asia.

2. LITERATURE REVIEW

2.1 Environmental sustainability

Environmental sustainability refers to the responsible management and conservation of natural resources to meet present needs without compromising the ability of future generations to meet their own needs [28]. It encompasses a wide range of practices and strategies aimed at minimizing environmental impact, preserving biodiversity, and maintaining ecological balance. Key aspects of environmental sustainability include reducing carbon emissions, promoting renewable energy sources, implementing sustainable agriculture and forestry practices, conserving water resources, and minimizing waste through recycling and responsible consumption [29]. This approach also involves developing green technologies, adopting circular economy principles, and fostering sustainable urban planning. Environmental sustainability requires a collective effort from individuals, businesses, governments, and international organizations to create policies, innovate technologies, and change behaviors that support long-term ecological health and human well-being [30].

2.2 Environmental sustainability in the Association of Southeast Asian Nations

ASEAN has been increasingly focused on environmental sustainability as a key regional priority. ASEAN member states have recognized the urgent need to address environmental challenges such as climate change, deforestation, air and water pollution, and biodiversity loss [31]. The organization has developed several initiatives and frameworks to promote sustainable development and environmental protection across the region. These include the ASEAN Socio-Cultural Community Blueprint 2025, which emphasizes environmental cooperation, and the ASEAN Agreement on Transboundary Haze Pollution, aimed at reducing air pollution from forest fires.

ASEAN has also established working groups on climate change, environmentally sustainable cities, and biodiversity conservation. Additionally, the region has been working towards implementing the UN SDGs, with a particular focus on clean water and sanitation, affordable and clean energy, and climate action [21]. Despite these efforts, ASEAN faces significant challenges in balancing rapid economic growth with environmental protection, and there is a need for stronger regional cooperation, more stringent enforcement of environmental regulations, and increased investment in green technologies and sustainable practices.

2.3 Renewable energy and industrialization in the Association of Southeast Asian Nations

Industrialization in ASEAN countries aligns with the SDGs by fostering economic growth, enhancing productivity, and

promoting environmental sustainability. ASEAN manufacturing firms that integrate SDGs into their business strategies experience increased productivity and efficiency [32]. The deployment of green technologies is leading to reductions in emissions [33]. This demonstrates the importance of country-specific policy interventions that capitalize on local economic and technological contexts to support environmental goals. A sectoral analysis within ASEAN also highlights the impact of green investments and renewable energy consumption on ESG practices, which are crucial for achieving SDGs. The focus on renewable energy and green finance exemplifies a sustainable advancement approach that ASEAN economies can adopt to achieve their SDG targets [34]. Additionally, infrastructure development and industrialization contribute to achieving carbon neutrality when combined with eco-innovations, green energy, and environmental taxes. Such measures are crucial for reducing emissions as part of SDGs, particularly concerning climate action, affordable and clean energy, and sustainable industrialization [21].

2.4 Renewable energy and industrialization to ES

Previous studies have shown that renewable energy has a positive impact on environmental sustainability. Research indicates that the transition to renewable energy significantly reduces carbon dioxide emissions, aiding the goal of achieving environmental sustainability [23, 35]. Evidence from the MENA region shows that increased investment in renewable energy enhances sustainable development by mitigating the impacts of geopolitical risks that traditionally favor fossil fuels [36]. Furthermore, studies highlight that policies encouraging renewable energy, along with technological innovations, are vital in the global endeavor to reduce environmental impacts and ensure sustainable development [22, 37]. The adoption of renewable energy technologies not only reduces ecological burdens but also leads to innovations in environmental governance, paving the way for a sustainable future [38, 39].

H1: Renewable energy has a positive impact on environmental sustainability.

Previous research highlighted industrialization and its impact on environmental sustainability. One study showed that industrialization contributes to increased carbon dioxide emissions, which is detrimental to environmental health [25, 26]. This process, while economically beneficial, places considerable stress on natural resources and escalates pollution, threatening the threshold limits of ecosystems' tolerance [1, 40]. The relationship between industrial activities and increased greenhouse gas emissions is evident in various studies, including those focused on Africa's ecological footprint and South Asian carbon emissions [27]. Furthermore, industrialization often leads to inefficient resource utilization, which further exacerbates environmental degradation, indicating the need for adopting more sustainable industrial practices [41].

