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THE IMPACT OF AGRICULTURAL VALUE ADDED AND BIOMASS ENERGY CONSUMPTION ON VIETNAM'S ENVIRONMENTAL QUALITY

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Abstract

This study investigates the impact of biomass energy consumption, agricultural value added, raw material productivity, and gross domestic product growth rate on Vietnam's environmental quality within the framework of the load capacity curve hypothesis over the period from 1986 to 2021. The analysis employs ARDL estimation and Granger causality tests to examine correlations. The results proved that agricultural value added and biomass energy are critical long-term drivers of environmental quality in Vietnam. The long-term estimation results suggest that a 1% increase in biomass energy consumption contributes to a marginal increase of 0.82% in the load capacity factor. In addition, agricultural value added appears to have a significant diminishing effect on the load capacity factor in Vietnam (an increase of 1% in agriculture value added versus a reduction of the load capacity factor by 2.28%). The study unveils a bidirectional relationship between biomass energy consumption and load capacity factor. These findings suggest that in Vietnam, biomass energy consumption improves environmental quality. In turn, improved environmental quality will promote biomass energy consumption.

Keywords agriculture value added, biomass energy, environmental quality, Vietnam

JEL Classification Q01, O13, Q15, Q56

INTRODUCTION

The deterioration of environmental quality has been receiving much attention from the world as its consequences have increasingly become a major challenge to the sustainable development of countries. This growing concern has increased research efforts on the factors causing climate change. Among the factors that affect environmental degradation, agricultural activities are recognized as principal contributors to global pollution and environmental degradation. Agricultural activities include deforestation for farming, irrigation, and chemical fertilizers that pollute soil, water, and atmosphere. In addition, the increase in economic activities promoting economic growth has driven up non-renewable energy demand for decades. The extensive exploitation of nature not only depletes natural resources but also pollutes the environment through the increase of carbon emissions from fossil fuel combustion. Among the alternatives to fossil energy, biomass energy has become a crucial energy option for the improvement of environmental quality and fostering sustainable growth.

Vietnam has witnessed substantial economic development since the economic reforms initiated in 1986. However, this growth has been accompanied by environmental pollution, which has negatively influenced the country's sustainability. Although agriculture in Vietnam contributes to GDP at a low level (10.8% in 2023), due to the fragmented and ignorant organization of agricultural activities, agricultural waste has contributed greatly to the reduction of environmental quality. Vietnam has a large amount of unprocessed agricultural waste and by-products, and biomass energy from this type of waste has not been properly exploited. Accordingly, the exploitation of biomass energy from agricultural waste still has great potential. Although several articles have assessed environmental quality by employing CO2 emissions variables, there are only a few other studies in Vietnam using the load capacity factor as a proxy for environmental sustainability.

1. LITERATURE REVIEW

Several studies have explored the effects of resource efficiency, agricultural value added, economic expansion, biomass energy consumption, and renewable energy on environmental quality through indicative variables like carbon emissions or the ecological footprint. Carbon emissions are widely chosen as a proxy for environmental quality. However, CO2 emissions only provide information about air pollution, while water and soil pollution are overlooked, making it insufficient to comprehensively assess environmental degradation (Awosusi et al., 2022). The ecological footprint, another proxy for environmental quality, serves as a broader measure of ecological harm compared to CO2 emissions. Nevertheless, the ecological footprint only addresses the demand aspect of nature, neglecting the supply side, namely biological capacity. In actuality, the supply side (i.e., input) of environmental quality holds significant importance for environmental conservation, as it mitigates the negative impacts arising from the demand side (Akhayere et al., 2023). Hence, recent studies have introduced the load capacity factor, proposed by Siche et al. (2010), as a novel indicator of environmental degradation.

