

THE NEXUS BETWEEN ELECTRIC ENERGY AND RENEWABLE ENERGY ON CARBON EMISSIONS

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Abstract. Developing markets like Indonesia still use natural gas, oil and coal as the main sources of electricity. These traditional energy sources will run out soon. Nowadays, Indonesia needs to pursue renewable energy while evaluating the environmental impact of carbon emissions from electricity generation and the use of oil, gas, and coal. This paper aims to investigate the relationship between the three main energy sources of electricity and renewable electricity to carbon emissions from Indonesia. Data series from 1990 to 2020, compiled by the International Energy Agency (IEA), are identified using the Partial Adjuster Model (PAM) with Robust Least Squares (RLS). Empirical results found that all major energy sources have a positive and significant effect on carbon emissions in both the short and long run. Specifically, electricity from coal has the most dominant impact, while gas contributes the least to carbon emissions. In both the short and long term, renewable electricity has been shown to reduce carbon emissions in Indonesia, albeit relatively modestly. In addition to the main findings, this paper implicitly reveals a strong structural dependence on coal-based electricity in Indonesia, which limits the effectiveness of efforts to reduce emissions despite the development and expansion of renewable energy. The findings indicate that the limited impact of renewable energy is due to limitations in institutional readiness, investment scale, and technological capacity. This paper also contributes to the literature by integrating disaggregated electricity sources (gas, oil, and coal) into the dynamic PAM-RLS framework, thereby offering a more nuanced and comprehensive perspective than conventional aggregate approaches. Notably, it provides policy implications by emphasising the urgency of accelerating renewable energy development to achieve environmental sustainability and inclusive economic growth. Other implications of the current study are discussed in the future.

Keywords: Traditional electric energy, renewable electric energy, carbon emissions, PAM-RLS, Sustainable development goals.

JEL Classification: L94, Q42, Q54, C22

1. INTRODUCTION

Electrical energy is a basic need of modern society because the equipment used daily is based on electricity. Therefore, the need for electrical energy continues to grow with population growth and the expansion of its various activities. Electrical energy is a key factor in economic activities, so it is correlated with economic improvement. From a cross-case perspective, for example, in Malaysia, Chandran et al. (2010) and Sharif Ali et al. (2020) found an elastic causality between electricity and Gross Domestic Product (GDP) over two time spans, namely 1971-2003 and 1970-2014. On a broad scale,

Narayan et al. (2010) found that trends in electricity consumption systematically affected the economy across 93 countries over the period 1980-2006. Ciarreta and Zarraga (2010) stated that electricity consumption growth is positively related to GDP across 12 European countries during 1970-2007. Dey and Tareque (2020) observed a significant role of electricity demand in GDP per capita in Bangladesh during 1971-2014. In their paper, Ozturk and Acaravci (2011) showed that long-term use of electrical energy had a positive effect on the GDP of 11 countries in the Middle East and North Africa (MENA) region during 1971-2006. Jamil and Ahmad (2010) published that an increase in electricity prices has the potential to increase Pakistan's economy from 1960 to 2008. For Indonesia, Priyagus (2021) concluded that energy consumption in the electricity sector was able to comprehensively drive transportation GDP, but greenhouse gas emissions increased during 2000-2019.

The International Energy Agency (2024) reports that Indonesia's per capita electricity consumption is relatively high compared with that of some countries in the Association of Southeast Asian Nations (ASEAN). The measure of electricity consumption per capita is expressed in megawatt-hours (MWh). In 1990, electricity consumption per capita was 0.2 MWh, rising fivefold to 1 MWh in 2020. For comparison in the same period, Malaysia's was 1.2 MWh to 4.8 MWh or a fourfold increase, Thailand's was 0.7 MWh to 2.7 MWh or a 3.8571-fold increase, the Philippines was 0.4 MWh to 0.8 MWh or a twofold increase, and Brunei Darussalam's was 4.3 MWh to 12 MWh or a 2.7907-fold increase. At the global level, electricity consumption increased from 2.1 MWh in 1990 to 3.1 MWh in 2020, a growth of only 1.4762 times. Although Indonesia's per capita electrical energy consumption is relatively low, its large population of 271.9 million results in a very high total demand for electrical energy. The majority of the need for electrical energy still relies on coal.

