Sustinere
Journal of Environment and Sustainability
Volume 9 Number 3 (2025) 254-266

Print ISSN: 2549-1245 Online ISSN: 2549-1253
Website: https://sustinerejes.com E-mail: sustinere.jes@uinsaid.ac.id

RESEARCH PAPER

Climate change promotes energy and economic downturns: Equator-based evidence

Siti Aubrey Salsabila Tisarani Putri[1], Muhammad Rafi Bakri[1], Rifky Pratama Wicaksono[2*], Agatha Malona Situmorang[3]

[1]*The Audit Board of the Republic of Indonesia, Indonesia*
[2]*Crawford School of Public Policy, Australian National University, Australia*
[3]*School of International and Public Affairs, Columbia University, United States of America*

Article history:
Received 3 March 2025 | Accepted 24 September 2025 | Available online 20 December 2025

Abstract. This study examines the impact of climate change on energy intensity and its cascading effects on national economies. Climate change constrains energy consumption, thereby influencing Gross Domestic Product (GDP), particularly in equatorial nations where its effects on the energy sector and economy are more pronounced. Using a dataset of 1,612 observations from 1990Q1 to 2020Q4 across 13 equatorial countries, this research employs the Vector Autoregressive (VAR) model, particularly the Impulse Response Function (IRF), to assess climate change's influence. Accordingly, the IRF is utilized to forecast the future trajectory of energy intensity and economic performance under worsening climate conditions. Findings indicate that natural disasters (-0.067), precipitation (-0.005), and rising temperatures (-0.317) significantly reduce energy intensity, ultimately disrupting economic stability. The analysis further reveals that these climate factors will continue to weaken energy intensity and economic growth over the next ten periods. To mitigate these risks, equatorial countries must adopt policies promoting sustainable energy and climate resilience. Governments should establish robust regulatory frameworks, enhance international collaboration, and share best practices to strengthen climate adaptation and mitigation efforts, ensuring economic stability and long-term sustainability.

Keywords: Climate change; Energy intensity; Gross Domestic Product (GDP); Natural disaster; Equator

1. Introduction

Climate change has become one of the most pressing challenges of the 21st century, reshaping both the energy system and economic performance worldwide. Since the onset of the industrial era, human activities have driven a 50% increase in atmospheric carbon dioxide, a rise significantly greater than natural variations observed in previous millennia (NASA, 2024). This accumulation of greenhouse gases has fueled unprecedented warming, with the past decade recording the hottest years on record. The consequences of this warming extend beyond environmental shifts to broader economic disruptions. Sectors that depend heavily on stable climate conditions, such as agriculture, fishing, and forestry, are particularly vulnerable. These

*Corresponding author. E-mail: rifky.wicaksono@bpk.go.id
DOI: https://doi.org/10.22515/sustinerejes.v9i3.528

disruptions can result in reduced productivity, increased production costs, and substantial economic losses.

Carleton and Hsiang (2016) demonstrate the central link between climate and energy, showing that climate conditions directly shape energy systems. Rising temperatures increase demand while simultaneously straining energy supply and transmission. At the same time, energy systems enable adaptation through activities like cooling, heating, and facilitating trade. Their study also underscores that energy consumption itself remains the primary contributor to anthropogenic climate change, highlighting the feedback loop between climate, energy, and economic outcomes.

Building on this connection, scholars have emphasized the need to improve energy efficiency and accelerate renewable energy adoption as part of global climate objectives. Numerous studies have delved into this topic, shedding light on its significance. Adebayo et al. (2022) emphasize the need for energy efficiency improvements and increased utilization of renewable energy sources to align with global climate objectives effectively. Likewise, Le and Nguyen (2019) highlighted the interconnected nature of energy in economic development, energy security, and climate change mitigation. They argued that these agendas should be pursued as integrated themes due to the inherent linkages among them. This underscores the importance of adopting holistic approaches that consider energy efficiency as a cornerstone for combating climate change while also addressing broader socio-economic objectives.

The relationship between climate change and economic performance is not merely linear, but rather a complex, multidimensional feedback loop. Deviations in temperature from historical norms directly diminish labor productivity and per capita output, thereby exerting a persistent drag on long-term economic growth across countries (Kahn et al., 2019). Furthermore, extreme climate events trigger surges in energy demand for cooling and heating, which in turn increase energy consumption and carbon emissions. This mechanism forms a feedback loop in which climate change worsens economic performance while increasing emissions through reliance on fossil fuels (Tao et al., 2023). This conclusion is reinforced by OECD (2015), which projects that in the absence of significant climate action, global GDP could experience cumulative annual losses of 1.0–3.3% by 2060. Moreover, if global temperatures were to rise by 4°C above pre-industrial levels by 2100, Gross Domestic Product (GDP) losses could reach 2–10%, with the most severe consequences concentrated in vulnerable regions such as Africa and Asia.

Yet the impacts of climate change on energy and economic performance vary greatly across geographies. Recent spatial economic theory emphasizes that warming is not uniform: equatorial countries, already operating at high baseline temperatures, face disproportionate damages, while colder regions may experience relatively modest or even beneficial effects. In this sense, climate change is inherently spatial (Desmet & Rossi-Hansberg, 2024). Burke et al. (2015) show that the relationship between temperature and economic productivity is markedly nonlinear, with output peaking at an annual average of approximately 13°C before declining sharply at higher temperatures. Consequently, tropical countries, which already operate above this optimal threshold, experience disproportionately larger economic losses from additional warming because they are hotter on average. Chamma (2024) shows that climate change also produces heterogeneous impacts across sectors. In 43 Sub-Saharan African countries, the effects are most pronounced in agriculture, which is the backbone of their regional economies. The effects on agriculture negatively affect other sectors' growth contributions and, consequently, overall economic growth.