The load capacity factor and its impact factors are presented in the load capacity curve. As income increases, the load capacity factor will improve in the long run, while there is a decreasing trend in the short run (Uche & Ngepah, 2024). Raihan et al. (2024) proved the negative relationship between economic growth and load capacity factor (LCF). The load capacity factor is computed by dividing the biological capacity (supply side) by the ecological footprint (demand side) and designating ‘1’ as the environmental sustainability threshold (Siche et al., 2010). The load capacity factor is considered a better proxy for environmental quality than the other two (Siche et al., 2010). The load capacity factor provides an indication of whether the existing ecosystem and societal lifestyle are sustainable. If the load capacity factor is below ‘1’, the present environmental conditions are deemed unsustainable. Conversely, a load capacity factor exceeding ‘1’ signifies that the available resources are adequate to meet human resource demands (Fareed et al., 2021). Numerous empirical studies have demonstrated a correlation between environmental sustainability and relevant predictive factors. Notably, the Environmental Kuznets Curve hypothesis remains the most prominent and robust theoretical foundation for forecasting environmental sustainability (Alola et al., 2023). Studies on LCF have become popular in recent years; most factors that affect environmental quality through LCF are economic growth, fossil fuel consumption, technological innovation, and human capital, while the impact of agriculture and biomass energy consumption on the environment through LCF has not been investigated. CO2, ecological footprint, and LCF are indicators representing environmental quality; impact factors of CO2 and ecological footprint are expected to have a similar effect on LCF.

In the past few years, the impact of agriculture on environmental pollution has become a frequent topic of discussion. The growth of the agricultural sector exerts a multifaceted influence on environmental quality. In emerging economies, the BRICS, the development of agriculture is greatly supported by the consumption of fossil fuels (Balsalobre-Lorente et al., 2019). There have been numerous studies that have documented the adverse effects of agricultural operations on environmental quality, such as agricultural land expansion and the use of chemical treatments that are associated with CO2 emissions (Parajuli et al., 2019; Naseem et al., 2020; Chowdhury et al., 2022; Alhashim et al., 2021); value addition in agriculture causes CO2 emissions (Yurtkuran, 2021; Usman et al., 2022). Activities in agriculture, forestry, and other land-use sec-

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tors result in greenhouse gas emissions (Raihan et al., 2023a; IPCC, 2022). Other research has shown that agriculture negatively influences environmental quality by increasing its ecological footprint (Olanipekun et al., 2019; Usman & Makhdum, 2021; Boluk & Karaman, 2024). Agriculture also degrades the natural environment (Raihan & Tuspekova, 2022; Kirwan et al., 2023).

However, there are also studies that have found positive impacts of highly developed agriculture on environmental quality. For example, research in Pakistan has shown that agricultural exports can contribute to an improvement in environmental quality (Aziz et al., 2020). Ecological footprint may initially increase and then improve as the agricultural sector develops (Muoneke et al., 2022). Several studies have indicated that agricultural value added positively impacts environmental quality by reducing CO2 emissions (Koshta et al., 2021; Raihan & Tuspekova, 2022b). Agricultural value contributes to boosting consumer demand, making the environment cleaner, and motivating governments to enforce environmental laws (Raihan & Tuspekova, 2022a).

The efficient utilization of biomass energy sources plays an essential role in attaining sustainable development goals, especially among developing economies. Biomass energy consumption is widely perceived to exert a beneficial influence on environmental quality, a proposition substantiated by numerous empirical studies. Biomass can be considered a viable alternative to fossil fuels with its environmental, economic, and political benefits (Bilgili et al., 2016). Empirical outcomes indicate a negative significant biomass energy demand and ecological footprints relationship, especially among the economies with high traits of ecological footprints (Anwar et al., 2023), causing increased CO2 emissions (Sulaiman et al., 2020; Liu et al., 2022). Additional research underscores the positive ramifications of biomass energy consumption on the load capacity factor across various nations. For instance, biomass energy has been found to enhance load capacity factor in the United States (Pata et al., 2023), BRICS countries (Yang et al., 2024), Malaysia (Zhang et al., 2024), and China (Usman et al., 2024). The negative impact of biomass energy consumption on CO2 emissions was found in the United States from 1970 to 2015, which was due to the use of low-quality biomass solutions that ultimately severely affected economic growth patterns (Zafar et al., 2021).

In addition to the positive impacts on the economy in general, bioenergy was also found to have a long-term positive impact on the transportation sector (Umar et al., 2021), one of the largest fossil fuel users. Conversely, biomass energy consumption increases ecological footprints in South Asian Association for Regional Corporation (SAARC) countries (Mehmood, 2022). The positive impacts of biomass energy on the ecosystem may be outweighed by the negative impacts of traditional household biomass burning on environmental degradation (Destek et al., 2021). Collectively, the preponderance of evidence suggests that the utilization of biomass energy contributes positively to environmental quality. Therefore, although many studies found a positive relationship between biomass energy consumption and environmental quality, it is necessary to develop modern biomass energy such as liquid biofuels, biogas, and biorefineries rather than using traditional biomass sources such as wood, animal waste, and charcoal (Destek et al., 2021).