As is known, electrical energy generation in Indonesia is sourced from coal, oil, natural gas, and alternative resources such as water, wind and solar. Electrical energy in Indonesia is created from non-renewable materials, especially coal, by two to three times more than oil and gas, while from renewable materials, only about 17.76% and the largest is from water (hydro). This situation triggers the extensive exploitation of non-renewable natural resources to generate electricity and poses a threat of increased carbon emissions. According to the World Bank Group (2023), the average annual emissions in Indonesia in 2018-2020, compared to countries with the same context, are 1,495 million tons of carbon dioxide (CO₂) with million tonnes of carbon dioxide equivalent (MtCO₂eq), which is classified as high. CO₂ is a gas produced from burning fossil fuels (Priyagus, 2022). In other words, the polemic needs to be reduced in absolute terms.

The issue of emissions associated with energy use has been a long-standing topic of debate. Friedl and Getzner (2003), Roca and Alcántara (2001), and Say and Yucel (2006) calculated the impact of energy consumption on emissions, or vice versa. With the trade-off (in this case, the scope of developing countries), trying to optimise energy capacity and economic growth. At the same time, the increased consumption of energy as a production input and the environmentally unfriendly nature of energy sources will only exacerbate the impact of carbon emissions at regional, national and international scales. Environmental damage problems, such as carbon emissions, do not recognise regional boundaries because they are concentrated in the air. Carbon emissions can move freely and are the main cause of global warming.

The aim of this paper is to dissect the relevance of electric energy based on three main sources: (1) natural gas, (2) oil, and (3) coal, on their carbon emissions. Also, its impact in influencing renewable electric energy policy in Indonesia. In particular, the main objective of this study is to analyze the impact of electricity generated from gas, oil, and coal, as well as renewable energy, on carbon emissions in Indonesia using the PAM-RLS technique. The paper's concept, aimed at deepening the literature on carbon emissions from electrical energy, is built on three premises. First, Indonesia is the largest coal-fired power producer in ASEAN. Second, examining the link between electricity and carbon emissions from a different perspective than before, thus opening up a new landscape. Third, the effectiveness of renewable electricity on carbon emissions from electricity. Most studies attribute the increase in carbon

emissions largely to energy (including electricity) and some macro components, such as economic growth, capital, and urbanization (*i.e.* Bhattarai & Hammig, 2001; Beckerman, 1992; Boujan et al., 2011; Coondoo & Dinda, 2002; Grossman & Krueger, 1995; Kasman & Duman, 2015; Mohapatra & Giri, 2009; Peng et al., 2014; Torras & Boyce, 1998; Wu, 1998). Given the unexplored opportunities from past editions, a model refresh is needed to evaluate the three main sources of electricity generation in terms of carbon emissions and impacts.

The findings of this paper are expected to help accelerate the transition from fossil fuel-based electricity to renewable energy, which is vital not only for ensuring long-term energy security and sustainability but also for reducing environmental degradation. From an economic perspective, the expansion of renewable energy investment warrants closer examination, as it has the potential to drive inclusive growth by lowering the external costs of carbon emissions, decreasing dependence on imported energy, and creating green jobs. Moreover, policymakers need to develop integrated energy policies that balance economic efficiency with environmental objectives, including effective financing strategies, technological support, and fiscal incentives to accelerate the adoption of renewable energy. The framework of the paper consists of the following four chapters: (1) Introduction, (2) Research methods, (3) Results and discussion, and (4) Conclusions.

2. RESEARCH METHODS

Basically, this paper is designed as an associative study centred on gas and oil as the main sources of electricity generation and their influence on carbon emissions. The unit of analysis is the national aggregate, with annual observations reflecting developments in the energy and environmental sectors. Data were collected through documentation techniques from secondary databases. The case study is set in Indonesia, using time-series data from 1990 to 2020. The quantitative approach, employing time series data, focuses on analysing the dynamic relationship between fossil-based and renewable energy sources and carbon emissions. Variables are selected based on the availability of consistent data and theoretical relevance, with the primary source being standardized and credible official documents, namely the EIA. Data selection criteria include compatibility among variables to support econometric model estimation, completeness of the observation period, and consistency in measurement units. The investigation period spans an extended timeframe to capture both short-term and long-term dynamics, enabling the identification of partial adjustment patterns in the relationships among variables. Table 1 summarizes the variable components.