Our study focuses on equatorial countries such as Ecuador, Colombia, Brazil, Gabon, Congo (DRC), Uganda, Kenya, São Tomé and Príncipe, Maldives, Indonesia, and Kiribati, chosen for their geographic span across three continents and their shared exposure to persistent high temperatures, intertropical convergence zone (ITCZ) dynamics, and climate-related stressors. These conditions mean that even small additional increases in temperature or shifts in rainfall patterns can produce outsized consequences for ecosystems, energy systems, and economic performance. Rising average temperatures and intensified extreme weather have already accelerated forest degradation, biodiversity loss, and crop damage in the region (UICN, 2013; Ridwansyah et al., 2023). In Ecuador, for example, glacier retreat linked to warming is projected to coincide with a 2–3°C rise in annual average temperature and a 3% increase in precipitation by 2049 (Ilbay-Yupa et al., 2021).

At the same time, equatorial countries hold significant potential as natural resource hubs, particularly in the energy sector. Uganda's power generation capacity reached 1,346 megawatts in 2023, with hydropower providing 80% of its supply and serving as a key contributor to the African regional electricity market (IEA, 2023). Indonesia, meanwhile, possesses vast non-traditional reserves, including coalbed methane, tight gases, fissile gases, and methanol hydrates, estimated at 1,800 trillion cubic feet (Maulana & Ranaputri, 2024). Yet these resources are themselves climate-sensitive: ITCZ-driven rainfall variability shapes hydropower reliability, while higher baseline temperatures amplify the economic and energy risks of climate shocks.

By analyzing a diverse set of equatorial countries, our study captures this shared vulnerability while recognizing institutional and economic differences, thereby illuminating dynamics often overlooked in studies centered on temperate or polar regions. This equator-based perspective highlights how geography shapes the intersection of climate change, energy systems, and economic outcomes, an angle largely missing from the existing literature.

Our contribution lies in linking climate change, energy intensity, and economic outcomes within the specific context of the tropics, where adaptation challenges are most acute. By drawing on empirical data and situating it within existing scholarship, the study not only expands understanding of the spatial dimensions of climate change but also highlights implications for energy policy and climate resilience. In doing so, we aim to inform strategies that strengthen both economic performance and community sustainability in equatorial nations.

2. Materials and methods

2.1. Modeling equations and software

This study employs a quantitative research approach and utilizes the Ordinary Least Squares (OLS) regression method. The selection of the appropriate regression approach depends on the outcomes of several tests that were conducted. The tests include the Chow, Hausman, and Lagrange Multiplier (LM) test. The regression model (Model 1) in this research employs Equation (1). A detailed explanation regarding the variables is provided in Table 1.

$$\mathbf{INT} = \alpha + \beta_1\mathbf{GRW}_{it} + \beta_2\mathbf{ORN}_{it} + \beta_3\mathbf{ECN}_{it} + \beta_4\mathbf{GHG}_{it} + \beta_5\mathbf{GRW}_{it} + \beta_6\mathbf{PRE}_{it} + \beta_7\mathbf{FRQ}_{it} + \beta_8\mathbf{TEM}_{it} + \varepsilon_{it} \quad (1)$$

Whereas α is a constant, β is the regression coefficient of the independent variable, t is the t-year period, i is the i-th country, and ε is an error term. Details of the variables are provided in Table 1.

Table 1. Variable definitions and source

Variables	Definition	Source
INT	Energy intensity by GDP	EIA
GHG	Greenhouse gas emission	EDGAR
FFC	Fossil fuel energy consumption (percentage of total consumption)	World Bank
FRQ	The frequency of climate change disasters in a year	IMF
GRW	GDP growth	World Bank
ORN	Oil rent	World Bank
PRE	Annual precipitation	World Bank
ECN	Energy consumption in a year	EIA
EMF	Emission by Fuel	EIA
TEM	Annual temperature change (in degrees Celsius)	IMF

Besides that, this research also uses an impulse response function to examine how the dependent variable changes when there is a shock to the independent variable. The impulse response in this study uses a Structural Vector Autoregressive (SVAR) model, excluding the deterministic terms, and the following reduced equation is denoted in Equation (2).

$$\mathbf{Y}_n = \mathbf{X}_1\mathbf{Y}_{n-1} + \cdots + \mathbf{X}_m\mathbf{Y}_{n-m} + \mathbf{U}_n \quad (2)$$

In the equation above, n denotes the period, and m represents the order of the VAR model. Assuming the model contains A endogenous variable, $\mathbf{X}_1, \dots, \boldsymbol{X}_m$ are a fixed coefficient matrix ($A \times A$), while $\mathbf{Y}_n$ is a random vector of ($A \times 1$). Furthermore, the disturbance term $\mathbf{U}_n$ follows a Z-dimensional white noise process with $E(\mathbf{U}_n) = 0$, as modeled by Kozluk and Mehrotra (2009) in their research. The white noise process is very important in the VAR model to ensure that random signals have the same intensity across periods. According to the A-B model from Amisano and Giannini (1997), $\mathbf{U}_n$ can be denoted as $\mathbf{U}_n = \mathbf{X}^{-1}\mathbf{Z}\varepsilon_n$. Based on the assumptions and conditions of the collected data, the SVAR model used in this study is presented in Equation (3).

$$\mathbf{X}\mathbf{Y}_n = \mathbf{X}_1\mathbf{Y}_{n-1} + \cdots + \mathbf{X}_m\mathbf{Y}_{n-m} + \boldsymbol{X}^{-1}\mathbf{Y}\varepsilon_n \quad (3)$$

2.2. Data collection

To explore the linkages between climate change, energy intensity, and economic growth, the study observes time-series data on 13 equatorial countries from the period of 1990-2020. The types of data used in this research are secondary data. The data for the current study were collected from the databases of the World Bank, the U.S. Energy Information Administration (EIA), the International Monetary Fund (IMF), and the Electronic Data Gathering, Analysis, and Retrieval (EDGAR) system. Table 2 presents a compilation of descriptive statistics for the data used, illustrating the overall distribution of the data.