Previous empirical literature has primarily focused on environmental quality indicators such as ecological footprint, CO2 emissions, greenhouse gases, and load capacity factor, with varying results across different countries. There is no consensus among studies on the factors affecting the environment. This is because of differences in methodology, study period, country, and environmental quality measures.

Notably, in Vietnam, there is a paucity of studies employing load capacity factor as a metric to evaluate environmental quality. The most recent research analyzed the relationship between energy consumption, trade openness, financial development, and load capacity factor (Xuan & Hung, 2024). The load capacity factor is recognized as a more robust measure of ecological sustainability. Current research on ecological sustainability in Vietnam reveals a research gap and opportunities for further exploration to simultaneously assess the impact of resource efficiency, biomass energy consumption, and agricultural growth on the load capacity factor in Vietnam. Moreover, there is a significant lack of empirical studies evaluating the relationship between biomass energy and load capacity factor in Vietnam, which is crucial for the formulation of sustainable energy policies. Additionally, policymakers in Vietnam are actively seeking strategies to mitigate environmental degradation.

The load capacity factor serves as a comprehensive indicator of environmental status, and examining its determinants can provide insights into the effectiveness of these policy measures.

Therefore, this study aims to address this gap and contribute to a more profound understanding of the impact of agricultural growth, resource efficiency, and biomass energy consumption on the load capacity factor in Vietnam. Accordingly, with the impacts of agriculture, biomass energy, and economic growth on CO2 and ecosystem footprint mentioned, these factors are also expected to have similar effects on the load capacity factor. The study's hypotheses are as follows:

H1: *Agricultural value added is expected to have a negative impact on environmental quality.*

H2: *Biomass energy is expected to have a positive impact on environmental quality.*

2. METHOD

Based on previous empirical studies (Pata et al., 2023; Usman et al., 2024; Awosusi et al., 2024; Boluk & Karaman, 2024), this model has been constructed for this study:

$$\ln LCF_t = a + b \ln AGR + c \ln MP + d \ln BIO + e \ln GDP + \varepsilon_t, \quad (1)$$

where LCF_t represents the load capacity factor coefficient, value-added agriculture is denoted as AGR_t, biomass energy consumption is BIO_t, economic growth rate is GDP_t, and raw material productivity is MP_t. (t) represents the year, and (ε_t) denotes white noise in year t.

Two control variables, *GDP* and *MP*, are included in the model to ensure that other factors do not influence the relationship between the dependent variable and the explanatory variables. In particular, GDP has been confirmed by many studies to have a relationship with environmental quality (Mehmood, 2022; Boluk & Karaman, 2024; Huilan et al., 2024; Raihan et al., 2023b). The relationship between economic growth and the environment is explained through the inverted U-shaped environmental Kuznets curve theory (Panayotou, 1993), and raw material productivity either positively influences or increases the load capacity factor in Malaysia (Zhang et al., 2024). Economies that rely heavily on natural resource-intensive industries find it difficult to achieve carbon emission reduction targets (Wang et al., 2019). In addition, many countries that rely on natural resource rental activities for economic development also face environmental pollution (Bekun et al., 2019). Therefore, to achieve resource efficiency, European countries have outlined the goal of resource-independent economic growth (Domenech & Bahn-Walkowiak, 2019).

The Autoregressive Distributed Lag (ARDL) methodology, developed by Pesaran et al. (2001), evaluates the relationships among the variables in both the long-term and short-term contexts. The ARDL model is particularly advantageous for estimating small sample sizes. This approach posits that both the dependent and independent variables are interconnected not only at the same point in time but also related to their lagged values.

The long-term and short-term relationship between the variables is estimated using the error correction model and is formulated as follows:

$$\begin{aligned} \Delta \ln LCF_t = {} & a_0 + \sum_{j=1} a_{LCF} \Delta \ln LCF_{t-j} \\ & + \sum_{j=0} a_{AGR} \Delta \ln AGR_{t-j} + \sum_{j=0} a_{MP} \Delta \ln MP_{t-j} \\ & + \sum_{j=0} a_{BIO} \Delta \ln BIO_{t-j} + \sum_{j=0} a_{GDP} \Delta \ln GDP_{t-j} \\ & + bECT_{t-1} + \varepsilon_t, \end{aligned} \quad (2)$$

where a represents the short-term coefficients, and b represents the long-term coefficients of the basic ARDL model, ε_t is white noise.