Tab. 1

Variable Size and Its Relevance to the SDGs

Abbreviations	Variable name	Classification (indicator)	SDG pillars (links)
EMILECT	Carbon emissions from electricity	Kilograms of carbon dioxide per kilowatt-hour (KgCO ₂ /kWh)	SDG 13: environmental impact indicators
ELECT_GAS	Electric energy from gas	Metric tons (M/T)	SDG 13: increasing carbon emissions
ELECT_OIL	Electric energy from oil	Metric tons (M/T)	
ELECT_COAL	Electric energy from coal	Metric tons (M/T)	
RENEWSELECT	Renewable electrical energy	Kilowatts per hour (kWh)	SDGs 7 and 13: reducing carbon emissions
EMILECT t-1	Lag time of carbon emissions from electricity	–	–

Source: International Energy Agency (2024)

The data was processed with a statistical tabulation named Partial Adjuster Model based on Robust Least Squares (PAM-RLS). PAM-RLS was applied to tabulate the data by employing EViews software.

The three procedures in PAM-RLS include: (1) descriptive statistics, (2) hypothesis testing, and (3) robust regression. The approach in predicting the effect of electric energy on carbon emissions and vice versa is adopted from manuscripts written by Abdallah and El-Shennawy (2013), Abokyi et al. (2021), Arcos-Vargas et al. (2023), Dinda (2004), Kijima et al. (2010), Li et al. (2023), Lin and Li (2020), Osobajo et al. (2020), and Rehman et al. (2019). The basic equation form is formulated as follows:

$$EMILECT = \alpha + \beta_1 ELECT_{GAS} + \beta_2 ELECT_{OIL} + \beta_3 ELECT_{COAL} + \beta_4 RENEWELECT + \beta_5 EMILECT_{t-1} + e \quad (1)$$

where; α = Constant, $\beta_1 \dots \beta_5$ = Path coefficient, e = Confounding factor; EMILECT = Carbon emissions from electricity, ELECT_GAS = Electrical energy from gas, ELECT_OIL = Electrical energy from oil, ELECT_COAL = Electrical energy from coal, RENEWELECT = Renewable electrical energy, and EMILECT t-1 = Lag time carbon emissions from electricity.

PAM-RLS was adopted to address potential deviations such as outliers and heteroscedasticity. It is important to note that this approach provides estimates that are more robust to violations of classical assumptions. Nonetheless, this paper has limitations, including its inability to capture spatial variation across regions and its exclusion of other macroeconomic variables that could influence carbon emissions. Additionally, the use of aggregate data limits the analysis's ability to examine sectoral characteristics in greater detail. As shown in Table 1, the three variables studied are interrelated because the composition of electricity sources (gas, oil, coal, and renewable energy) directly determines the level of carbon emissions generated during electricity production. Greater reliance on fossil fuels increases carbon emissions, potentially hindering progress toward the Sustainable Development Goals (SDGs), particularly Goal 13 (Climate Action). Conversely, increased use of renewable energy supports Goal 7 (Affordable and Clean Energy) by providing cleaner energy. Fundamentally, transitioning the energy structure toward renewable sources is essential for promoting sustainable energy systems while simultaneously reducing carbon emissions.

3. RESULTS AND DISCUSSION

Overall, the variables used are normally distributed, so the calculated results are unbiased. Table 2 presents descriptive statistics, including the mean, standard deviation, maximum, and minimum values for each variable. Table 3 shows the impact of carbon emissions from electricity generation in the long and short term. Hypothesis testing validates that electrical energy from gas, oil and coal has a positive and significant effect on carbon emissions. The short-term assessment results indicate that for each 1 M/T increase in electrical energy, carbon emissions from gas increase by 0.0296 kgCO₂/kWh, from oil by 0.05 kgCO₂/kWh, and from coal by 0.0719 kgCO₂/kWh. In the long term, every 1 M/T increase in electrical energy can bring a positive and significant shift in carbon emissions generated by gas by 0.0449 kgCO₂/kWh, by oil by 0.0758 kgCO₂/kWh, and by coal by 0.1089 kgCO₂/kWh.