3. Result and discussion

3.1. Simulation results

3.1.1. Ordinary Least Squares results

The common effects regression method using OLS aims to investigate relationships between variables and measure the influence of independent variables on dependent variables. This approach disregards individual and time dimensions, which means that its intercept and slope coefficients remain constant. To determine which variable has an impact, we compare the p- value against the significance level (α = 0.05). If the p-value < α, then we can conclude that the independent variable affects the dependent variable.

Table 2. Descriptive statistics

Variable	Observation	Mean	Std. Deviation
Energy intensity by GDP	1,612	2.549	1.092
Oil rent	1,612	6.743	11.091
Annual precipitation	1,612	1718.439	692.840
Annual temperature change (in degrees Celsius)	1,612	0.731	0.419
Gross Domestic Product (GDP) growth	1,612	3.123	4.988
Greenhouse gas emission	1,612	171.431	327.458
The frequency of climate change disasters in a year	1,612	0.558	0.497
Fossil fuel energy consumption (percentage of total consumption)	1,612	29.564	29.244
Emission by fuel	1,612	61.488	129.427
Energy consumption in a year	1,612	1.2876	2.832

From Table 3, it is observed that all independent variables have an impact on energy intensity by GDP except for temperature and emissions variables, with *p*-values of 0.1660 and 0.6755, respectively, which are greater than 0.05. Oil rents, GDP growth, GHG emissions, and the frequency of climate change disasters show a negative relationship with energy intensity, where each unit increase in these variables is associated with a decrease of 0.012, 0.026, 0.0042, and 0.4298 in energy intensity, respectively. On the other hand, precipitation, fossil fuel consumption, and energy consumption have a positive impact on energy intensity, with an increase of one unit in these variables contributing to an increase of 0.000330, 0.0159, and 0.5784 in energy intensity, respectively.

3.1.2. Fixed effect model results

Through the utilization of the fixed effects model, the results shown in Table 4 demonstrate how various independent variables, namely ORN, PRE, TEM, GRW, GHG, FRQ, FFC, EMF, and ECN, influence INT as the dependent variable. The results show that there is a negative trend between GRW and INT. The regression coefficient (β) for this association is -0.0118. These results indicate that a one-unit change in GRW leads to a decrease of 0.0118 in INT. With regard to GHG emissions, a strong negative correlation is also observed, as indicated by a regression coefficient β = -0.0067. According to the results, it can be concluded that a one-unit increase in GHG leads to a decrease of 0.00067 in INT.

Table 3. OLS common effect regression results

Variable	Coefficient	Std. Error	*t*-Statistic	Prob.
C	1.875802	7.91×10^{-2}	23.71973	0.0000
ORN	-0.012232	1.99×10^{-3}	-6.14681	0.0000
PRE	0.000330	3.93×10^{-5}	8.39453	0.0000
TEM	0.069417	5.01×10^{-2}	1.38569	0.1660
GRW	-0.026708	4.10×10^{-3}	-6.50777	0.0000
GHG	-0.004216	8.57×10^{-4}	-4.92184	0.0000
FRQ	-0.429824	5.30×10^{-2}	-8.11038	0.0000
FFC	0.015961	1.02×10^{-3}	15.63548	0.0000
EMF	-0.000536	1.28×10^{-3}	-0.41864	0.6755
ECN	0.578379	5.42×10^{-2}	10.67587	0.0000

Table 4. Fixed effect method

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.083210	1.96×10^{-1}	10.64035	0.0000
ORN	-0.002839	3.99×10^{-3}	-0.70999	0.4778
PRE	-5.96E-05	8.83×10^{-5}	-0.67430	0.5002
TEM	0.317938	4.35×10^{-2}	7.31544	0.0000
GRW	-0.011835	3.28×10^{-3}	-3.61352	0.0003
GHG	-0.006700	1.25×10^{-3}	-5.35121	0.0000
FRQ	-0.067355	4.82×10^{-2}	-1.39821	0.1622
FFC	0.029376	4.39×10^{-3}	6.69862	0.0000
EMF	0.001906	1.51×10^{-3}	1.26543	0.2059
ECN	0.459854	8.05×10^{-2}	5.71277	0.0000

In contrast, there is a noteworthy correlation between ECN and INT, as indicated by a regression coefficient of 0.4598. Therefore, a one-unit increase in ECN results in a 0.4598 increase in INT. Similarly, the TEM also shows a strong positive correlation with INT, with a β value of 0.3179, which demonstrates a significant positive correlation between TEM and INT. Therefore, a one-unit increase in TEM leads to an increase of 0.3179 in INT. Moreover, the high correlation between FFC and INT is equally important to acknowledge. The regression coefficient (β) of 0.0293 signifies that for every one-unit increase in FFC, there is a corresponding increase of 0.0293 in INT.

Nevertheless, other variables, namely Oil Rent (ORN), Precipitation (PRE), Climate-related Disaster Frequency (FRQ), and Emission by Fuel (EMF), have no significant influence on INT. For example, although the regression coefficient for ORN is -0.0028, the hypothesis test results suggest that there is no significant effect on INT. Such an interpretation is supported by the fact that -0.7099 (the t-value) is very close to zero and the probability of 0.4778 ($p > 0.05$). Despite the negative regression coefficient for PRE (-5.96×10^{-5}), the hypothesis test findings indicate that PRE has no significant impact on INT. This is evidenced by a t-statistic value of -0.6743 and a probability of 0.5002 ($p > 0.05$). The regression coefficient for FRQ (β_7) is -0.0673, indicating a negative relationship. However, the hypothesis test results reveal that FRQ does not have a significant influence on INT, with a t-statistic value of -1.3982 and a probability of 0.1622 ($p > 0.05$).