H2: Industrialization has a negative impact on environmental sustainability.

3. METHODOLOGY

This study employs a panel dataset of 234 observations covering Indonesia and other ASEAN countries (Thailand, Singapore, Laos, Vietnam, the Philippines, Brunei Darussalam, Malaysia, and Cambodia) over the period 1996–2021. We exclude Myanmar because of data availability. Main independent variables are renewable energy (RE) and industrialization (IN), while economic growth (EC), institutional quality (IQ), population (PO), and foreign direct investment (FD) are incorporated as control variables. The dependent variable is ecological footprint (EF), which serves as a proxy for environmental sustainability. Table 1 gives detailed information about all variables used.

Table 1. Measurement and data sources of variables

Variables	Abbreviation	Measurement	Data Sources
Ecological footprint	EF	In global hectares	Global Footprint Network (GFN)
Institutional Quality	IQ	Economic Freedom Index is ranked in scale of 0-100	The Heritage Foundation
Industrialization	IN	Employment in industry as % of total employment	World Development Indicators (WDI)
Population	PO	Population growth in annual %	
Economic Growth	EG	Annual growth in %	
Renewable Energy	RE	In % of total final energy consumption	
Foreign Direct Investment	FD	Net inflows (% of GDP)	

We employ three models to analyze the relationship between industrialization and renewable energy on environmental sustainability:

$$EF_{it} = \mu + EF_{it-1} + \alpha_1 RE_{it} + \alpha_2 IN_{it} + \alpha_3 EC_{it} + \alpha_4 PO_{it} + \varepsilon \quad (1)$$

$$EF_{it} = \mu + EF_{it-1} + \alpha_1 RE_{it} + \alpha_2 IN_{it} + \alpha_3 RE_{it}*IN_{it} + \alpha_4 EC_{it} + \alpha_5 PO_{it} + \varepsilon \quad (2)$$

$$EF_{it} = \mu + EF_{it-1} + \alpha_1 RE_{it} + \alpha_2 IN_{it} + \alpha_3 EC_{it} + \alpha_4 PO_{it} + \alpha_5 IQ_{it} + \alpha_6 FD_{it} + \varepsilon \quad (3)$$

The three models are employed as a hierarchical strategy to progressively isolate direct effects, interaction mechanisms, and robustness. Model (1) serves as the dynamic baseline, establishing the average direct impact of industrialization and renewable energy on the ecological footprint. The progression to Model (2) introduces an interaction term $RE_{it}*IN_{it}$ to test the hypothesis that renewable energy *moderates* the environmental impact of industrialization; any discrepancies in the industrialization coefficient between these two models are therefore structural and expected, as Model (1) captures the unconditional average effect, whereas Model (2) captures the conditional effect (specifically when renewable energy is zero). Finally, Model (3) extends the analysis by adding institutional quality and FDI to control for omitted variable bias; the persistence of the main signs and significance levels in this model, despite the inclusion of these governance and financial variables, serves to justify the model choice by confirming that the findings are robust and not driven by external institutional factors.

Variables used are defined as follows. The dependent variable is the ecological footprint EF_{it}, representing the level of environmental pressure in country *i* at time *t*. To account for dynamic effects, the lagged value of ecological footprint (EF_{it-1}) is also included [1]. The key independent variables are renewable energy consumption (RE_{it}), measured as the share of renewable sources in total final energy use, and industrialization (IN_{it}), proxied by the proportion of the labor force employed in the industrial sector. Several control variables are incorporated, namely GDP per capita growth (EC_{it}) to capture economic growth, population growth rate (PO_{it}) to account for demographic dynamics, institutional quality (IQ_{it}) as a measure of governance and institutional performance, and foreign direct investment (FD_{it}), expressed as net inflows relative to GDP.