Tab. 2

Descriptive Statistics

Item	ELECT_GAS	ELECT_OIL	ELECT_COAL	EMIELECT	RENEWELECT
Mean	31,905.71	23,227	67,221.39	104.4626	1,793.29
Maximum	65,699	42,843	180,869	225.3	2,664
Minimum	734	7,906	9,768	22.6	1,216
Std. Dev.	18,575.72	10,575.81	53,066.12	63.71241	321.1211
Jarque-Bera	0.960267	2.550896	3.571693	2.244547	5.053728
Probability	0.618701	0.279306	0.167655	0.325539	0.079909
Sum	989,077	720,037	2,083,863	3,238.34	5,5592
Sum Sq. Dev.	1.04E+10	3.36E+09	8.45E+10	121,778.1	3,093,562
Obs.	31	31	31	31	31

Source: data elaborated with EViews

Furthermore, renewable electricity has a negative and insignificant impact on carbon emissions. The growth of renewable electricity can reduce carbon emissions in the short term, but the long-term prospects for further reductions are relatively limited. Renewable electrical energy has not functioned optimally due to limited resource support. Limited technological capacity, human resources, and investment have prevented the large-scale deployment of renewable electricity projects. Naturally, renewable electricity generation is not as large or as easy as electricity from coal.

Tab. 3

Hypothesis Testing of Carbon Emissions Generated by Electrical Energy

Variables	Coefficient (β)	Short-run	Long-run	Probability (p)
Constant	6.486836	6.486836	9.828485	0.4530
ELECT_GAS	0.000296	0.000296***	0.000449***	0.0039
ELECT_OIL	0.000500	0.000500***	0.000758***	0.0000
ELECT_COAL	0.000719	0.000719***	0.001089***	0.0000
RENEWELECT	-0.002220	-0.002220	-0.003364	0.5050
EMILECT t-1	0.332114	-	-	0.0003

Source: data elaborated with EViews

Note: * $p < 0.01$

The robustness of the regression is verified in Table 4 above. All independent variables included in the econometric model explain 70.7% of the variation in the dependent variable (carbon emissions), while 29.3% is explained by confounding factors not included in the model. Carbon emissions are significantly determined by renewable electricity ($p = 0.000$). When compared with the other three variables, carbon emissions from coal per M/T are the most dominant, followed by gas and oil. In Indonesia, the installed capacity of coal-fired power plants is the highest among all electricity generation sources. This condition is inseparable from Indonesia, as one of the world's coal producers, alongside China. Until now, Indonesia continues to export coal commodities according to high market demand.

Tab. 4

Robust Test

Robust Statistics			
R-squared	0.707171	Adjusted R-squared	0.646164
Rw-squared	0.998776	Adjust Rw-squared	0.998776
Akaike info criterion	67.04894	Schwarz criterion	78.97075
Deviance	348.8214	Scale	2.440550
Rn-squared statistic	9,211.806	Prob. (Rn-squared stat.)	0.000***
Non-robust Statistics			
Mean dependent var	107.1913	S.D. dependent var	62.93217
S.E. of regression	6.299015	Sum squared resid	952.2622

Source: data elaborated with EViews

Note: * $p < 0.01$

The availability of electricity supply across the three main sources is shown in Figure 1. Throughout 1990-2020, although electricity generation from gas, oil, and coal fluctuated, coal had the strongest upward trend among the three. This fact emphasises that the coal commodity is not only exploited for export abroad, but also used for domestic main power generation. From an economic perspective, the transition to renewable energy may require significant initial investment; however, it offers long-term efficiency, leading to more sustainable economic growth and reduced environmental costs.