However, the Emission Factor (EMF) has a small positive regression coefficient of 0.001906, but it does not have a significant impact on INT. This is supported by a t-statistic value of 1.265431 and a probability of 0.2059 ($p > 0.05$). Moreover, the results of the F-statistic test reveal that at least one independent variable has a considerable simultaneous effect on INT, supported by a significant F-statistic value of 164.6119 and a low probability (F-statistic) value of 0.0000, which is below the threshold of 0.05. Furthermore, the value of Adjusted R^2 at 0.6807 means that the model can explain approximately 68% of the changes in INT using the independent variables included.

From the model results, it appears that the independent variables TEM, GRW, GHG, FFC, and ECN have a significant influence on the INT parameters, with significance levels less than 0.05. This means that increasing the value of these parameters by one unit has a substantial impact on INT. However, the variables ORN, PRE, FRQ, and EMF have no significant influence on INT, since their significance levels are higher than 0.05, indicating that their effects on INT do not significantly change.

3.1.3. Impulse response results

To identify the response of energy intensity and economic growth in the VAR model, we used the Cholesky Decomposition method, whose purpose is to generate the impulse response. In this research, the period used for analyzing the response is projected into future years. Through the impulse response function (IFR), we predict how energy intensity and economic growth respond to shocks from climate change variables, henceforth. Figure 1 illustrates the response of energy intensity to nine different independent variables.

In Figure 1, the x-axis is the forecast period of the data. The numbers represent periods after 2020, the last year of the data used in this paper. Meanwhile, the y-axis describes the response of the affected variable (energy intensity) if a shock occurs in the corresponding variable. From Figure 1, the results show that energy intensity will have a high response to shocks in energy consumption (ECN), fossil fuel energy consumption (FFC), and oil rent (ORN) in the future. A shock in ECN of one standard deviation in the first year will lead to a high impact on the energy intensity of 1.49%. However, in the second year, this response decreases drastically to 0.32%. After the second year, the responses tend to stabilize. Intensive responses are also observed when shocks occur in FFC and ORN.

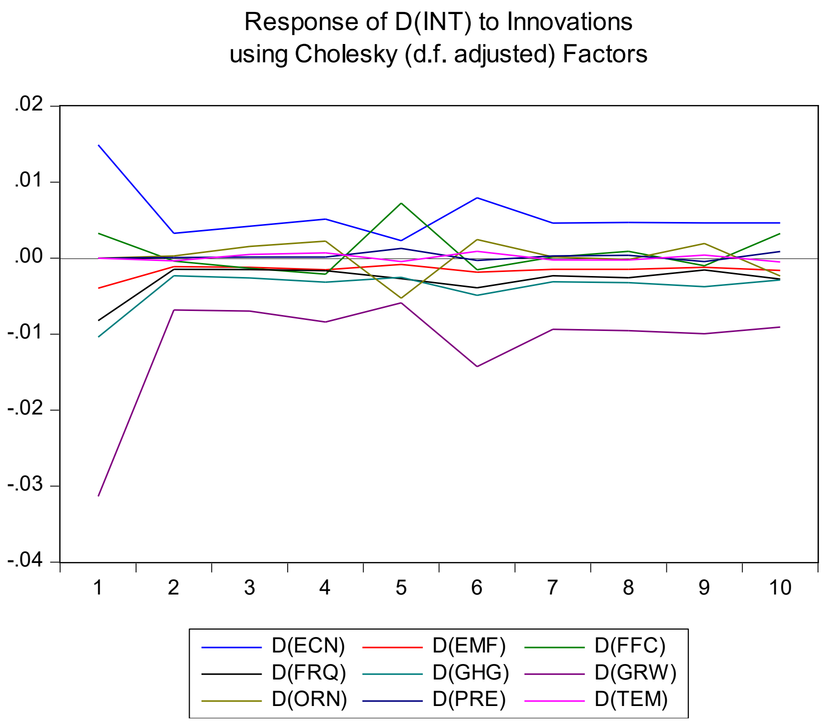

Figure 1. Impulse response of energy intensity against climate change variables

However, energy intensity will have a low response to shocks in emission by fuel (EMF), climate disaster frequency (FRQ), greenhouse gas emissions (GHG), and GDP growth (GRW). A shock in GRW in the first year will create an extremely low impact on the energy intensity of -3.13%. The response decreases sharply in the second year to -0.68% and then increases slightly to -1.42% in the sixth year. Afterwards, the response becomes steady. Another low impact will occur when there is a shock in EMF, FRQ, and GHG. When there is a shock in GHG, energy intensity responds negatively by -1.03% in the first year. This response experiences a slight decrease to -0.23% in the second year and then becomes relatively constant in the following years. Meanwhile, there are minimal changes in energy intensity when there is a shock in annual precipitation (PRE) and annual temperature change (TEM).

3.2. Robustness

The purpose of quartile regression in this study is to validate the results obtained from the FEM Regression analysis that has been conducted. According to Maduka et al. (2022), unequal variances in statistical data can cause the connection between variables to change at different points in the dependent variable's conditional distribution. Consequently, estimating methods that rely solely on average values may produce inaccurate outcomes. Therefore, the quantile regression is advantageous since it provides a more accurate depiction of the relationship between variables (Allard et al., 2018). Moreover, quantile regression can capture heterogeneity across different economies and climate groups. The results of the quartile regression are presented in Table 5.