The bounds test is applied to evaluate cointegration. The null hypothesis of no cointegration is H_0: $b_0 = b_j = 0$ with $\forall j$, while the alternative hypothesis is H_1: $b_0 \neq b_j \neq 0$.

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Table 1. Data sources

Variables	Symbols	Measurement	Sources
Load Capacity Factor	LCF	Biocapacity/Ecological Footprint calculated as average global hectares per capita	Global Footprint Network data
Raw material Productivity	MP	GDP/Domestic Material Consumption (USD/kg)	International Resource Panel (n.d.)
Biomass Energy	BIO	Average Domestic Biomass Energy Consumption (ton)	
Agricultural Growth	AGR	Average Value-Added Agriculture (fixed price in 2015, USD)	WDI (n.d.)
Economic Growth	GDP	Gross Domestic Product Growth Rate (%)	

Finally, the study employs the Granger causality test (Granger, 1969) to explore the causal relationships between pairs of variables within the research model.

This study seeks to assess the influence of raw material productivity, biomass energy, agricultural growth, and economic growth on the load capacity factor. Time series data are employed to address the specific research goals concerning Vietnam. The analysis incorporates data from 1986 onwards, coinciding with Vietnam's initiation of the renovation process that year, and continues up to 2021. The variables, units of measurement, and data sources are detailed in Table 1.

3. RESULTS AND DISCUSSION

3.1. Descriptive statistical analysis

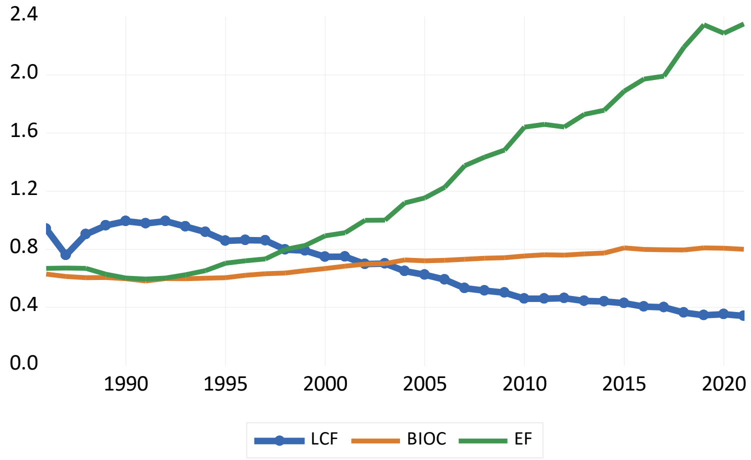
Table 2 shows the descriptive statistics of the research model in Vietnam during the period from 1986 to 2021.

From 1986 to 2021, Vietnam was classified as one of the nations with high economic growth rates. The results of the Jarque-Bera (J-B) test also indicate the normal distribution of all variables. The mean and median values of the variables displayed notable consistency (Table 2). Figure 2 illustrates that during the study period, the agricultural growth rate (AGR) exhibited an upward trend, while the biocapacity (BIO) showed an increasing trend until 2019, followed by a decreasing trend from 2019 to 2021. The GDP and raw material productivity (MP) variables demonstrated fluctuating trends over time.

Figure 1 presents the annual trends of biocapacity, ecological footprint, and the load capacity factor in Vietnam. Due to ecological degradation, biocapacity has been decreasing while the ecological footprint has been increasing, leading to a decline in the load capacity factor. In Vietnam, from 1986 to 2021, the load capacity factor exhibited a decreasing trend and consistently remained below 1, with an average value of 0.66, thereby posing a threat to environmental sustainability.