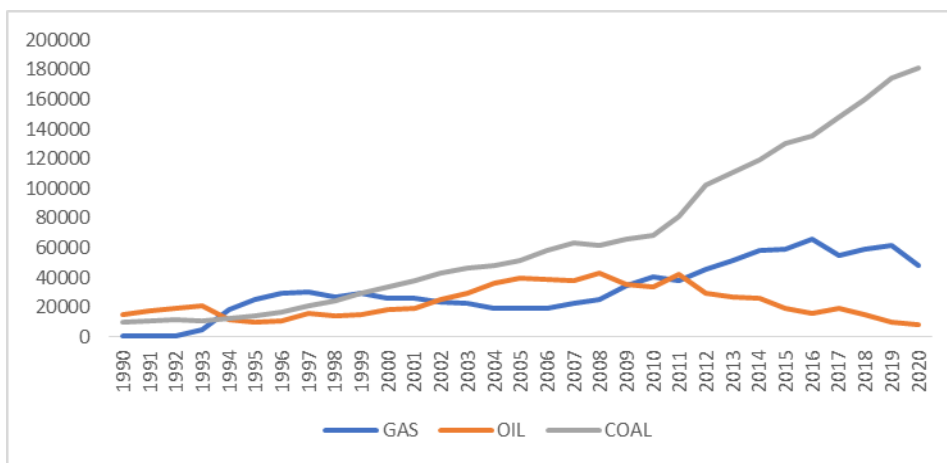


Fig. 1. Electrical Energy from Natural Gas, Oil and Coal

Source: modified from International Energy Agency (2024)

Electric energy causes an increase in carbon emissions, so complex strategies are needed. Some practical strategies to reduce carbon emissions are through efficient use of electricity and switching to renewable energy. The IEA (2024) released data on Indonesia's per capita carbon emissions converted into total Carbondioxyde (tCO₂) over 31 periods. Carbon emissions in 1990 amounted to 0.7 tCO₂ per capita, while in 2020 it became 2 tCO₂ per capita, an increase of up to 1.3 tCO₂ (see Figure 2). This phenomenon signals that carbon emissions in Indonesia must be controlled to realize zero emission in 2060.

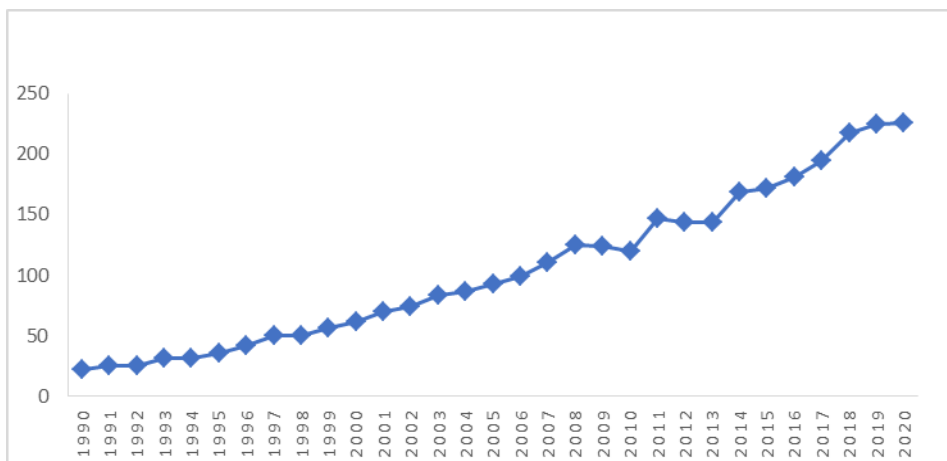


Fig. 2. CO₂ Emissions Generated from Electricity

Source: modified from International Energy Agency (2024)

There is thematic debate on energy to carbon emissions and other projected variable components. Jafari et al. (2012) explained that there is no significant causality between economic growth in Indonesia during 1971-2007. Ssali et al. (2019) examined the bidirectional relationship between energy and emissions in six Sub-Saharan African countries during 1980-2014. Quantitatively, a 1% increase in energy consumption can increase emissions by 49% in both the short and long term. Apergis and Payne (2010) confirmed that energy consumption impacts carbon emissions and is reciprocally related in 11 Commonwealth countries during 1992-2004. Hossain (2011) revealed that the high energy dependence of Newly Industrialized Countries (NICs) during 1971-2007 further increased carbon emissions.

