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THE DYNAMIC INFLUENCE OF INNOVATION AND RENEWABLE ENERGY CONSUMPTION ON SUSTAINABLE DEVELOPMENT: AN EVALUATION OF VIETNAM

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ABSTRACT

At the COP26, Prime Minister Pham Minh Chinh stressed the role of climate change and environmental management in economic growth. Vietnam has committed to a clean energy transition, phasing out coal, and achieving net-zero CO2 emissions by 2050, demonstrating its efforts to combat climate change. This paper aimed to explore the relationship between the change of CO2 emissions and factors including renewable energy consumption, population growth rate, GDP per capita, and innovative advances by using the ARDL model covering periods from 1990 to 2021. The results indicated that long-term increases in renewable energy and population growth can reduce CO2 emissions. However, a positive relationship is found between economic growth and CO2 emissions within the same period observed. Whereas innovation was not a determinant of CO2 emissions in the long run. In the shorter term, lags of renewable energy can lead to increased CO2 emissions while lags of innovation and economic growth exhibited a negative impact on emissions. Meanwhile, population growth's lags have no significant effect on CO2 emissions. Based on these research findings, this paper suggested some comments on the transition to consumption of clean and renewable energy, hopefully achieving net zero by 2050.

Keywords: *CO2 emissions, innovation, renewable energy, sustainable development, population growth*

1. INTRODUCTION

The expansion of commercial activities has spurred economic growth but has also resulted in environmental disruption, including global warming, natural resource depletion, and increased pollution (Pan, et al., 2022). A report by the United Nations Environment Program in 2022 found that failure of companies to integrate sustainable development practices into their operations could lead to a yearly rise of 5% in carbon emissions, ultimately significantly affecting the climate. Recognizing the urgency of sustainable development, as a developing country with a rapidly growing economy, Vietnam faces significant environmental challenges such as deforestation, biodiversity loss, and urbanization, threatening its long-term sustainability.

The concept of "green factors" encompassing renewable energy use, waste management, and sustainable agriculture, holds promise in mitigating environmental degradation while fostering economic growth and social welfare. However, the dynamic influence of green factors on sustainable development in Vietnam remains underexplored, prompting this study. By investigating this relationship, the thesis aims to inform policymakers, researchers, and practitioners in environmental economics amid Vietnam's commitment to environmental sustainability.

Framed within Vietnam's context and utilizing data from 1990 to 2021 sourced from reputable organizations, the study examines the impact of renewable energy consumption, population growth rate, GDP per capita, and innovative advances on CO2 emissions. This paper uses the Autoregressive Distributed Lag (ARDL) model to study the link between CO2 emissions and green factors. The ARDL model is chosen for its ability to estimate both short-term and long-term effects, handle variables of different integration orders, and provide reliable results even with a small sample size (Moslehpour, et al, 2023). By utilizing the ARDL model, this study aims to provide a comprehensive understanding of the dynamics between CO2 emissions and green factors in Vietnam. The insights derived from this analysis will be instrumental in informing policy decisions and strategies aimed at achieving sustainable development and net-zero emissions by 2050.

This paper consists of: Introduction, Literature Review, Research Methodology, Results and Discussions, Conclusions and Suggestions, and References. Through this comprehensive approach, the study endeavors to contribute to the understanding of environmental economics and sustainable development in Vietnam, with potential implications for policy and practice.

Influence of renewable energy consumption on CO2 emissions

Vietnam, similar to other developing nations, confronts the complex task of balancing its increasing energy needs with the imperative of environmental preservation and reducing dependence on fossil fuels according to Nguyen, et al. (2020). In this regard, renewable energy sources have emerged as a viable and promising solution.

Dawn Stover (2018) provides a definition of renewable energy as energy derived from sources that are continuously available and considered infinite. The concept of "infinite" can be understood in two ways: first, as energy that is naturally abundant and cannot be depleted, and second, as energy that replenishes itself within a short period of time. Examples of globally recognized renewable energy resources include hydropower, solar power, wind power, wave power, geothermal power, waste energy from landfills and incineration, biomass, and liquid biofuels. Kele and Bilgen further emphasize that achieving a sustainable energy supply requires the utilization of renewable resources that are limitless, do not harm the environment, ensure long-term economic efficiency, and meet the needs of communities.

A thorough research carried out by Dong, et al. in 2020 suggested that renewable energy has a negative impact on CO2 emissions. In 2020, Hayat, et al. share a similar conclusion that the consumption of renewable energy has a negative influence on the emission of CO2, after looking into data of 192 countries. Another research conducted by Szetela, et al. in 2022 observed statistics in a 15-year period also pointed out that 1 percentage point increase in renewable energy consumption causes a 1.25% decrease in CO2 emissions per capita.

