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Linking among economic growth, technology innovation, carbon dioxide emissions in Vietnam: evidence from three stage least squares models

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ABSTRACT

To accomplish the goal of net emissions to 'zero' by 2050 while maintaining growth in Vietnam, interrelationship among technological innovation (TI), growth and emissions need to be considered. The goal of this research is to evaluate the bidirectional causality linkages among TI, growth and CO_2 emissions (CO_2E) in Vietnam over the period of 1990–2021 by using the simultaneous equation model with the three-stage least squares models. Empirical results show the existence of bidirectional causality among growth, CO_2 emissions and TI. Specifically, growth positively influence on carbon emissions, and CO_2 emissions affect on growth positively. Furthermore, innovation positively influences on growth, while growth positively impact on innovation. There is a negative link among innovation and carbon emissions. Implying that innovation negatively effect on CO_2 emissions and carbon emissions has a negative influence on innovation. Findings indicate that growth contributes to environmental pollution in Vietnam, and technology innovation is an important factor for promoting economic growth and protecting the environment. Therefore, policymakers should encourage technology innovation for the advancement of clean energy, and apply advanced techniques in production to save fuel, contribute to protect the environment by reducing emissions.

IMPACT STATEMENT

The results of this research have considerable policy implications for Vietnam with respect to innovations, growth, and environmental quality.

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SUBJECTS
Sustainable Development; Environmental Economics; Economics

1. Introduction

Global economies, including Vietnam, are aiming for sustainable development, reducing emissions by half by 2030 and achieving zero emissions by 2050, while ensuring growth. This can be done through applying technological innovation (TI) in production, and enhancing the use of clean technology. According to Stocker et al. (2013), carbon emissions is the main cause of greenhouse gas emissions globally. The research also found that 76.7% of greenhouse gas emissions caused by carbon emissions are mainly from developing nations in the world. Hope (2006) argues that although the change of climate may initially have some positive effects on many developed countries, in the long run, it will harm the environment. According to Grossman and Krueger (1995), growth pollutes the environment in the early stages, then improves as the nations reaches a certain level of income, as the adoption of better technology can reduce environmental degradation. It is necessary to encourage technology innovation to ensure energy efficiency and environmental sustainability while maintaining growth.

Many studies indicated that higher growth through industrial activities lead to environmental pollution (X. Chen et al., 2023; Jiang & Liu, 2023; Raihan, 2023). However, others show the opposite outcomes (Mughal et al., 2022; Zhang, 2021). A lot of research showed that CO_2 emissions (CO_2E) stimulate economic

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growth (Iqbal et al., 2023; Olubusoye & Musa, 2020). On the other hand, some researches have explored that carbon emissions has a negative impact on economic expansion (Abdouli & Hammami, 2020; Abdouli & Omri, 2021; F. Sharif & Tauqir, 2021). Also, some works suggested that TI is an vital driver for economic development (Fan & Hossain, 2018; Manigandan et al., 2023). Meanwhile, others showed the opposite (Ayvaz & Över, 2023; Mtar & Belazreg, 2023). Many studies explored that technology innovation may increase environmental quality by lessening emissions (Rafique et al., 2020; Saliba et al., 2022; Shahbaz et al., 2020). On the contrary, Demircan Çakar et al. (2021) argued that innovation effect on CO_2 emissions positively. Several studies found the bidirectional relation among growth, innovation and CO_2 emission (Khan et al., 2023); and a bidirectional relation among growth and innovation (Mtar & Belazreg, 2023); bidirectional relation among growth and carbon emissions (Chang et al., 2023). Previous studies show that the interrelationship between innovation, growth and emissions is likely to exist. There have been no empirical studies investigating this relationship in Vietnam, and that is the gap for this study.

After doi moi, Vietnam's economic growth has changed significantly, namely the value of GDP per capita increased from 96.719 US $ in 1990 to 3756.489 US $ in 2021 (World Development Indicators [WDI], 2023), along with an increase in CO_2 emissions from 0.318 tons per capita in 1990 to 3.344 tons per capita in 2021. According to Raihan (2023) the consumption of energy and economic growth are responsible for emissions in Vietnam, the study suggest adoption of clean technology is necessary to lessen emissions, while ensuring growth. How to lessen emissions while maintaining economic growth is a challenge for policymakers in Vietnam. As suggested by Ren et al. (2021) and Khan et al. (2023) use a simultaneous equation model (SEM), namely applying three-stage least squares equation models (3SLS) to consider the interrelationship among growth, innovation and emissions because this method is considered more effective than other approach. Findings indicate that there exists a two-way relationship among growth, innovation and CO_2 emissions in Vietnam. Specifically, economic growth positively affects on CO_2 emission, and carbon emissions impact on growth positively. Furthermore, technology innovation has a positive influence on growth, and economic expansion positively influence on innovation. Moreover, there is a negative link among innovation and emissions. Empirical results support the view that innovation is an important factor in promoting growth and lessening CO_2E.