The table above presents notable disparities between the OLS and FEM regression findings. Some variables, such as oil rent, precipitation levels, frequency of natural disasters, and levels of emissions by fuel, which previously exhibited no significant effect on energy intensity, now demonstrate substantial impacts. Conversely, several variables that were initially significant become insignificant under the quantile regression approach, such as greenhouse gas emissions and temperature. The *p*-values for greenhouse gas emissions in the first, second, and third

Table 5. Quartile regression result

Variable	Quantile	Coefficient	Std. Error	t-Statistic	Prob.
C	0.333	1.233446	0.049639	24.84821	0.0000
	0.667	1.415623	0.069802	20.28056	0.0000
	1.000	1.523038	0.084226	18.08280	0.0000
ECN	0.333	0.427572	0.045583	9.380121	0.0000
	0.667	0.424616	0.035547	11.94534	0.0000
	1.000	0.537171	0.114934	4.673718	0.0000
EMF	0.333	-0.004692	0.001088	-4.311594	0.0000
	0.667	-0.005972	0.000830	-7.195308	0.0000
	1.000	-0.006289	0.000987	-6.374163	0.0000
FFC	0.333	0.018968	0.000862	22.01148	0.0000
	0.667	0.016200	0.000879	18.42373	0.0000
	1.000	0.017199	0.000983	17.49385	0.0000
FRQ	0.333	-0.252032	0.053208	-4.736707	0.0000
	0.667	-0.242522	0.061538	-3.940987	0.0001
	1.000	-0.281434	0.074954	-3.754729	0.0002
GHG	0.333	-0.001334	0.000860	-1.550263	0.1213
	0.667	-0.000862	0.000634	-1.360080	0.1740
	1.000	-0.001724	0.001150	-1.498493	0.1342
GRW	0.333	-0.019304	0.004508	-4.282325	0.0000
	0.667	-0.012152	0.003497	-3.475090	0.0005
	1.000	-0.009781	0.002638	-3.707519	0.0002
ORN	0.333	-0.010396	0.002360	-4.404949	0.0000
	0.667	-0.008867	0.001859	-4.770146	0.0000
	1.000	-0.008006	0.002207	-3.627402	0.0003
PRE	0.333	0.000381	2.51E-05	15.19676	0.0000
	0.667	0.000468	3.26E-05	14.33381	0.0000
	1.000	0.000509	3.65E-05	13.95579	0.0000
TEM	0.333	0.031254	0.036324	0.860418	0.3897
	0.667	-0.045216	0.040675	-1.111631	0.2665
	1.000	0.007299	0.056267	0.129718	0.8968

quartiles are 0.1213, 0.1740, and 0.1342, respectively. The temperature variable exhibits a similar pattern, with *p*-values of 0.3897, 0.2665, and 0.8968, across the three quartiles.

The level of greenhouse gas emissions and rising temperatures greatly affects the intensity of energy use in a country (Zhang et al., 2023). Elevated levels of greenhouse gas emissions and higher temperature levels often correlate with increased energy use and reliance on fossil fuels. However, the quantile regression output reveals the opposite relationship. Countries located on the equator experience an insignificant impact on their energy intensity levels as a result of climate change events.

These results unequivocally contradict numerous previous studies. In their study, Dilanchiev et al. (2023) discovered that carbon gas emissions had a detrimental impact on energy intensity in developed countries. These countries have discovered alternative renewable energy sources to replace fossil fuels. Developed countries have reached the point of actively seeking a sustainable economy due to the beneficial effects that it has on the economy when carbon emissions are decreased (Khan et al., 2022; Marimuthu et al., 2021).

However, this phenomenon appears to be limited to developed nations. Upon examining Figure 2, it is evident that there is no apparent association between the trajectory of greenhouse gas emissions and economic growth in equatorial countries. A similar pattern is observed in the temperature curve when compared to economic growth. This circumstance contributes to a lack of concern among emerging countries regarding climate change, as they perceive it to have a less significant impact on their economy.

All countries situated on the equator are classified as developing countries. This fact helps explain the anomalies and the specific outcomes obtained from the quantile regression. Developing countries often need more resources, including personnel and technology, to establish renewable energy sources. This creates a reliance on fossil energy for equatorial countries. Figure 3 demonstrates a parallel pattern between energy intensity and economic growth in tropical countries. In such circumstances, tropical countries tend to find it advantageous to rely on fossil energy as the primary driver of their economy.