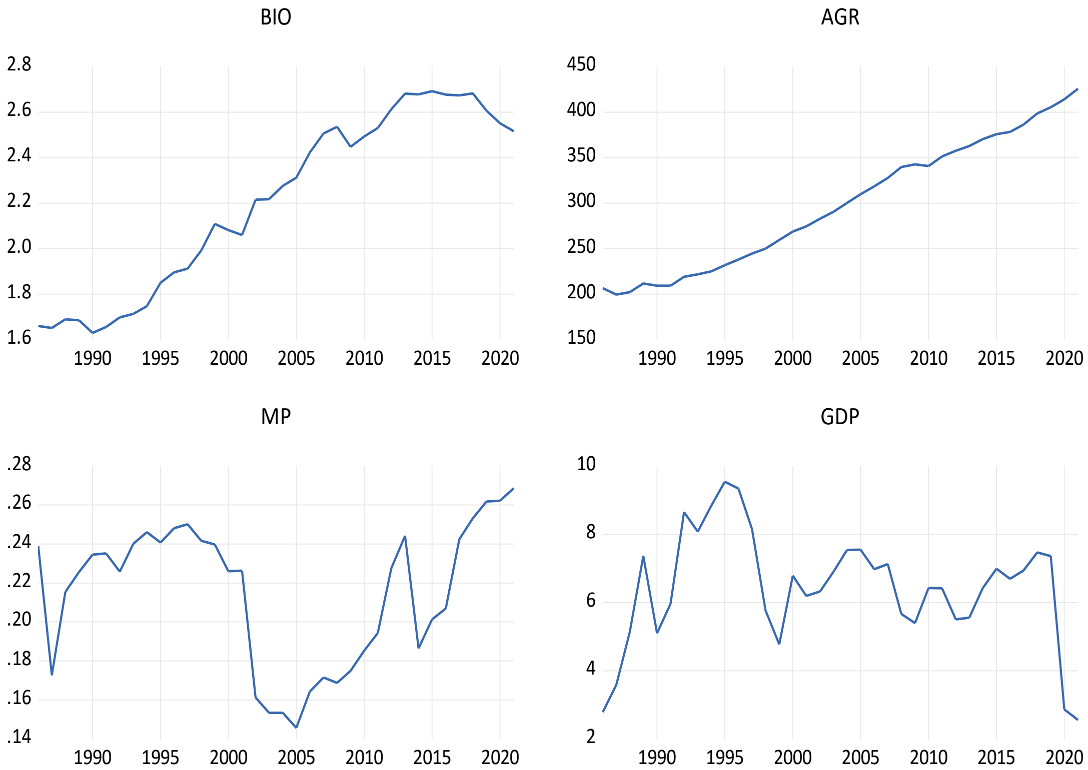
Table 2. Descriptive statistics

Statistical measure	lnLCF	lnBIO	lnAGR	lnMP	lnGDP
Mean	0.660526	2.203926	298.4708	0.214847	6.408077
Median	0.673699	2.246493	295.1790	0.226200	6.556627
Maximum	0.993116	2.691631	425.6563	0.268600	9.540480
Minimum	0.340478	1.629185	199.3269	0.145700	2.553729
Std. dev.	0.223261	0.389054	71.48667	0.036221	1.697463
Skewness	0.057750	–0.205266	0.135339	–0.470744	–0.504319
Kurtosis	1.536292	1.488196	1.659760	1.869176	3.124770
Jarque-Bera	3.233673	3.681133	2.804265	3.247741	1.549380
Probability	0.198526	0.158727	0.246072	0.197134	0.460847
Observations	36	36	36	36	36



Note: LFC = load capacity factor; BIOC = biocapacity; EF = ecological footprint.

Figure 1. Load capacity factor



Note: BIO = biomass energy consumption; AGR = agricultural growth rate; MP = raw material productivity.

Figure 2. Variation of variables

3.2. Unit root test

The results of the unit root test are detailed in Table 3. The data achieved stationarity upon first differencing at the 1% significance level. Consequently, the data series satisfies the prerequisites for proceeding with the subsequent steps of the ARDL model to assess the impact of raw material productivity, biomass energy, agricultural growth, and economic growth on the load capacity factor in Vietnam during the period from 1986 to 2021.

Based on the AIC criterion with the dependent variable LnLCF, the ARDL (1, 1, 1, 2, 3) model is identified as the appropriate model for analysis.

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Table 3. Unit root test results

Variables	ADF Test		PP Test	
	I(0)	I(1)	I(0)	I(1)
LnLCF	–2.487871	–7.877875***	–2.302470	–7.300393***
LnMP	–1.683233	–7.285545***	–1.688781	–7.128890***
LnBIO	0.121388	–4.761272***	0.054754	–4.774837***
LnARG	–2.785948	–6.921735***	–2.995285	–6.980526***
LnGDP	–2.992770	–5.153312***	–2.456101	–5.145887***

Note: *** corresponds to a 1% level of statistical significance.