We use the Generalized Method of Moments (GMM) estimation technique to assess the relationship between renewable energy and industrialization on ecological footprint in ASEAN. GMM is a versatile estimation technique widely used in econometrics due to its flexibility and robustness to failures in auxiliary distributional assumptions that are not necessary for identifying key parameters [42]. GMM is powerful for analyzing complex datasets such as longitudinal and panel data [43]. It can address issues of endogeneity, often encountered in econometric analyses involving instrumental variables. This is evident from its application in various models, including count data models, where simultaneous equations might lack straightforward reduced forms [44]. GMM also provides a convenient framework for model selection and estimation in nonlinear systems with endogenous variables. GMM allows simultaneous estimation and model selection in environments with potentially infinite parameters and high collinearity [43].

4. RESULTS AND DISCUSSION

We start the analysis with descriptives and correlation analysis, as shown in Appendix 1. Environmental sustainability, as proxied by ecological footprint, is strongly correlated with renewable energy, industrialization, institutional quality, and foreign direct investment, and weakly correlated with economic and population growth.

We employ one step system GMM estimation technique to assess the impact of renewable energy and industrialization towards environmental sustainability, as proxied by ecological footprint. Results are seen in Table 2 for short-term effects and Table 3 for long-term effects. We used significant variables (*RE, IN, EC, PO*, and *IQ*) to run short-term effects to determine the long-term effects. Based on Table 2, we assess the validity of the model employed, and we run Arellano-Bond (AR) and Sargan test to detect autocorrelation between the variables. AR(2) contains coefficient with probability values of approximately 0.507, 0.608, and 0.587 for all three models, the Sargan statistic, with p-values of 0.001, 0.000, and 0.000. These values imply that the residuals lack autocorrelation, suggesting that the models are well-specified. The result indicates that in ASEAN, for the short term, renewable energy has a significant negative relationship with ecological footprint. A change in renewable energy reduces the ecological footprint by .12 hectares, thus improving environmental sustainability. Therefore, H1 is supported. This result supports previous research [23, 35, 36] that renewable energy could reduce the impact of environmental degradation. In the context of ASEAN, these countries are actively pursuing renewable energy as a means to reduce carbon emissions and enhance environmental sustainability, through the ASEAN Plan of Action for Energy Cooperation that aims to achieve a 23% renewable energy target in the primary energy supply. However, ASEAN currently faces a challenge as the current pace of energy transition is inadequate, primarily due to insufficient investment [18, 45]. Renewable energy significantly helps in reducing CO_2 emissions and fostering sustainable development in ASEAN [46]. Additionally, ASEAN has established regulations and incentives to encourage the use of renewable energy, yet the deployment and governance reforms needed to enhance the share of renewables remain limited, leading to modest progress towards these goals [47]. Thus, while ASEAN's renewable energy initiatives hold promise, realizing their full potential requires overcoming regulatory hurdles and increasing investment to expedite the transition to a more sustainable energy landscape [19].

Table 2. Short-term estimation results

	(1)	(2)	(3)
L.EF	.1248489	.1621659	.1208775
	(.1298989)	(.141555)	(.114083)
IN	.2513387**	.2112112	.1473403
	(.1128957)	(.1299777)	(.1167678)
RE	-.1256538***	-.1153072***	-.0781321*
	(.0303962)	(.0345574)	(.039993)
*IN*RE*	-	-.0009149	-
		(.0016238)	
EC	.0382333***	.038229***	.0530765***
	(.0102709)	(.0098918)	(.013356)
PO	.1849579***	.1771186***	.2440425***
	(.0497334)	(.0498779)	(.0560904)
IQ	-	-	.0531667*
			(.0312033)
FD	-	-	-.0131411
			(.0182942)
Cons	1.741212	2.551869	-1.382398
	(1.288019)	(1.899696)	(2.167336)
Observation	225	225	225
AR(2)	0.507	0.608	0.587
Sargan	0.001	0.000	0.000

Significant at ***p < 0.01, **p < 0.05, *p < 0.1

Industrialization has a significant positive relationship with ecological footprint. A change in employment in the industry contributes to the increase of .25 hectares of ecological footprint, and impacts environmental sustainability negatively. Therefore, H2 is supported. This result aligns with other research, which stated industrialization is hazardous to the environment [1, 25, 26]. This is due to the region's rapid economic growth, which has been largely fueled by industrial activities, leading to increased energy consumption and a reliance on fossil fuels. ASEAN's increasing energy demand, driven by industrialization, has led to a growing ecological footprint [48, 49]. Policies aimed at increasing the use of green energy, implementing strict environmental guidelines, and fostering regional cooperation are crucial for sustainable industrial growth [50, 51]. These results contradict the study [27], which suggests industrialization has a mitigating effect on the environment. This could be due to the level and stage of industrialization and variations in environmental regulations that differ from those in ASEAN.