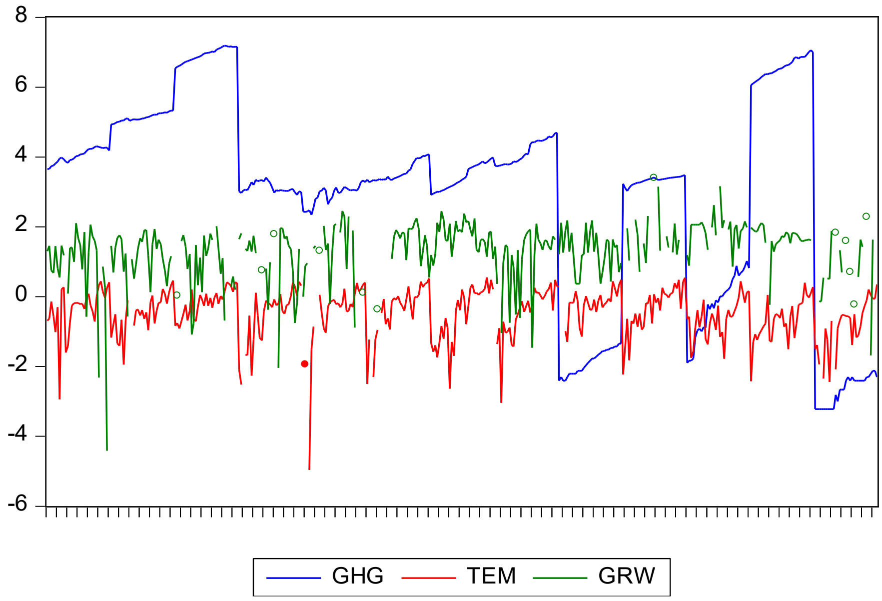

Figure 2. Climate change and the economy graph

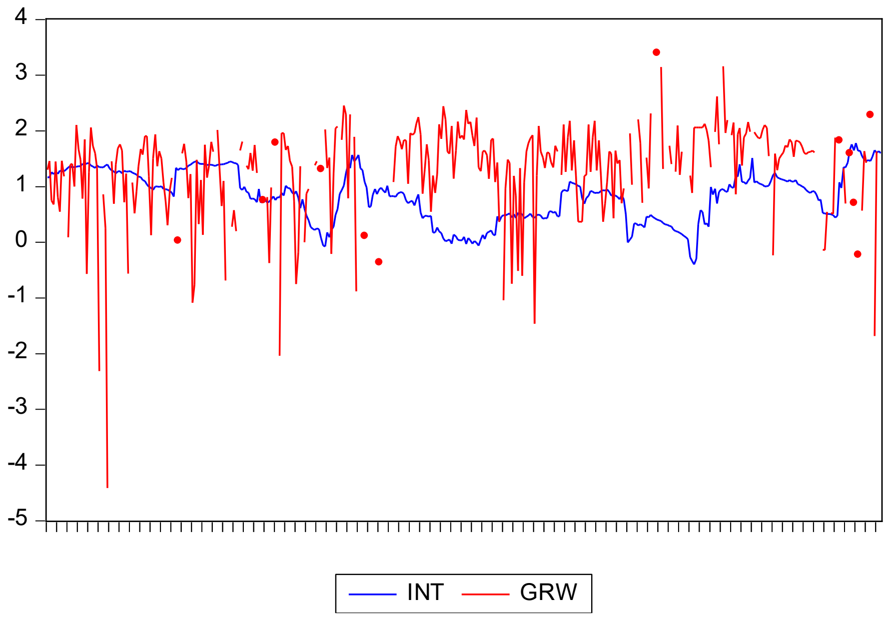

Figure 3. Energy intensity and economy graph

The findings of this quantile regression analysis contradict the research conducted by Cian et al. (2012) and Catherine et al. (2017), which suggests that rising temperatures increase power use, causing oscillations in energy intensity. Cian and Wing (2014) discovered a substantial rise in energy use in regions of China with severe weather. Winter is particularly impactful, as it experiences a threefold increase in energy intensity compared to other seasons. An elevation in temperature during these seasons diminishes the need for certain energy carriers, but it occurs solely in places with temperate climates. Cold countries tend to consume less electricity during the summer. Instead, colder locations tend to experience a rise in electricity consumption during the spring season.

Tropical countries situated on the equator undergo a phenomenon known as biseasonality, in which they only have two distinct seasons. These two seasons also lack the pronounced disparities observed in countries with four distinct seasons. This situation reduces the degree of change in energy intensity during specific seasons, leading to a steady energy demand regardless of temperature fluctuations.

3.3. Discussions

Our findings that greenhouse gas emissions negatively covary with energy intensity exhibit interesting anomalies compared to the majority of the literature in developed countries. Previous studies suggest that an increase in emissions tends to lead to a higher level of energy intensity due to increased demand for energy and reliance on fossil fuels. However, the result in equatorial countries shows the opposite direction. A sample interpretation that greenhouse gas emissions trigger awareness of energy efficiency appears too normative. Our regression model shows that, although there is a signal of decreasing energy intensity, the magnitude of the coefficient is relatively small and inconsistent across models. It indicates that "awareness" does not necessarily transform into policy or a tangible change in energy consumption. In other words, the relationship between greenhouse gas emissions and energy intensity in equatorial countries should be more precisely understood as a "structural weakness indicator" rather than as evidence of climate policy effectiveness.

In contrast, fossil fuel consumption displays a stronger and more consistent pattern. The significant positive coefficient across almost all models shows that energy intensity in equatorial countries is directly affected by the level of fossil fuel use in production, transportation, and industrial activities (Kandewatta & Fernando, 2024; Asafu-Adjaye et al., 2016). The development paradox is apparent: economic growth that relies on affordable fossil energy drives up energy intensity despite the increasing awareness of emissions (Tsai & Huang, 2023; Koengkan et al., 2020; Yang, 2015). When the impulse response shows that a shock to fossil fuel consumption triggers a short-term spike in energy intensity, while a shock to greenhouse gas emissions almost no effect, it can be concluded that the root cause is not the low level of awareness, but rather the inability of equatorial economies to withdraw from the fossil energy trap (Mukhopadhyay & Pani, 2022; Chen et al., 2019).

Why do the results differ from the pattern in developed countries? The answer lies in the differences in technology and institutional capacities. Developed countries have the ability to position awareness of emissions as a catalyst for energy transition, for instance, through low-carbon technology innovation or strict regulation. In equatorial countries, awareness is not translated beyond discourse. Although Mahmood and Ahmad (2018) highlight the potential of energy efficiency improvements through adopting environmentally friendly technologies and transitioning towards less energy-intensive products, the energy systems are still locked into fossil fuels. Agrarian- and extractive-driven economic structures, fiscal constraints, weak renewable energy infrastructures, as well as inconsistent policies hinder equatorial countries from shifting toward sustainable development (Dharmapriya et al., 2025). Simply put, our results underscore the absence of capacity, not the presence of awareness.

The policy implication is prevalent: energy transition strategy in equatorial countries should not depend on awareness or normative campaigns. If awareness and campaigns are not enough, then what should the government actually do? Concrete interventions are needed in three aspects. First, the fiscal aspect: tax incentives for renewable energy and the elimination of fossil subsidies that burden public expenditure. Second, the technological aspect: R&D investment along with international collaboration to provide alternative energy that aligns with the tropical context. Third, the institutional aspect: regulatory and governance capacity enhancement to transform awareness into action.