In the case of China, Li et al. (2011) reviewed the relationship among GDP per capita, energy consumption, and carbon emissions for the period 1985-2007. As a result, every 1% increase in GDP per capita raises energy consumption by 0.48% to 0.5% and increases carbon emissions by 0.41% to 0.43%. Saboori et al. (2016) examined the interaction between energy consumption and urbanisation on carbon

emissions in Malaysia with a dataset over 1980-2008. In the long run, energy consumption and urbanization are positively related to carbon emissions. Soytas et al. (2007) concluded that the cause of carbon emissions in the United States from 1960 to 2004 was excessive energy consumption. Tran (2022) analyzed economic development on CO₂ emissions in Vietnam with data variations from 1986 to 2018. Vietnam's economic development performance integrated into energy imports, renewable energy, economic growth, and green finance proved to have a significant impact on pollution. The study illustrates that inefficient consumption of renewable energy does not have a reciprocal impact on carbon emissions. El Hedi Arouri et al. (2012) support the Environmental Kuznets Curve (EKC) hypothesis, which in their article shows that energy consumption has a positive and significant impact on CO₂ emissions in 12 MENA group countries during the period 1981-2005.

The dynamics of the higher intensity of electricity consumption in Indonesia is also a concern to be studied. For example, Amiruddin et al. (2024) highlighted the penetration rate of electric vehicles based on renewable energy networks and energy policies on emissions. Compared to conventional vehicles, the scenario of using electric vehicles is able to produce substantial improvements in emission reduction and renewable energy utilization. Rokhmawati (2020) examined the effect of the type of energy consumed by 475 manufacturing companies in Indonesia on emissions. In the contemporary period, it is evident that coal, natural gas, and diesel increase CO₂ emissions, while electricity decreases them.

Recent scientific manuscripts have revealed that the relationship between electricity consumption—whether from renewable or fossil fuel sources—and carbon emissions is increasingly complex and context-dependent. Research on developed countries, such as the G7 group (France, Italy, Japan, the United States, Germany, the United Kingdom, and Canada), emphasises that electricity from non-renewable sources remains the primary driver of increased CO₂ emissions. In contrast, renewable energy contributes positively to emission reductions, although the magnitude of this effect varies across countries (Voumik et al., 2023). In Europe, using high-frequency data and nonlinear analytical methods, Kartal et al. (2024) affirm that the effectiveness of renewable energy in reducing emissions depends heavily on each country's structural conditions and the specific types of renewable sources employed (solar, wind, and hydro). For developing markets, studies indicate that energy consumption, urbanisation, and economic growth remain the dominant drivers of carbon emissions, suggesting that the energy transition is closely intertwined with the dynamics of economic development (Mehmood et al., 2025).

Furthermore, recent literature indicates that the effectiveness of renewable energy in carbon-emission reduction strategies is strongly influenced by supporting factors, including trends in financial system development, human capital quality, institutional frameworks, and technological innovation. As an illustration, Liu and Han (2024) demonstrate that renewable energy development substantially reduces carbon emissions across many provinces in China, with this effect being more pronounced when supported by mature financial systems and technological advancements. On a broader scale, similar findings indicate that human capital plays a critical role in amplifying the impact of renewable energy on significant emission reductions across 67 countries (Shabani, 2024). In the ASEAN region, recent nonlinear panel analyses indicate that renewable energy consumption not only contributes to emission reductions but also fosters more inclusive and sustainable economic growth (Othman et al., 2025). In summary, these publications reinforce this paper's position and situate it within the global literature that emphasises the urgency of an integrated energy transition encompassing environmental, policy, and economic dimensions.

4. CONCLUSIONS

Generally, studies on emissions associated with macro variables (e.g., economic growth, per capita primary energy consumption, investment, economic openness, and urbanisation) using cross-sectional data have been conducted in many countries. Nevertheless, the literature review on electric energy and

emissions has not been specifically highlighted. Hence, this paper fills the literature gap by refining the model of the relationship between electricity generated from traditional energy sources and their carbon emissions. Notably, the paper also examines the impact of renewable electricity on carbon emissions. Through the PAM-RLS method, two important findings are obtained. First, the use of electric energy from gas, oil, and coal has significantly increased carbon emissions. Electricity produced from coal has the largest impact on emissions, while electricity produced from gas has the smallest impact. Second, the growth of renewable electricity can reduce carbon emissions, although the effect is not significant. Renewable energy has drawbacks that prevent it from fully replacing fossil fuels, including cost, technical and social issues, and dependence on weather. This paper advances academic innovation by applying the PAM-RLS to a dynamic model that examines the relationship between various sources of electrical energy and carbon emissions, with a particular focus on Indonesia. Quantitative results reveal that conventional energy sources, such as coal, have the greatest impact on carbon emissions, whereas renewable energy helps reduce emissions despite its limited availability. From an economic landscape, transitioning to renewable energy has the potential to enhance long-term efficiency and accelerate sustainable economic growth, although it requires relatively large initial investments. These findings support the achievement of the Sustainable Development Goals (SDGs). Thus, strengthening renewable energy policies is a strategic measure to maintain economic sustainability, including reducing carbon emissions.