Influence of population growth on CO2 emissions

The relationship between population growth and CO2 emissions has been a subject of considerable interest and debate in the field of environmental studies. As the global population continues to expand rapidly, it is crucial to understand the impact of this growth on the emission of CO2.

The impact of population change on environmental stress was posited by Holdren and Ehrlich (1974) in the form of an equation relating environmental impact to the production of population size, affluence, and environmental impact per unit of economic activity known as “IPAT”. The equation initiated from much earlier ideas, demonstrates that the population size has a positive relationship with the emission of CO2. Shi (2003) also concluded a direct positive relationship between growth in population and CO2 emissions in 93 countries over a 21-year period starting from 1975.

In more recent years, the relationship between CO2 emissions and population growth has been further examined and elucidated through a range of literature from diverse backgrounds. One notable study conducted by Inmaculada, et al. in 2007 shed light on this connection, emphasizing that an upsurge in population directly correlates with an increase in the volume of CO2 emissions in European Union (EU) countries. Furthermore, the research findings indicated that CO2 emissions have been expanding at a faster rate than population growth itself, which means the CO2 emissions per capita have decreased. A research conducted by Zhang, et al. (2023) in China also witnessed a similar trend. This relationship was also found to be more pronounced in developing countries compared to developed nations. On the other hand, looking into a poorer country as Nigeria (The Guardian, 2018), a positive relationship between CO2 emission and population growth was also found by Lawal, et al. in 2019.

Influence of economic growth on CO2 emissions

The relationship between economic growth and CO2 emissions has been mentioned in some previous studies. For the case of developing countries, the study of Aye and Edoja (2017) which applied dynamic panel threshold framework found out that economic growth has a negative impact on CO2 emission in the low-income nations but positive in the middle-income nations. Another research by Acheampong (2018) applied panel vector autoregression (PVAR) and system-generalised method of moment (System GMM) for 116 countries over the period of 1990-2014 to examine the dynamic causal relationship between economic growth and carbon emissions. This concluded that economic growth negatively affects CO2 emissions at global level. The explanation for two-direction causality of economic growth on carbon emissions has been empirically estimated in the paper of Dauda, et al (2019). In this study, the authors used panel fully modified ordinary least square (FMOLS) and panel dynamic ordinary least square (DOLS) to estimate the impacts of innovation and economic growth on CO2 emissions for 18 developed and developing countries from 1990 to 2016. The results suggested that economic growth only helped reduce CO2 emissions in G6 nations, while major manufacturing countries faced an increase of carbon emissions as their economy expanded.

For the case of Vietnam, recent studies have suggested a positive relationship between economic growth and CO2 emissions. The study of Le and Ngo (2023) employed Quantile on Quantile Regression and Granger Causality in different quantiles and indicated that Economic growth increases CO2 emission in Vietnam in the period 1995 to 2020. Later research by Raihan (2023) and Bui, et al (2023) using ARDL model also indicated that economic growth worsens environmental degradation by increasing CO2 emissions.

Influence of innovation on CO2 emissions

Innovation, especially in green technology, has a crucial role in achieving sustainable development. It is increasingly acknowledged as a key driver in the reduction of CO2 emissions and the promotion of environmental sustainability.

A thorough review of the literature conducted by Zupancic highlights the interconnectedness of resilience, sustainability, and innovation. The study suggests that innovation serves as a pathway to achieving both resilience and sustainability. Resilience ensures the continuity of system functions in the face of shocks and stresses, while sustainability ensures the overall effectiveness of the system. In the context of corporate sustainability, Oliveira, et al. found that earlier research, conducted at the beginning of the previous decade, primarily focused on the adoption of corporate sustainability. However, more recent studies have shifted their focus towards exploring new approaches and methodologies for its implementation.

The relationship between innovation and CO2 emissions is complex. A study conducted by Yu, et al. found that innovative activities can lead to increased environmental degradation, based on data from 52 countries between 1990 and 2014. However, the study also revealed that countries with advanced financial development tend to cause less environmental damage through their innovative activities. On the other hand, green technology innovation has been identified as a means to improve carbon emission efficiency. Dong, et al. discovered that economic development and urbanization play a mediating role in the relationship between green technology innovation and carbon emission efficiency. Essentially, green technology innovation can indirectly influence carbon emission efficiency by affecting economic development and urbanization.