This research supplies to existing literature in some ways. Most of previous works assessed the one-way effect among variables. For instance, many studies have examined either the influence of innovation on CO_2E or the influence of CO_2 emissions on innovation. Some researches have investigated either the effect of technology innovation on growth or the influence of growth on technology innovation. Likewise, most studies examined either the effect of growth on emissions or the effect of CO_2 emissions on growth. As suggested by Khan et al. (2023) showed that an interrelationship exists between innovation, growth and CO_2 emissions. Our research will accrete more proofs to the literature in Vietnam, by considering this interrelationship in Vietnam. From the results, some suggestions will be given to policy makers.

The rest of the research follows the following structure: the literature review will be shown in Section 2, the methodology and data description will be shown in Section 3, Section 4 is about empirical outcomes and discussions, Section 5 represents conclusion.

2. Literature review

2.1. Studies on the linking among innovation and emissions

Many researches have been conducted investigating the linkages between innovation and environmental pollution. Some studies have found that innovation slows down environmental degradation (Ahmed et al., 2022; Amin et al., 2023; X. Chen et al., 2023; Jena et al., 2022; Jin et al., 2022; Thi & Do, 2024; Razzaq et al., 2021), while others show the opposite outcomes (Demircan Çakar et al., 2021; Khan et al., 2022; Raghutla & Chittedi, 2023). Additionally, some studies suggest that renewable energy (RE) and foreign direct investment (FDI) inflows help improve environment quality (Karaaslan & Çamkaya, 2022; Samour et al., 2022), while growth and global tourism stimulate environmental degradation (Kumail et al., 2020; Nawaz et al., 2020; Raihan, 2023; Raihan et al., 2022).

Furthermore, some articles investigated the response of innovation implementation in the context of increasing the change of climate. For the case of 70 countries, Su and Moaniba (2017) have investigated

the response of innovation to climate change, they show that rising of emissions from gas and liquid fuels allow increase innovations, while increases in emissions from the use of solid fuel and other greenhouse gas emissions make reduce innovations. Besides, Khan et al. (2022) indicated that CO_2 emissions and the growth stimulate innovations while FDI lessen innovations. In contrast, Song et al. (2023) show that air pollution impedes urban innovation. Studies demonstrate the existence of a two-way causal relation among innovation and environmental pollution (Mensah et al., 2019).

In general, many studies have examined either the influence of innovation on CO_2E or the influence of CO_2 emissions on innovation. Our research will supplement to the existing literature on the link among innovation and CO_2 emissions by examining their interrelationship in the case of Vietnam.

Thereby, the following hypothesis is formed:

H_1: There exists a two-way nexus among carbon emissions and innovation.

2.2. Studies on the nexus among innovation and economic development

Many studies investigated the relation among technology innovation and growth, some studies have suggested that TI is a vital driver for economic development (Acheampong et al., 2022; Ahmad et al., 2023; Fan & Hossain, 2018; Thi & Do, 2024). However, some studies argued that TI has not yet promoted economic growth (Mtar & Belazreg, 2023).

Moreover, some research found that growth pressure reduce innovation (Shen et al., 2021; Yu et al., 2023). For examples, Mtar and Belazreg (2023) investigate linkages among innovation, trade, financial development (FD) and growth applying a panel-a vector autoregression (VAR) approach and found that a negative relation among innovation and growth. Yu et al. (2023) indicate that growth pressure negatively affects green technology innovation, using data from 285 cities in China from 2006 to 2018. Shen et al. (2021) found that growth targets negatively influence on innovation in 244 cities of China from 2004 to 2016. Meanwhile, Khan et al. (2023) showed that economic growth increase innovation.

Other research showed the interrelationships among innovation and growth (Akinwale, 2022). Khan et al. (2023) indicated a bidirectional causality among innovation and growth. Akinwale (2022) showed a bidirectional among innovation and growth for 1985–2015 period in South Africa. Maradana et al. (2019) showed a nexus among innovation and growth for 19 European nations from 1989 to 2014. Pradhan et al. (2018) indicated a bidirectional among innovation and growth in 49 European nations from 1961 to 2014.