Carbon emissions are a major cause of environmental degradation, damaging ecosystems, disrupting economies, and threatening human health. The release of carbon emissions into the earth's atmosphere due to human activities is more than naturally, including the use of electrical energy for living needs. From this paper, it is concluded that electrical energy has a worse impact, with coal as the main source of electricity generation contributing significantly to carbon emissions. Practical recommendations that can be offered to stakeholders include ensuring the availability of renewable electrical energy to generate electricity sustainably. Transitioning from traditional electrical energy to renewable electrical energy is a practical effort that enables cost savings. Establishing a renewable energy equipment manufacturing industry requires a large upfront investment. Encouraging investment in the development of renewable electrical energy is expected to be key to reducing carbon emissions.

The success of the findings in this paper is inseparable from academic preferences. Technically, the research's weaknesses can be addressed through further breakthroughs and improvements, such as in the data and objects studied. For this reason, the addition of data samples needs to be considered. Then, the object analyzed is also recommended to consider a panel study.

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Пріягус Пріягус, Мухаммад Салех, Джіухарді Джіухарді, Нурфіза Відяті, Діо Кайсар Дарма. Зв'язок між електроенергією та відновлюваною енергією та викидами вуглецю. *Журнал Прикарпатського університету імені Василя Стефаника*, 13 (2) (2026), 117-128.

Такі країни з розвитком ринків, як Індонезія, все ще використовують природний газ, нафту та вугілля як основні джерела електроенергії. Ці традиційні джерела енергії вичерпаються за короткий час. Сьогодні Індонезія повинна шукати відновлювані джерела енергії, одночасно оцінюючи вплив викидів вуглецю, що утворюються під час виробництва електроенергії та використання нафти, газу та вугілля, на забруднення навколишнього середовища. Ця робота має на меті дослідити взаємозв'язок між трьома основними джерелами електроенергії та відновлюваною електроенергією і викидами вуглецю в Індонезії. Дані за період 1990-2020 рр., зібрані Міжнародним енергетичним агентством (МЕА), були проаналізовані за допомогою моделі часткового коригування (PAM) з використанням методу найменших квадратів (RLS). Емпіричні результати показали, що всі основні джерела енергії мають позитивний і значний вплив на викиди вуглецю як у короткостроковій, так і в довгостроковій перспективі. Зокрема, електроенергія, вироблена з вугілля, має найсильніший вплив, тоді як газ має найменший вплив на викиди вуглецю. Як у короткостроковій, так і в довгостроковій перспективі відновлювана електроенергія, як було показано, сприяє зменшенню викидів вуглецю в Індонезії, хоча і відносно незначно. На додаток до основних висновків, ця робота непрямо виявляє сильну структурну залежність Індонезії від електроенергії, що виробляється на основі вугілля, що обмежує ефективність зусиль щодо скорочення викидів, незважаючи на розвиток і розширення відновлюваних джерел енергії. Висновки показують, що слабкий вплив відновлюваних джерел енергії зумовлений обмеженнями в інституційній готовності, масштабах інвестицій та технологічних можливостях. Ця робота також робить внесок у літературу, інтегруючи розрізнені джерела електроенергії (газ, нафта та вугілля) у динамічну структуру PAM-RLS, тим самим пропонуючи більш нюансований та всебічний погляд, ніж традиційні агреговані підходи. Зокрема, вона надає політичні імплікації, підкреслюючи нагальність прискорення розвитку відновлюваних джерел енергії для досягнення екологічної стійкості при одночасному прискоренні інклюзивного економічного зростання. Інші наслідки цього дослідження будуть обговорені в майбутньому.

Ключові слова: Традиційна електрична енергія, відновлювана електрична енергія, викиди вуглецю, PAM-RLS, Цілі сталого розвитку.