Vietnam has made significant strides in its pursuit of sustainable development, with a particular focus on green growth and resilience. To successfully achieve its climate targets, the country must establish a strong climate governance system, implement streamlined policies, enhance planning and budgeting processes, and secure the necessary climate finance for transformative actions. In summary, innovation, particularly in green technology, plays a crucial role in reducing CO2 emissions and advancing sustainable development. However, the impact of innovation on CO2 emissions can vary depending on factors such as the level of financial development and the specific circumstances of each country. Further research is needed to gain a deeper understanding of these dynamics and to inform policymaking accordingly.

2. RESEARCH METHOD

Vietnam's annual data in this paper spans from 1990 to 2021. The data were collected from World Development Indicators of World Bank and IP Vietnam. CO2 emissions per capita is chosen as the dependent variable, while renewable energy consumption, population growth rate, economic growth, and innovation are the independent variables.

Table 1. Data Description

Abbreviation	**Variable**	**Source**	**Impact on dependent variable**
CO_2	Negative impact on the environment (CO_2 emissions per capita in metric ton)	WB	Dependent variable
PG	Population growth rate (%)	OECD	+
REC	Renewable energy consumption (% of total energy output)	WB	-
GDPC	GDP per capita (PPP in current USD)	WB	-
INN	Innovation (number of accepted patents)	IP Vietnam	+/-

From the models proposed by Chindo (2018), Pham, et al (2023), and Moslehpour, et al (2023), this study suggested an empirical model of the relationship between sustainable development and green factors as follows:

$$lnCO2_t = \beta_0 + \beta_2 REC_t + \beta_3 INNt + \beta_4 PG_t + \beta_5 lnGDPC_t + u_t$$

Where:
Subscript t denotes time index
a) CO_2: CO_2 emissions, serving as a measurement for negative impact on the environment in the study. The lower CO_2 the better quality of sustainable development.
b) PG: population growth rate.
c) REC: Renewable energy consumption.
d) GDPC: GDP per capita, serving as measurement for economic growth
e) INN: Innovation

To determine the regression model for this paper, the authors carried out two tests: Stationarity test and Bounds test for cointegration.

Stationarity test
To determine an appropriate model for the study, Augmented Dickey-Fuller unit root test (ADF; 1981) is used to check for the stationarity of variables. The hypothesis is given as below:
H0: The data is non-stationary (presence of unit root)
H1: The data is stationary

Table 2. Augmented Dickey-Fuller Unit Root Test Results

	Level		First difference		
Variables	**Constant & Trend**	**Constant**	**Constant & Trend**	**Constant**	**Interpretation**
lnCO2	-2.643	-0.453	-4.565***	-4.652 ***	I(1)
REC	-3.190	-0.609	-4.942***	-4.980***	I(1)
INN	1.944	3.075**	—	—	I(0)
PG	-3.067	-2.957**	—	—	I(0)
lnGDPC	-3.243*	-1.340	-3.355*	-3.205**	I(1)

The findings indicate that $lnCO_2$, REC, and lnGDPC are stationary at first difference while INN and PG are stationary at level. In the situation where the model includes a mixture of I(0) and I(1) variables, a suitable approach for estimation is the Autoregressive Distributed Lags model (ARDL) as suggested by Pesaran, et al. (2001).

Optimum lag length to be used
Before testing the cointegration relationship among the variables, multiple criteria are applied to identify the optimal lag length to be used. Lag 4 is chosen as the most appropriate one by all criteria.

Table 3. Optimum Lag Length Results

Lag	LogL	LR	FPE	AIC	HQIC	SBIC
0	-225.577		18.0033	17.0798	17.1511	17.3197
1	-41.0569	369.04	.000138	5.26347	5.69161	6.70329
2	-4.62825	72.857	.000073	4.41691	5.20182	7.05657
3	33.9714	77.199	.000051	3.40953	4.55121	7.24904
4	116.591	165.24*	4.0e-06*	-0.858621*	.639847*	4.18074*

Note: LR = sequential modified LR test statistic; FPE = final prediction error; AIC = Akaike information criterion; HQIC = Hannan–Quinn information criterion; SBIC = Schwarz information criterion; LogL = log likelihood; LR = likelihood ratio; * indicates the lag suggested by each criterion.