In general, most studies have investigated either the effect of technology innovation on growth or the influence of economic growth on technology innovation. There exists a two-way nexus among innovation and growth (Khan et al., 2023). Our research will supplement to the existing literature on the nexus among innovation and growth by examining their interrelationship in the case of Vietnam.

In general, the following hypothesis is formulated:

H_2: There is a bidirectional relation among technology innovation and economic growth.

2.3. Studies on the link among economic development and CO_2 emissions

Many works have analyzed the link among economic development and environmental pollution. Some studies show that CO_2 emissions promote the economic growth (Iqbal et al., 2023; İnal et al., 2022; Olubusoye & Musa, 2020). On the other hand, some researches have found that CO_2 emissions has a negative influence on economic expansion (Abdouli & Hammami, 2020; Abdouli & Omri, 2021; F. Sharif & Tauqir, 2021).

Besides, others explored that economic growth harms the environment by increasing CO_2E (Bhuiyan et al., 2023; Mamkhezri & Khezri, 2023; Raghutla & Chittedi, 2023; Raghutla & Kolati, 2023; Raihan & Tuspekova, 2023). Meanwhile, some studies show that GDP growth curbs emissions (Mughal et al., 2022; Zhang, 2021). Some studies show a two-way causal relationship among economic growth and CO_2 emissions (Naseem et al., 2023; You et al., 2022).

In general, many studies examined either the effect of growth on emissions or the effect of CO_2 emissions on growth. Therefore, we will put on more proofs to existing literature on interrelationship among emissions and growth in the case of Vietnam.

Thereby, the following hypothesis is formed:

H_3: There is a bidirectional relation among carbon emission and growth.

3. Methodology

3.1. Data and variables

This article analyzes the linkages among TI, economic growth and CO_2 emissions in Vietnam from 1990 to 2021. The data of all variables have collected from Our World in Data, International Monetary Fund and World Bank by using the 3SLS. Table 1 presents details of variables

3.2. Theoretical framework and methodology

Ehrlich and Holdren (1971) first proposed the IPAT (Impact by Population, Affluence, and Technology) model to measure the effect of economic growth on the environment degradation. Dietz and Rosa (1994) reconstructed the IPAT model in a stochastic form called the STIRPAT model to test the hypotheses more rigorously. The general STIRPAT model is represented as follows:

$$I_t = a \cdot P_t^b \cdot A_t^c \cdot T_t^d \cdot \varepsilon_t, \quad (1)$$

where I, P, A and T represent environmental degradation, the size of population, national influence and the progress of technology, respectively. a is the intercept term, b, c and d show elasticities of the environmental influence on P, A and T, respectively. ε_t is a random error term, and subscript t indicate the time dimension of model.

To evaluate the link among innovation, growth and CO_2 emissions in Vietnam, authors extend the STIRPAT model according to the STIRPAT theoretical framework. More specifically, based on the original model, labor force, the capital stock, FDI inflows, RE consumption, tourism, corruption and FD are included in the new expansion models.

3.2.1. Economic growth model

Achieving the goal of sustainable, zero-emissions development by 2050 requires that investment factors for economic development such as capital, labor force and energy be combined and used in an eco-friendly manner environment. Economic expansion requires higher energy consumption, which has a negative impact on the environment, TI can help promote growth, minimizing harmful influence on the environment. Based on STIRPAT model and inheritance from previous studies (Abdouli & Omri, 2021;

Table 1. Details of variables.

Variables	Symbol	Variables measurement	Data source
Carbon dioxide emissions	CO_2	Annual CO_2 emissions (tons per capita)	(Our World in Data-OWID, 2023)
Gross domestic product	GDP	GDP per capita (current US$)	(WDI, 2023)
Technology innovation	TI	Patent applications, residents	(WDI, 2023)
Renewable energy	RE	Renewables (% equivalent primary energy)	(Our World in Data-OWID, 2023)
FDI inflows	FDI	FDI, net inflows (% of GDP)	(WDI, 2023)
Tourism	Tourism	International tourism, number of arrivals	(WDI, 2023)
The capital stock	K	Gross fixed capital formation (constant 2015 US$)	(WDI, 2023)
Labor force	L	Labor force participation rate, total (% of total population ages 15–64)	(WDI, 2023)
Control of corruption	CC	Control of Corruption captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption	(WDI, 2023)
Financial development	FD	Financial development index	(International Monetary Fund, 2023)

WDI, World Development Indicators.