Without these three pillars, equatorial countries will likely experience the paradox: being aware of the impact of emissions but remaining trapped within intensive and inefficient energy consumption patterns. Therefore, addressing policy uncertainty and promoting technological innovation, with the aid of government subsidies and investments in research and development, can effectively control environmental pollution and reduce energy intensity (Chen et al., 2019; Danish et al., 2020). This is also supported by Article 10 of the Paris Agreement (2016), which emphasizes the importance of technology development and transfer in enhancing resilience to climate change and reducing greenhouse gas emissions.

Overall, this study provides two contributions. Empirically, it reveals that the greenhouse gas emissions-energy intensity correlation in equatorial countries is not linear as generally assumed, but rather is confounded by technological and institutional capacities. Conceptually, it highlights that the dominating climate-energy literature from developed countries cannot necessarily be generalized to equatorial areas. Moreover, the shock in energy consumption, fossil fuel consumption, and oil rent might occur in the future because of several issues, such as geopolitical instability, natural disasters, and policy changes. For example, conflicts in the Middle East could disrupt oil production and transportation, causing a shock to global energy markets and driving up prices (World Bank, 2023). Thus, the novelty of the "equator-based evidence" approach lies in drawing attention to the gap between awareness and action in developing countries, while offering a critical lens that energy transition is only effective if supported by a combination of fiscal incentives, technological innovation, and adequate institutional capacity.

4. Conclusion

In summary, our research found that current energy use in equatorial countries is inefficient and contributes to adverse environmental impacts. The rise in fossil fuel energy consumption and other climate change variables has a direct impact on energy intensity, particularly in relation to production processes and economic activities, as evidenced by the positive coefficients derived from the Fixed Effect Method (FEM). This result is further supported by the quantile regression output, which shows that fossil fuel energy consumption significantly affects energy intensity across all quantiles. Moreover, the impulse response results suggest that shocks in fossil fuel energy consumption will lead to increased energy intensity in the future and may disrupt the economy in the thirteen equatorial countries studied. Therefore, collaborative measures should be considered by governments to address the root causes of this issue and accelerate the transition toward cleaner and more efficient sources.

References

Adebayo, T. S., AbdulKareem, H. K. K., Bilal, Kirikkaleli, D., Shah, M. I., & Abbas, S. (2022). CO2 behavior amidst the COVID-19 pandemic in the United Kingdom: The role of renewable and non-renewable energy development. *Renewable Energy*, *189*, 492–501. https://doi.org/10.1016/j.renene.2022.02.111

Amisano, G., Giannini, C. (1997). From VAR models to Structural VAR models. In G. Amisano, & C. Giannini (Eds.), *Topics in Structural VAR Econometrics* (2nd ed., pp. 1–28). Springer. https://doi.org/10.1007/978-3-642-60623-6_1

Allard, A., Takman, J., Uddin, G. S., & Ahmed, A. (2018). The N-shaped environmental Kuznets curve: an empirical evaluation using a panel quantile regression approach. *Environmental Science and Pollution Research, 25*(6), 5848–5861. https://doi.org/10.1007/s11356-017-0907-0

Asafu-Adjaye, J., Byrne, D., & Alvarez, M. (2016). Economic growth, fossil fuel and non-fossil consumption: a pooled mean group analysis using proxies for capital. *Energy Economics*, *60*, 345–356. https://doi.org/10.1016/j.eneco.2016.10.016

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, *527*, 235–239. https://doi.org/10.1038/nature15725

Carleton, T. A., & Hsiang, S. M. (2016). Social and economic impacts of climate. *Science, 353*(6304). https://doi.org/10.1126/science.aad9837

Catherine, H., Auffhammer, M., Baylis, P., & Hausman, C. H. (2017). Climate change is projected to have severe impacts on the frequency and intensity of peak electricity demand across the United States. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1613193114

Chamma, D.D. Climate change and economic growth in sub-Saharan Africa: an empirical analysis of aggregate- and sector-level growth. *J. Soc. Econ. Dev.* (2024). https://doi.org/10.1007/s40847-024-00377-x

Chen, J., Wu, Y., Xu, C., Song, M., & Liu, X. (2019). Global non-fossil fuel consumption: driving factors, disparities, and trends. *Management Decision*, *57*(4), 791–810. https://doi.org/10.1108/md-04-2018-0409

Chen, Z., Huang, W., & Zheng, X. (2019). The decline in energy intensity: does financial development matter? *Energy Policy*, *134*, 110945. https://doi.org/10.1016/j.enpol.2019.110945

Cian, E. De, Lanzi, E., & Roson, R. (2012). Seasonal temperature variations and energy demand. *Climatic Change*, *116*(3–4), 805–825. https://doi.org/10.1007/s10584-012-0514-5

Cian, E. De, & Wing, I. S. (2014). Climate change impacts on energy demand. *Climate Impacts and Policy Division, December*.

Danish, Ulucak, R., & Khan, S. U. D. (2020). Relationship between energy intensity and CO2 emissions: Does economic policy matter? *Sustainable Development, 28*(5), 1457–1464. https://doi.org/10.1002/sd.2098

Desmet, K., & Rossi-Hansberg, E. (2024). Climate Change Economics over Time and Space. *Annual Review of Economics, 16*, 271–274. https://doi.org/10.1146/annurev-economics-072123-044449

Dharmapriya, N., Gunawardena, V., Methmini, D., Jayathilaka, R., & Rathnayake, N. (2025). Carbon emissions across income groups: exploring the role of trade, energy use, and economic growth. *Discover Sustainability*, *6*, 621. https://doi.org/10.1007/s43621-025-01261-2

Dilanchiev, A., Nuta, F., Khan, I., & Khan, H. (2023). Urbanization, renewable energy production, and carbon dioxide emission in BSEC member states: implications for climate change mitigation and energy markets. *Environmental Science and Pollution Research, 30*(25), 67338–67350. https://doi.org/10.1007/s11356-023-27221-9