Bounds test for cointegration

After having identified the optimal lag length, Bounds test is carried out to check for Cointegration. According to this test, if the value of F statistic is greater than the upper critical bound, there is cointegration between variables. On the other hand, if the value of F statistic is smaller than the lower critical bound, cointegration does not exist in the long term. In case F-statistic is between the lower and upper bounds, we cannot know whether cointegration exists or not. The hypothesis for this test is given as below:

H0: There exists cointegration

H1: There is no cointegration

Table 4. Bounds Test Results

Test Statistics	**Value**	**Significant level**	**I(0)**	**I(1)**
F-statistic	14.931	10%	2.45	3.52
		5%	2.86	4.01
		1%	3.74	5.06
t-statistic	-6.144	10%	-2.57	-3.66
		5%	-2.86	-3.99
		1%	-3.43	-4.60

As shown in Table 4, F statistic (14.931) is greater than the value of the upper bound of the test (3.52, 4.01, 4.49, 5.06)) at 90%, 95%, and 99% confidence level respectively. This result is confirmed by the bound t-test where t statistic (-6.144) is higher than the upper bound of the test (-3.66, -3.99, -4.26, -4.60) at 90%, 95%, and 99% confidence level respectively. We, therefore, can conclude that there is a long-term relationship between dependent and independent variables. Thus, both short-run and long-run relationships shall be analysed in this study using Autoregressive Distributed Lags Model (ARDL) and Error Correction Model (ECM).

3. RESULTS AND DISCUSSIONS

Since a cointegration relationship exists between dependent and independent variables, the long-run model was estimated with lnCO2 is dependent variable.

Table 5. Long-run Results from the ARDL Estimation

Regressors	**Coefficients**	**T-ratio**	**p-value**
REC	-0.0096657	-2.35*	0.100
INN	0.0000445	1.05	0.371
PG	-0.0796587	-2.82*	0.066
lnGDPC	0.8228834	8.59***	0.003

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The results showed that renewable energy has a negative impact on CO2 emissions per capita. For 1% increase of REC, given other variables remain the same, CO2 decreases by 0.96%. Population growth has negative impact on CO2 emissions, 1% increase of PG leads to 7.96% decrease of CO2 emissions per capita. While economic growth exhibits a positive relationship with CO2 emissions per capita. For 1% increase of GDPC, CO2 also increases by 0.82%. Innovation, with a positive coefficient, is the only variable that is insignificant, which suggests that innovation was not responsible for an increase in CO2 emissions in the long run.

In general, the long-run estimation showed that renewable energy consumption is one of the main determinants of CO2 emissions reduction in Vietnam. The negative relationship between renewable energy consumption and CO2 emissions is supported by Dong, et al. (2020). Unlike finite fossil fuels, renewable energy derives from sustainable and naturally replenished resources, thereby circumventing the depletion of non-renewable reserves and associated CO2 emissions. Some renewable energy sources, such as biomass energy, offer opportunities for carbon sequestration, thus contributing to a net reduction in CO2 levels. The imperative shift towards renewable energy is indispensable for addressing climate change challenges and fostering sustainable development on a global scale.

In addition, population growth also negatively affects CO2 emissions per capita. This result is supported by Inmaculada, et al. in 2007 and Zhang, et al. in 2023. This phenomenon is found to be attributed to the gap between the accelerating rate of population growth and total CO2 emission growth. Since the population increases at a faster pace, the marginal increase in CO2 emission per capita is much slower, leading to a decrease in the trend of the figures. It is possible that as population increases together with the expansion of renewable energy consumption led to the slow increase of total CO2 emissions. This results in lowering CO2 per capita, which is calculated by taking total CO2 emissions divided by total population.

For the coefficient of lnGDPC, which is positive. This result has been proved by previous research (Aye and Edoja, 2017; Dauda, et al, 2019; Nguyen, 2022; Raihan, 2023; Bui, et al, 2023) as mentioned in literature review. Vietnam, like other developing economies, is a place where multinational companies established their factories, "a manufacturing hub of commodities for export to the rest of the world" as stated by Dauda, et al (2019). The manufacturing process requires a large amount of fossil fuel energy, a major contributor to CO2 emissions. In addition, several costly projects with carbon capture and storage (CCS) technology for manufacturing in the past might delay the transition to cleaner energy sources. The authors presume some causes of the insignificant impact of innovation on CO2 emissions in the long run. This might be due to the lack of patents serving sustainable development in Vietnam. Another plausible reason is that these innovations are not effective due to lack of modern technology or financial budget.