İnal et al., 2022; Khan et al., 2023; Meirun et al., 2021; Mtar & Belazreg, 2023; X. Wang et al., 2023) to fully understand the influence of CO_2E (*I*), TI (*T*), labor (*P*) and other factors (*U*) on the growth (GDP) is built as follows:

$$GDP_t = a_1 \cdot I_t^{b_1} \cdot T_t^{c_1} \cdot P_t^{d_1} \cdot U_t^{e_1} \cdot \varepsilon_{1t}, \tag{2}$$

where a_1 is the intercept term, b_1, c_1, d_1 and e_1 show elasticities of the growth influence on *I*, *T*, *P* and *U*, respectively. $\varepsilon_{1t'}$ is a random error term, and subscript *t* indicate the time dimension of model.

3.2.2. Environmental pollution model

According to Raihan and Tuspekova (2023); Raihan and Voumik (2022); Ren et al. (2021) and W.-Z. Wang et al. (2021) economic expansion and international tourism causes harmful effects on the environment while TI, REC, FDI inflows allows to reduce environmental degradation, based STIRPAT model and the inheritance from previous studies, to fully understand the influence of economic growth (*A*), technology innovation (*T*), labor (*P*) and other factors (*X*) on carbon emissions (*I*) is developed as follows:

$$I_t = a_2 \cdot A_t^{b_2} \cdot T_t^{c_2} \cdot P_t^{d_2} \cdot X_t^{e_2} \cdot \varepsilon_{2t}, \tag{3}$$

where a_2 is the intercept term, b_2, c_2, d_2 and e_2 show elasticities of the environmental influence on *A*, *T*, *P* and *X*, respectively. $\varepsilon_{2t'}$ is a random error term, and subscript *t* indicate the time dimension of model.

3.2.3. Technology innovation model

Ahmad et al. (2023) show that innovation play a vital role for sustainable development, helping economic expansion without harmful effects on the environment. Furthermore, there are many studies investigating the response of innovation to increasing the change of climate and economic growth (Khan et al., 2022; Su & Moaniba, 2017). Based on the inheritance of previous studies (Akinwale, 2022; Dauda et al., 2019; Naseem et al., 2023; A. Sharif et al., 2023), to more fully understand the influence of economic expansion (*A*), CO_2E (*I*) and other factors (*Y*) on innovation (*T*) is built as follows:

$$T_t = a_3 \cdot A_t^{b_3} \cdot I_t^{c_3} \cdot Y_t^{d_3} \cdot \varepsilon_{3t}, \tag{4}$$

where a_3 is the intercept term, b_3, c_3 and d_3 show elasticities of the TI influence on *A*, *I* and *Y*, respectively. $\varepsilon_{3t'}$ is a random error term, and subscript *t* indicate the time dimension of model.

According to the above analytical framework, to comprehensively study the linking among the growth, innovation and CO_2E in Vietnam, based on the STIRPAT model, and the inheritance from previous studies, this study utilizes, labor force, the capital stocks, FDI inflows, the use of RE, tourism, corruption and FD as control variables.

TI, growth, and CO_2 emissions represent three endogenous variables in this paper. To solve concurrency among innovation, growth and emissions (cause of endogeneity), the SEM combined with three-stage least squares is applied. Because this method is considered more effective than two-stage least squares method (3SLS) (Belsley, 1988; Intriligator, 1978). As suggested by Malik (2021) and Gani (2021), a SEM combined with 3SLS, will be used in our study.

The econometric model is presented as follows:

$$GDP_t = \alpha_0 + \alpha_1 CO_{2t} + \alpha_2 TI_t + \alpha_3 FDI_t + \alpha_4 K_t + \alpha_5 L_t + \varepsilon_{1t}, \tag{5}$$

$$CO_{2t} = \beta_0 + \beta_1 GDP_t + \beta_2 TI_t + \beta_3 FDI_t + \beta_4 RE_t + \beta_5 TOURISM_t + \varepsilon_{2t}, \tag{6}$$

$$TI_t = \mu_0 + \mu_1 CO_{2t} + \mu_2 GDP_t + \mu_3 FDI_t + \mu_4 CC_t + \mu_5 FD_t + \varepsilon_{3t}, \tag{7}$$

where CO_2 emission is measured by annual carbon dioxide emissions (tons per capita); GDP is measured by gross domestic product per capita (current US$); TI proxy by the number of patent applications, residents; FDI is measured by foreign direct investment, net inflows (% of GDP); The capital stocks (K) proxy by gross fixed capital formation (constant 2015 US$); Labor force is measured by the rate of labor force participation, total (% of total population ages 15–64); RE is measured by renewables (% equivalent primary energy); Tourism is measured by international tourism (number of arrivals); Control of corruption (CC) is measured by the extent to which public power is exercised for private gain, including both petty and grand forms of corruption; FD is measured by FD index; α_0, β_0 and μ_0 are intercept, α_1, α_2, α_3, α_4, α_5,