3.3. ARDL testing

Table 4 presents the results of the ARDL bounds test. The findings indicate a long-term relationship among the variables in the research model, as the *F*-statistic value surpasses the upper bound critical value at the 1% significance level.

Table 4. ARDL bounds test results

F-Bounds Test				
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	12.88234	10%	2.2	3.09
k	4	5%	2.56	3.49
–	–	2.5%	2.88	3.87
–	–	1%	3.29	4.37

Table 5 presents the estimated results of the long-term and short-term coefficients of the ARDL model.

Table 5. Estimated results

Variables	Coefficients	Std. errors	t-Statistic	p-value
Long-term results				
LnAGR	–2.280378	0.298646	–7.635729	0.0000
LnBIO	0.824002	0.372019	2.214946	0.0385
LnMP	–0.004248	0.080987	–0.052453	0.9587
LnGDP	–0.127799	0.087092	–1.467405	0.1578
C	11.98546	1.562508	7.670650	0.0000
Short-term results				
∆Ln(AGR)	0.412077	0.187996	2.191948	0.0404
∆Ln(BIO)	–0.197366	0.155408	–1.269989	0.2187
∆Ln(MP)	–0.003892	0.037655	–0.103370	0.9187
∆Ln(MP(–1))	–0.148988	0.037104	–4.015462	0.0007
∆Ln(GDP)	–0.064411	0.016634	–3.872308	0.0009
∆Ln(GDP(–1))	0.028251	0.014527	1.944755	0.0660
∆Ln(GDP(–2))	0.033323	0.020567	1.620165	0.1209
ECM (–1)	–0.468467	0.047660	–9.829423	0.0000

The findings in Table 5 demonstrate a statistically significant positive relationship between biomass energy consumption and load capacity factor at the 5% significance level over the long term. It was observed that a 1% increase in biomass energy corresponds to an average increase of 0.824% in load capacity factor, holding other factors constant. In contrast, no statistical significance was detected in the short-term relationship between biomass energy and load capacity factor. Nevertheless, the long-term analysis underscores the positive impact of transitioning to clean energy on the load capacity factor. Consequently, these results align with prior analyses regarding the role of biomass energy. It can be asserted that the energy transition constitutes a significant positive predictor for the improvement of the load capacity factor in Vietnam. Biomass energy is in a short cycle, encouraged by organizations on sustainable development and the environment. Taking advantage of this fuel source will simultaneously provide energy for economic development and ensure environmental protection.

In Vietnam, biomass energy is consumed in different fields; the average biomass energy consumption in 1986 was 1.66 tons, and by 2021, it was 2.52 tons. Vietnam has a relatively developed agriculture, so the potential for biomass energy development in Vietnam is still great. Although there is a lot of potential for development, the government has also introduced preferential policies for renewable energy. They include biomass energy, such as land incentives for project implementation; long-term electricity purchase contracts within 20 years and Decision No. 08/2020/QD-TTg, amending and supplementing a number of articles of Decision No. 24/2014/QD-TTg dated March 24, 2014 on the mechanism to support the development of biomass power projects in Vietnam. However, the widespread application of biomass energy in the socio-economic sector still has many limitations for several reasons. People's awareness of the benefits and uses of biomass energy and related technologies is still limited, affecting the popularity and application of this energy source. There is no specific strategy or plan for developing and effectively exploiting biomass resources. The budget for the development and application of biomass technology is still limited, and an ineffective management system is hindering this process. In addition, the specialized human resources for this field are still limited. Therefore, the country must also implement additional policies to facilitate the shift to clean energy and gradually embrace comprehensive clean energy practices in production and consumption.

The outcomes of this study are consistent with those of numerous previous studies (Pata et al., 2023; Yang et al., 2024; Zhang et al., 2024), which have corroborated the positive impact of biomass energy consumption on the load capacity factor.