Table 6. Short-run Results from the ARDL Estimation

Regressors	Coefficients	T-ratio	p-value
ΔREC	0.0136343	0.184	0.184
ΔRECt-1	0.0246609	0.067*	0.067
ΔRECt-2	0.0418263	0.029**	0.029
ΔRECt-3	0.0330228	0.015**	0.015
ΔINN	0.0000379	0.300	0.781

ΔINNt-1	-0.0002692	-1.380	0.262
ΔINNt-2	-0.0004913	-2.680*	0.075
ΔINNt-3	-0.0003501	-3.160*	0.051
ΔPG	0.5277304	1.920	0.150
ΔPGt-1	0.6122802	1.740	0.181
ΔPGt-2	-0.3732177	-0.800	0.481
ΔLnGDPC	-0.6719284	-0.940	0.416
ΔLnGDPCt-1	-1.3486810	-2.880*	0.064
ΔLnGDPCt-2	-1.6925960	-2.340	0.101
ΔLnGDPCt-3	-2.1789300	-3.370**	0.044
Constant	-15.2136100	-3.850**	0.031

In the short run, while renewable energy consumption’ s impact on CO2 is insignificant, its lags show positive and significant impact. This indicated that the consumption of renewable energy in the past might have caused CO2 emissions to rise in the short run for some reasons. First, CO2 emissions associated with the manufacturing, installation, and maintenance of renewable energy projects. Second, large-scale renewable energy projects require land use resulting in clearing forests for wind farms or hydroelectric reservoirs. These changes could lead to the release of carbon stored in vegetation or soil and temporarily increase CO2 emissions.

While innovation showed no significant on CO2 emissions, its lags had a negative and significant influence on CO2 emissions in the short run. Possibly, it took time for innovation to be effective in reducing emissions yet the effect is small.

Population growth and its lags have positive effects on CO2 emissions, yet not significant. In the short run, population growth might lead to the increase of fossil fuel usage thus increasing CO2 emissions. Only the first and third lag of economic growth exhibited negative and significant impact on emissions.

4. CONCLUSIONS AND SUGGESTIONS

The study's outcomes determine the causal nexus between renewable energy, population growth rate, GDP per capita, innovation and CO2 emissions changes in Vietnam from 1990 to 2021. The relationship among these green factors is a complex web that makes a foundation for developing the sustainability of Vietnam during the industrialization and modernization timescales. By understanding the link between green factors and CO2 emissions and implementing key policies to leverage green initiatives, Vietnam can position itself competitively on the global stage and enhance carbon emission efficiency.

Vietnam, in its pursuit of achieving net zero CO2 emissions by 2050, should consider a multi-pronged approach. For long-term development, Vietnam should prioritize the implementation of policies that promote the adoption of renewable energy sources, such as solar, wind, and hydroelectric power, while gradually phasing out fossil fuel dependency. This not only involves the construction of more renewable energy facilities but also the provision of incentives for businesses and households to switch to renewable energy. Implementing tax incentives and subsidies is essential to encourage domestic and foreign businesses to invest in renewable energy projects or adopt energy-efficient technologies. By applying the Feed-in Tariff scheme to support renewable energy projects, Vietnam can drive the increase of renewable energy supply and consumption, thus mitigating environmental problems. However, the mechanism should encourage debate among project developers and should be "market-oriented". Furthermore, competitive auctions have proven to be very successful in attracting investors and are currently a trend around the world. Vietnam, therefore, can consider maintaining both the FiT electricity price mechanism for small-scale projects and the auction form for large-scale projects. However, the relationship between economic growth and CO2 emissions cannot be ignored. As the economy grows, so does the potential for increased emissions. Therefore, it is crucial for Vietnam to strive for sustainable economic growth. This could involve the implementation of policies that promote green industries and practices, while discouraging pollution and waste. Innovation, although not a determinant of CO2 emissions in the long run, can play a pivotal role in reducing emissions. By fostering innovation in clean technologies and energy efficiency, Vietnam can make strides in various sectors towards reducing emissions.

The effects of renewable energy, innovation, and economic growth on CO2 emissions can vary in the short term due to time lags. Therefore, these time lags should be taken into account when planning and implementing policies. While population growth can help reduce emissions in the long run, its short-term effects are less clear. Therefore, careful management of population growth is necessary, which could involve promoting family planning and sustainable urban development. Achieving net zero emissions is a complex task that requires a comprehensive, multi-faceted approach. It is also important to regularly review and adjust strategies as new data and technologies become available. This will ensure that Vietnam is on the right path towards achieving its goal of net zero emissions by 2050.

The study has several limitations, including the use of only four independent variables in the research model. Renewable energy, population growth, GDP, innovation as independent variables and CO2 emissions as a dependent variable. Outside of this research model, other variables such as FDI, trade, natural resources depletion might explain the change of CO2 emissions. Furthermore, the research is specifically tailored to the circumstances in Vietnam, hence its conclusions are only applicable within this context.

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