β_1, β_2, β_3, β_4, β_5, and μ_1, μ_2, μ_3, μ_4, μ_5 indicate the coefficients, $\epsilon_{1t'}$, $\epsilon_{2t'}$ and $\epsilon_{3t'}$ are errors term, *t* indicates the time dimension.

4. Results and discussions

In this work, we present the outcome of the link among innovation, economic growth and emissions. Variables descriptive statistics outcomes are shown in Table 2, describing characteristics of the variables used in the three-stage least squares equation model (3SLS). There is a difference among the average values of the variables. The variables maximum values such as GDP per capita and the capital (K) are higher than the values of other variables.

We check the data with serial correlation test, Table 3 indicates that no high connection between independent variables utilized in Equations (1)–(3). The correlation coefficient among independent variables is less than 0.5, so the data is reliable and suitable for regression analysis.

Before analyzing time series data, it is necessary to check the (non) stationarity of the data set. if authors apply a nonstationary series for regression, it will lead to the occurrence of pseudo-regression. Therefore, before performing regression analysis, authors need to check the robustness of economic variables. This article use augmented Dickey Fuller test to check the stationarity of data. Table 4 show all variables are stationary at first difference, therefore, it is appropriate to use them for further statistical analysis.

Table 2. Statistical value of variables.

Variables	Mean	Minimum	Maximum	Standard deviation
GDP	1335.378	96.7193	3756.489	1221.11
CO_2	1.370059	0.307592	3.560416	0.9809968
TI	250.4839	22	1021	262.2487
RE	20.28217	12.84675	24.9727	3.399654
FDI	5.485844	2.781323	11.93948	2.219416
Tourism	5434000	1351000	18009000	4421609
K	49538849734	11110952440	110459947208.857	30887499453
L	79.84812	75.863	82.476	1.957135
CC	−0.54632	−0.75666	−0.28578	0.12137
FD	0.322215	0	0.454462	0.101632

Data source: World Bank and International Monetary Fund.

Table 3. Correlations between variables.

	GDP	CO_2	TI	RE	FDI	Tourism	K	L	CC	FD
GDP	1									
CO_2	0.9761	1								
TI	0.1341	0.0905	1							
RE	−0.0782	−0.229	0.2604	1						
FDI	−0.2479	−0.2685	−0.3013	0.1981	1					
Tourism	0.2761	0.2675	−0.0658	−0.4344	−0.1689	1				
K	0.4357	0.3751	0.2351	−0.2514	−0.1467	0.578	1			
L	0.2623	0.1284	0.3249	0.4619	0.2084	−0.1338	0.0456	1		
CC	−0.7496	−0.7228	−0.2194	0.0061	0.1976	−0.3016	−0.3689	−0.084	1	
FD	0.2818	0.2888	0.1769	−0.4019	−0.1981	0.3778	0.4292	0.3035	−0.1649	1

Source: Author's own compilation from data processing using Stata.

Table 4. Test unit root for each variable.

Variables	Level	First difference
GDP	3.538 (1.0000)	−2.960 (0.0388)**
CO_2	1.340 (0.9968)	−4.272 (0.0005)***
TI	−2.676 (0.0782)*	−5.665 (0.0000)***
RE	−2.464 (0.1245)	−5.361 (0.0000)***
FDI	−2.442 (0.1303)	−4.835 (0.0000)***
Tourism	−2.080 (0.2528)	−5.364 (0.0000)***
K	−1.737 (0.4122)	−5.511 (0.0000)***
L	−1.296 (0.6311)	−3.077 (0.0283)**
CC	−2.914 (0.0438)**	−11.453 (0.0000)***
FD	−2.918 (0.0433)**	−6.198 (0.0000)***

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
Source: Author's own compilation from data processing using Stata.

Next, authors proceed the 3SLS approach to consider interrelationships among growth, carbon emissions, and technology innovation. The three corresponding equations (Equations 1–3) are estimated simultaneously.