We also conduct an additional analysis to examine whether industrialization can benefit environmental sustainability

through the utilization of renewable energy. However, the results indicate that industrialization does not necessarily contribute to environmental sustainability even when combined with renewable energy use. This could be due to ASEAN countries still transitioning from an agricultural to an industrial society. Transitioning to use renewables can help ASEAN countries meet energy demands while contributing to carbon neutrality goals [18], while also implementing policies that promote renewable energy, such as energy governance reforms and incentives for green energy projects [45]. Population growth is positively related to the ecological footprint, as an increase in population tends to elevate consumption and waste. Simultaneously, economic growth is another driver positively associated with the ecological footprint, as the expansion of industrial activities and heightened energy consumption tied to economic growth usually result in increased carbon emissions and environmental degradation [52]. Institutional quality also exhibits a positive relation to ecological footprint, which means that stronger institutions can facilitate economic expansion, infrastructure development, and increased consumption, which in turn raise resource use and emissions [53]. Lastly, foreign direct investment does not have a relationship with the ecological footprint, because of varying institutional quality and governance in different ASEAN countries, which can regulate and leverage its impacts on the environment [54].

Table 3. Long-term estimation results

	RE	IN	EC	PO	IQ
Coef	-.079**	.157	.047***	.238***	.068
f.	(.039)	(.113)	(.010)	(.264)	(.027)

Significant at ***p < 0.01, **p < 0.05, *p < 0.1

We also analyze the long-term effect of all significant variables that are presented in Table 3. We found that, in the long run, a percentage increase in renewable energy can further decrease 0.08 hectares of ecological footprint, a percentage increase in economic growth and population growth can increase 0.05 and 0.23 hectares of ecological footprint, while industrialization and institutional quality do not. These results suggest that these aspects in the future can actually have a positive impact on the environment, by improving a greener industry and making a green, environmentally friendly policy for industries [55]. Renewable energy consumption can significantly decrease emissions [56] and has been found to mitigate environmental degradation [57]. On the other hand, economic growth can increase environmental degradation due to higher energy demands, resulting in elevated ecological footprints and emissions [58, 59]. Population growth necessitates greater energy production, often escalating the reliance on fossil fuels in the long run [24, 60].

5. CONCLUSIONS

This study aims to investigate the relationship between renewable energy and industrialization on environmental sustainability in the short and long term. Based on findings discussed above, both hypothesis is supported. In the short term, renewable energy has a negative relationship with ecological footprint, meaning that utilizing renewable energy is beneficial to the environment, while industrialization has a positive relationship, meaning that industrialization could lead to environmental degradation. In the long term, the findings confirm that renewable energy can be used over time to reduce ecological risk, while industrialization does not have a long-term effect. This means that ASEAN countries in the future could still mitigate and conduct a transition towards greener industrial practices.

This study has several limitations. The analysis primarily focuses on the ASEAN region, which may limit the generalizability of findings to other geographical contexts. The short-term and long-term effects observed may not capture the full complexity of environmental dynamics, as ecological systems often respond to changes over extended periods. Additionally, the study's reliance on ecological footprint as the primary measure of environmental degradation may not encompass all aspects of environmental impact. Other indicators, such as biodiversity loss or specific pollutant levels, could provide a more comprehensive picture. Future research also could benefit from incorporating a wider range of environmental indicators, exploring sector-specific impacts, and conducting comparative analyses across different regions.

The findings suggest several important policy implications for managing industrialization and its environmental impacts in ASEAN countries. Policymakers should adopt a balanced approach to industrialization, carefully managing the process to mitigate negative environmental effects, especially in the short term. Promoting renewable energy adoption could help offset environmental degradation associated with industrial growth. Strengthening institutional quality through improved governance, regulatory frameworks, and enforcement mechanisms is crucial for better environmental outcomes. Investing in clean technologies and supporting research and development in cleaner industrial processes and more efficient renewable energy technologies is essential.

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