The long-term results indicate that the agricultural growth rate has an impact on the load capacity factor. The influence of agricultural growth rate on the load capacity factor is negative and statistically significant at the 1% level. A 1% increase in the agricultural growth rate will reduce the load capacity factor by an average of 2.28%. The estimated results of the study suggest that agricultural production in Vietnam degrades environmental quality, as agricultural production can lead to the depletion of resources (water, land) and deforestation at a rate exceeding the rate of regeneration, particularly in developing countries (Shah et al., 2022). Furthermore, in recent years, agricultural production in Vietnam has expanded rapidly (the total area of agricultural land has increased significantly), coupled with low agricultural labor productivity and high usage of fertilizers and pesticides. This has exerted increasing pressure on water and land resources, thereby generating negative environmental impacts. These consequences pose serious challenges for Vietnam on its path to achieving the Sustainable Development Goals by 2030. Therefore, in recent years, Vietnam has integrated climate change mitigation and adaptation into all agricultural sector plans and strategies, including the development of the Climate Change Action Plan for Agriculture and Rural Development for the 2016–2020 period; the Green Growth Action Plan for Agriculture and Rural Development up to 2020; and the Action Plan for the Implementation of the Paris Agreement on Climate Change for the 2021–2030 period of the Ministry of Agriculture and Rural Development. The state is restructuring the agricultural sector toward shifting from quantity-oriented production to market-based agribusiness and increasing added value at low environmental costs, i.e., achieving economic value with fewer resources (natural resources, labor). However, growth in the agricultural sector has so far paid little attention to sustainability. Therefore, it is imperative for Vietnam to enhance productivity and quality to produce more agricultural products while utilizing fewer resources. The findings of this study indicate that agriculture degrades environmental quality, consistent with the results of several previous studies (Cetin et al., 2022). However, in the short term, at the 5% significance level, the agricultural growth rate has a positive impact on load capacity factor, with a 1% increase in agricultural growth rate leading to an average increase of 0.412% in load capacity factor, consistent with the study by Aziz et al. (2020).

The anticipated negative impact of raw material productivity on load capacity factor has been found to be statistically insignificant in the long term. At the first difference level, raw material productivity has been observed to negatively affect the load capacity factor in the short term. This observation is attributed to the inefficient and wasteful exploitation and utilization of resources in Vietnam compared to global and regional standards. Land resource degradation and depletion are happening in many provinces/cities. The demand for water and marine resources is increasing to meet development requirements. The situation of wasteful land management and use and loss of state assets in the land sector has not been strictly controlled and has not been thoroughly overcome. The recent expansion of the economy, urban development, and increased consumption of resources in Vietnam have exacerbated environmental disasters. These findings are in contrast with previous studies (Awosusi et al., 2024; Zhang et al., 2024), which suggested that resource efficiency enhances the load capacity factor in Malaysia.

In the long term, GDP does not exhibit a significant impact on the load capacity factor. However, in the short term, a 1% increase in GDP is shown to reduce the load capacity factor by 0.064% at a

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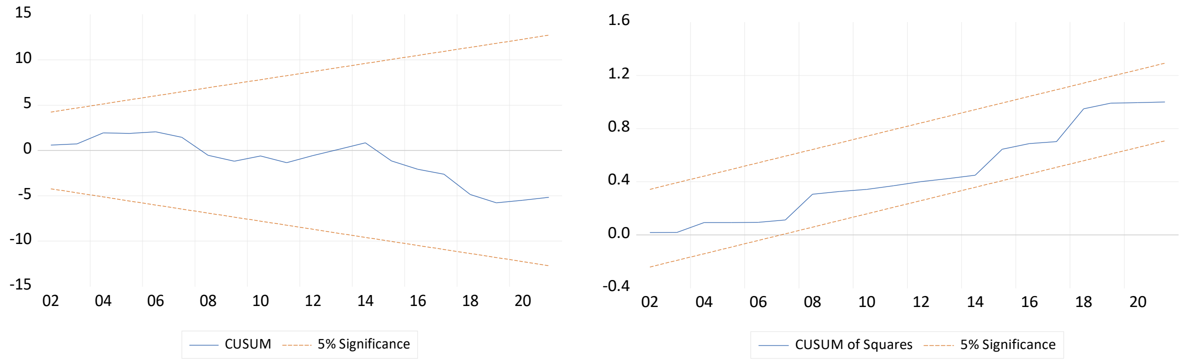

Figure 3. Stability test of the CUSUM and CUSUMSQ models

Table 6. Summary of the model tests

Tests	Statistic	Statistic Value	p-value	Conclusion
Ramsey test	F (1,19)	2.884061	0.1058	The model does not suffer from omitted variable bias
Serial Correlation LM test	Chi-2(1)	0.270877	0.6027	The model does not exhibit autocorrelation
Breusch-Pagan-Godfrey test	Chi-2(12)	11.43176	0.4923	The model has homoscedastic residuals
Jarque-Bera test	–	1.529845	0.46537	The residuals are normally distributed

significance level of 1%. This finding aligns with the results of Huilan et al. (2024), who identified a negative impact of economic growth on the load capacity factor. It is, however, contradictory to the conclusions drawn by Raihan et al. (2023b), who argued for a positive impact of economic growth on the load capacity factor.