4.1. Our baseline results from 3SLS estimates

Table 5 indicates the evidence of bidirectional causality among growth and CO_2 emissions, growth and technology innovation, CO_2 emissions and technology innovation. Therefore, H_1, H_2, H_3 hypothesis are accepted.

Specifically, Table 5 reports that CO_2 emissions positively effect on growth at 1% significant level, showing that a 1% rise of emissions allow GDP per capital increase by 1175.065%. This results is the same with the finding of Ren et al. (2021) for China. They explored that CO2 emissions in the steel industry of China influence on growth positively. Similarly, Raihan (2024) have investigated the impact of FDI and CO_2 emissions on economic growth in Vietnam for 1990–2021 period. They found that CO_2E has a positive influence on the growth in Vietnam. This is explained because during this period Vietnam's economy witnessed rapid growth, GDP per capita increased from 96 US dollars in 1990 to 3756 US dollars in 2021. Also, during this period, Vietnam witnessed an increase in CO_2 emissions per capita from about 0.318 tons in 1990 to 3,345 tons in 2021. However, to achieve the goal of sustainable development, Vietnam's emissions must halve by 2030 and reach zero by 2050. To achieve this goal, it requires policies for green growth to be implemented by all levels of government. Moreover, a positive and significant influence of innovation on growth is found at 1% level. The coefficient of innovation variable is 42.519, indicating that GDP per capital increase by 42.519 percent when there is a 1% rise in innovation. This outcome is consistent with empirical study of Meirun et al. (2021) for Singapore. This mean that the number of patent applications help promote growth. Similarly, research result by Thi and Do (2024) also show that innovation is an important factor promoting the economy of countries. This is also understandable because innovation allows the optimization of national resources with a reasonable and modern economic structure, in order to achieve high economic growth rates toward sustainable development. In Vietnam, during this period, innovation activities also increase significantly, which allowed to promote economic growth. Therefore, the Vietnamese government needs to have appropriate policies to promote sustainable growth in the coming time. Furthermore, FDI inflows are found to be a positive and significant correlation with GDP per capita with a coefficient of 51.835. Implying that 1% increase in FDI inflows will increase economic growth by 51.835%. This finding is similar with outcome of Khan et al. (2023) for 35 Belt and Road nations. Besides, Raihan (2024) show that FDI has a positive influence on the growth in Vietnam. During this period, Vietnam also relied on foreign direct investment to promote economic growth, accompanied by an increase in CO_2 emissions. Therefore, in the coming time, Vietnam's economic growth based on scientific and TI is necessary because it allows reduce emissions and toward the goal of sustainable development. Besides, the capital and labour force positively impact on growth but not statistically significant.

The empirical outcomes about Equation (2) illustrate that growth positively influence on CO_2 emissions. These outcomes are consistent with Thi et al. (2023) for 53 countries, Raihan (2023) for Vietnam, Karaaslan and Çamkaya (2022) for Turkey. The findings show the growth reduce environmental quality by upsurging

Table 5. Our baseline results from 3SLS estimates.

Variables	Equation 1: GDP	Equation 2: CO_2	Equation 3: TI
GDP		0.001*** (0.00005)	0.022*** (0.004)
CO_2	1175.063*** (83.818)		−26.457*** (5.270)
TI	42.519*** (8.815)	−0.039*** (0.012)	
RE		−0.002 (0.008)	
FDI	51.835*** (30.871)	−0.048* (0.026)	−1.264* (0.709)
Tourism		−0.002 (0.003)	
K	1.355 (3.712)		
L	6.903 (22.131)		
CC			−0.019 (0.176)
FD			−0.022 (0.063)
Constant	−1791.688 (1685.547)	1.181*** (0.240)	29.708*** (7.589)

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
Source: Author's own compilation from data processing using Stata.