IEA. (2023). Uganda 2023 Energy Policy Review. *Ministry of Energy and Mineral Development - Uganda*, 1–184. www.iea.org/t&c/%0Ahttps://memd.go.ug/wp- content/uploads/2020/07/Uganda2023-Energy-Policy-Review.pdf

Ilbay-Yupa, M., Ilbay, F., Zubieta, R., García-Mora, M., & Chasi, P. (2021). Impacts of climate change on the precipitation and streamflow regimes in equatorial regions: Guayas River basin. *Water (Switzerland), 13*(21), 3138. https://doi.org/10.3390/w13213138

Kandewatta, K., & Fernando, A. (2024). The prodigious need for fueling South Asian economies through sustainable energies. *Sri Lanka Journal of Economic Research*, *11*(2), 03–18. https://doi.org/10.4038/sljer.v11i2.202

Kahn, M. E., Mohaddes, K., Ng, R. N. C., Pesaran, M. H., Raissi, M., & Yang, J.-C. (2019). Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis (Working Paper No. 2019/215). https://doi.org/https://doi.org/10.5089/9781513514598.001

Khan, M. K., Trinh, H. H., Khan, I. U., & Ullah, S. (2022). Sustainable economic activities, climate change, and carbon risk: an international evidence. *Environment, Development and Sustainability, 24*(7), 9642–9664. https://doi.org/10.1007/s10668-021-01842-x

Koengkan, M., Fuinhas, J. A., & Santiago, R. (2020). The relationship between CO_2 emissions, renewable and non-renewable energy consumption, economic growth, and urbanisation in the Southern Common Market. *Journal of Environmental Economics and Policy*, *9*(4), 383–401. https://doi.org/10.1080/21606544.2019.1702902

Kozluk, T., & Mehrotra, A. (2009). The impact of Chinese monetary policy shocks on East and South-East Asia. *Economics of Transition and Institutional Change, 17*(1), 121–145. https://doi-org.virtual.anu.edu.au/10.1111/j.1468-0351.2009.00335.x

Le, T. H., & Nguyen, C. P. (2019). Is energy security a driver for economic growth? Evidence from a global sample. *Energy Policy, 129*, 436–451. https://doi.org/10.1016/j.enpol.2019.02.038

Maduka, A. C., Ogwu, S. O., & Ekesiobi, C. S. (2022). Assessing the moderating effect of institutional quality on economic growth—carbon emission nexus in Nigeria. *Environmental Science and Pollution Research, 29*, 64924–64938. https://doi.org/10.1007/s11356-022-20346-3

Mahmood, T., & Ahmad, E. (2018). The relationship of energy intensity with economic growth: evidence for European economies. *Energy Strategy Reviews, 20*, 90–98. https://doi.org/10.1016/j.esr.2018.02.002

Marimuthu, R., Sankaranarayanan, B., Ali, S. M., Jabbour, A. B. L. de S., & Karuppiah, K. (2021). Assessment of key socio-economic and environmental challenges in the mining industry: implications for resource policies in emerging economies. *Sustainable Production and Consumption, 27*, 814–830. https://doi.org/10.1016/j.spc.2021.02.005

Maulana, R. F., & Ranaputri, U. K. (2024). Potential development of unconventional oil and gas resources in Indonesia. *Indonesian Journal of Energy, 7*(1), 27–42. https://doi.org/10.33116/ije.v7i1.194

Mukhopadhyay, U., & Pani, R. (2022). Emission and sectoral energy intensity: a variance decomposition analysis. *Management of Environmental Quality an International Journal*, *33*(4), 955–974. https://doi.org/10.1108/meq-08-2021-0201

NASA. (2024). Carbon Dioxide. Climate Change. https://climate.nasa.gov/vital-signs/carbon-dioxide/?intent=121

OECD. (2015). The Economic Consequences of Climate Change. OECD. https://doi.org/10.1787/9789264235410-en

Paris Agreement. (2016). *Official Journal*, L 282, 4-18. CELEX. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:22016A1019(01)

Ridwansyah, I., Apip, A., Wibowo, H., Rahmadya, A., Susiwidiyaliza, S., Handoko, U., Setiawan, F., & Utami, N. (2023). The impact of land-use and climate change on water and sediment yields in Batanghari watershed, Sumatra, Indonesia. *Sains Malaysiana, 52*(3), 705–721. https://doi.org/10.17576/jsm-2023-5203-03

Tao, Z., Ren, Z. X., Chen, Y., Huang, X., & Liu, X. (2023). Pathway to sustainable economic growth: Linkage among energy consumption, carbon emissions, climate change and technological innovation. *Energy Strategy Reviews, 50*. 101253. https://doi.org/10.1016/j.esr.2023.101253

Tsai, B., & Huang, Y. (2023). Comparing the substitution of nuclear energy or renewable energy for fossil fuels between the United States and Africa. *Sustainability*, *15*(13), 10076. https://doi.org/10.3390/su151310076

UICN. (2013). *Comment aborder la REDD+ au Cameroun*.

World Bank. (2023). *Special focus: Potential near-term implications of the conflict in the Middle East for commodity markets: A premilinary assessment.* In *Commodity Markets Outlook*. World Bank. Retrieved from https://bit.ly/CMO_October_2023_SpecialFocus

Yang, P. (2015). Major economies: black energy intensity and policy implications. *IAFOR Journal of Sustainability, Energy & the Environment*, *2*(1), 63-98. https://doi.org/10.22492/ijsee.2.1.04

Zhang, X., Shi, X., Khan, Y., Khan, M., Naz, S., Hassan, T., Wu, C., & Rahman, T. (2023). The impact of energy intensity, energy productivity and natural resource rents on carbon emissions in Morocco. *Sustainability (Switzerland), 15*(8), 6720. https://doi.org/10.3390/su15086720