The estimated error correction model resulting from the ARDL model yields a value of –0.468467, demonstrating significance at the 1% level (Table 5). Consequently, the hypothesis of a long-term cointegration relationship among agricultural growth, economic growth, biomass energy consumption, resource efficiency, and load capacity factor is substantiated. This is crucial in affirming the reliability of the policy recommendations proposed in this study.

To evaluate the stability and appropriateness of the ARDL estimation model, a series of diagnostic tests were conducted, including assessments for autocorrelation, heteroscedasticity, residual distribution, and functional form. The results of these tests, as tabulated in Table 6, demonstrate that the model is not impacted by non-normal distribution of residuals, heteroscedasticity, autocorrelation, or omitted variable bias. Consequently, the estimation results are considered reliable for deriving policy implications.

Figure 3 illustrates the stability of the CUSUM and CUSUMQ regression coefficients. The analysis reveals that both the CUSUM and CUSUMQ statistics remain within the confidence interval at the 5% significance level, indicating that the model's residuals are stable. Consequently, the model is deemed appropriate for analytical purposes.

Table 7 presents the results of the Granger causality test. However, the analysis is confined to variables demonstrating a long-term relationship, as detailed in Table 5.

Table 7. Granger causality test

Null Hypothesis	F-Statistic	p-value
∆LnAGR does not affect ∆LnLCF	15.1664	0.0005
∆LnLCF does not affect ∆LnAGR	0.84171	0.3658
∆LnBIO does not affect ∆LnLCF	5.86383	0.0213
∆LnLCF does not affect ∆LnBIO	3.61696	0.0662
∆LnBIO does not affect ∆LnAGR	1.34727	0.2543
∆LnAGR does not affect ∆LnBIO	0.85066	0.3633

Table 7 indicates a unidirectional Granger causality running from agriculture growth rate to load capacity factor and a bidirectional Granger causality between biomass energy and load capacity factor. It can be inferred that there is a causal relationship between biomass energy and the load capacity coefficient, which aligns with the conclusions drawn in various prior research studies (Pata et al., 2023).

CONCLUSION

This study examines the influence of value-added agriculture, biomass energy consumption, economic growth rate, and raw material productivity on Vietnam's load capacity factor during the period from 1986 to 2021. Employing the Autoregressive Distributed Lag methodology, the paper analyzes long-term relationships and examines the Granger causality among the variables within the model. The findings revealed a substantial long-term relationship between biomass energy consumption, value-added agriculture, and the load capacity factor. Specifically, biomass energy consumption exhibited a positive impact, while value-added agriculture negatively impacted the load capacity factor. Notably, raw material productivity and economic growth were found to be insignificant in relation to the load capacity factor. Furthermore, the study's results also highlighted the Granger causality effect of the load capacity factor on biomass energy consumption.

The findings of this study carry significant policy implications for Vietnam, particularly in the following areas. Biomass energy contributes to enhancing the load capacity factor. To promote energy security and ecological sustainability, it is imperative for Vietnam to prioritize raising public awareness about the positive effects of biomass energy in addressing ecological degradation. Additionally, the establishment and enhancement of specific legal standards are crucial to ensure the sustainable production and consumption of biomass energy. At the state level, it is necessary to have a specific strategy: raising funds from state, private, and international sources to research, deploy, and develop biomass energy; study the mechanism of socialized investment in the transfer system to develop energy research projects. Concurrently, the government should implement training programs tailored to the workforce within the biomass energy sector. Furthermore, considering the typically high costs associated with biomass energy, the government should incentivize its adoption in the industrial sector and households through preferential policies, support for innovation, and improvements in conversion efficiency, while also promoting sustainable practices.

AUTHOR CONTRIBUTIONS

Conceptualization: Phuong Vo Hang Hoang.
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