CO_2 emissions. This can be explained because Vietnamese people still depend on non-RE sources for production and economic activities. According to scientists, fossil energy consumption is one of the causes of environmental pollution. Therefore, investing in RE production is necessary for the future. Currently, some provinces in Vietnam are also producing RE like Bac Lieu province, specifically wind energy. In addition, Vietnam is also implementing circular economic development, aiming to reduce the exploitation of raw materials, extend product life cycles, limit waste and minimize negative impacts on the environment. In agriculture, carry out agricultural production with low carbon emissions, and research clean energy production from waste of livestock and farming activities. In the Mekong Delta, the government has a policy to produce 1 million hectares of rice with low carbon output. These will contribute to promoting sustainable growth for the future. Besides, the influence of technology innovation on CO_2 emissions is negative and significant implying that increasing of the number of patent applications enhance the environmental quality (Qin, Su, et al., 2023; Qin, Zhang, et al., 2023; Su et al., 2023). This outcome is consistent with empirical research (Thi & Do, 2024; Thi et al., 2023) for world countries. To achieve the goal of zero emissions by 2050, it is necessary for Vietnam to promote the application of science and technology in production activities. Because TI allows efficient use of energy sources and reduces emissions from production activities, contributing to significantly reducing the demand for energy, fossil fuels and minimizing environmental pollution. Furthermore, the effect of FDI inflows on carbon emissions is found to be negative and significant at 10% level. The coefficient of FDI inflows is −0.048, with 1% increases in FDI inflows lead carbon emissions decrease by 0.048 percent. This result is similar with the finding of Ren et al. (2021) who show that FDI inflows increase environmental quality by mitigating carbon emissions. It is explained that because multinational companies apply advanced technology in production and there is transfer to domestic companies, this is beneficial for the environment. The global tourism and RE sources have a negative influence on carbon emissions. These results show that international travel development and the using of RE allow improve the environmental quality though the influence is not statistically significant. These outcomes are similar with findings of Qin et al. (2022).

The empirical outcomes about Equation (3) show that growth positively effect on technology innovation at 1% level. This outcome is supported by previous researches of Khan et al. (2022) for 181 global nations. However, Thi and Do (2024) showed the opposite result, they pointed out that economic growth inhibits innovation. This may be because innovation-related policies have not been effective. Vietnam, in recent years, the government has paid great attention to innovation activities, encouraging businesses to invest in science and technology, which contributes to promoting innovation in this country. CO_2 emissions have a negative and significant effect on TIs. Findings show that as carbon emissions increase by 1 percent, TIs would reduce by around 26.457%. The similar outcomes were supported by Song et al. (2023) for China. This is explained as CO_2 emissions increase, it will affect the quality of human resources, which reduces innovation. Similarly, Su and Moaniba (2017) stated that carbon emissions from liquid fuel consumptions is negatively related to innovation. However, Thi and Do (2024) show the opposite outcome, they indicate that carbon emissions stimulate innovation. Therefore, in Vietnam, to adapt to climate change, policies related to TI to combat climate change need to be strengthened in the coming time. Regarding the FDI inflows, the effect of FDI inflows on the number of patent applications is negative and significant at 10%. The coefficient estimate is −1.264, showing that the number of patent applications reduce by 1.264% when there is a 1% rise in FDI inflows. Finding is supported by study of Khan et al. (2022). FDI inflows can bring modern technology and thanks to spillover effects, which can promote TIs. However, projects that require intensive technology are limited, so the government needs to have policies to attract technology-intensive projects to promote TI. The impact of CC and financial development have a negative relationship with TI but not statistically significant.

4.2. Discussion

In our attempt to investigate the interrelationships among innovation, growth and CO_2 emissions by employing SEM combined with 3SLS. The findings show a positive interrelationship among growth and CO_2E is supported by finding of Naseem et al. (2023) in BRICS countrie. This positive relationship is considered appropriate because developing economies such as Vietnam are growing rapidly and GDP has also extended significantly in recent decades. Vietnamese businesses also use fossil fuels for production and

business activities. According to scientists, fossil energy use is one of the causes of emissions increasing. Therefore, managers need to pay attention to find alternative sources for future economic development activities. Furthermore, the empirical findings point out that there exists a two-way positive association between growth and innovation is supported by outcomes of Khan et al. (2023) in 35 Belt and Road countries. Economic expansion enhance technology innovation is strengthened by findings of A. Sharif et al. (2023) in ASEAN-6 countries; Khan et al. (2022) in 181 countries. Meanwhile innovation promote growth is reinforced by findings of Razzaq et al. (2023) in 10 countries with top GDP; Ahmad et al. (2023) in China; X. Wang et al. (2023) in China. However, our results are contrary to the finding of Mtar and Belazreg (2023) in European countries, which reported a negative relation among innovation and growth. The positive impact of innovation on growth reflects efficiency for production investment, fuel savings, cost savings, and reasonable technology transfer, and patents bring efficiency in business practice. Moreover, results indicate the existence of the negative interrelationship among innovation and CO_2 emissions. Innovation allow abate carbon emissions is strengthened by outcomes of Dauda et al. (2019); Ahmad et al. (2023); Raihan and Tuspekova (2023); Razzaq et al. (2023); Adebayo et al. (2023). This may be due to the increasing of the number of patents related to environmental protection in Vietnam in recent years. Economic sectors tend to create green technologies to solve the problem of environmental pollution. Therefore, the trend of such patents has increased over the years, which contributes to reducing emissions. Meanwhile, carbon emissions negatively effect on technology innovation is reinforced by findings of Su and Moaniba (2017), who found carbon dioxide emissions from the consumption of solid fuels and other greenhouse gas emissions abate innovation. This suggests that the response of innovation is weak to the increase of CO_2 emissions. This can also be explained because Vietnam is a developing country, technology is not as modern as developed countries. The outcomes from Equation (3) indicate that FDI inflows negatively influence on innovation, which shows in case of Vietnam, technology transfer through investment attraction is not effective due to lack of skilled workers, and inadequate facilities.

5. Conclusion

5.1. Conclusion

This study analyzes interrelation linkages of innovation, growth and carbon emissions in Vietnam for the period of 1990–2021 by the SEM, namely 3SLS models to investigate the bidirectional nexus among them. Augmented Dickey Fuller test is used for checking the stationarity of all variables, the outcomes show the data are suitable for statistical analysis. The empirical results document a complete the bidirectional causality among growth and CO_2 emissions, growth and technology innovation, CO_2 emissions and technology innovation in Vietnam for the 1990–2021 period. There exists a positive and bidirectional causality of carbon emissions and GDP per capita, while the existence of negative and bidirectional causality of CO_2 emissions and technology innovation. Moreover, a positive two-way linkages of innovation and GDP per capital proves that the number of patent applications allow improve GDP per capita and vice versa (Figure 1).

Furthermore, FDI inflows enable economic growth, while its impact on CO_2 emissions and innovation is negative. Besides, RE sources and international tourism have a negative impact on CO_2 emissions but not statistically significant. Likewise, the capital and labour force positively effect on economic growth but not statistically significant.

5.2. Policy implications

Through the findings, the article makes a number of policy recommendations to promote growth in Vietnam along with reducing environmental degradation, contributing to the achievement of the country's sustainable development goals, namely:

First, TI is an important factor for promoting economic growth. Therefore, managers need to have policies to encourage the development of science and technology, attracting technology-intensive projects, and train high-quality human resources.

Second, innovation can improve the environment quality. Therefore, Vietnamese government needs to issue policies to encourage innovation in the future, especially innovation policies related to clean energy.

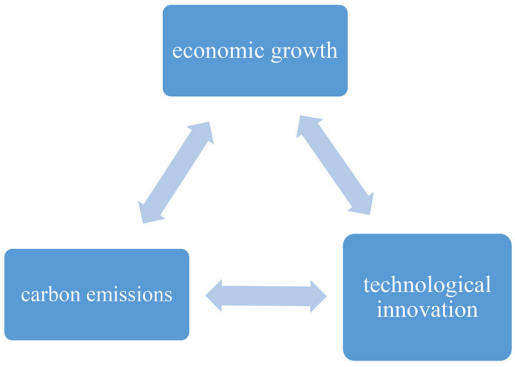

Figure 1. The bidirectional causality between technology innovation, GDP per capital and carbon emissions. Source: Author's own compilation.

Likewise, government needs to invest more capital to support RE projects, financial sources should be used to support the installation of RE sources. Because RE plays a vital role in decreasing climate change by reducing emissions.

Besides, the government should issue policies to encourage businesses to create environmentally friendly products, contributing to green growth in the future. For the goal of sustainable development, toward achieving the goal of zero emissions by 2050, government needs to invest and encourage the use of RE sources in production, living, and eco-friendly tourism, and reduce dependence on fossil energy consumption.

In addition, the authorities should issue policies to encourage the development of forest carbon markets to contribute to goals of reducing net emissions to 'zero' by 2050.

Additionally, FDI inflows enable economic growth, while its impact on CO_2 emissions and innovation is negative. This give us a look that Vietnam should concentrate more on technology transfer which can boost economic growth, minimize harmful effects on the environment, and increase technology transfer from multinational companies to enhance innovation.

5.3. The limitations of study

Although this study has explored empirical results about the bidirectional causality among technology innovation, growth and CO_2 emissions in Vietnam for the 1990–2021 period. This article still has certain limitations. This study only analyzes for Vietnam, the following research can study for more countries and then compare the results. In addition, follow-up research may investigate other factors which might impact on CO_2 emissions, growth and TI such as globalization, natural resources and institutional quality. Finally, further studies can investigate the bidirectional relationship between these variables for other countries and regions.

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