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Dynamic association between technological advancement, green finance, energy efficiency and sustainable development: evidence from Vietnam

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ABSTRACT

GHG emissions growth of Vietnam is highest all over the globe and the carbon intensity of this economy is considered second highest in Asian economies. As the energy intensity level is rising constantly, thereby, the predictions indicate that Vietnam will become highest GHG emission in the region. In order to address the issue, the current article aims to investigate the impact of green finance, technology advancement, energy efficiency, industrialization, and population growth on sustainable development in Vietnamese context. The time chosen for the study is 1991 to 2020. The study has used the Dynamic Auto-regressive Distributed Lags (DARDL) and the Bayesian Auto-regressive Distributed Lags (BARDL) model for data analysis. Findings exposed that green finance, technology advancement, REO, REC, industrialization, and population growth all are positively connected with sustainable development. The study guides the regulators in establishing regulations related to sustainable development through the adoption of green finance, energy, and technology.

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1. Introduction

Sustainable development makes the country's survival possible in a longer run. It is sustainability which helps economies to achieve goals that are made to preserve environment, protect society and enhance economy. Sustainability not only helps in

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establishing a healthy society but also support economy by looking into ways that are also beneficial for environmental stability. It means it reflects on the activities and methods which do not jeopardize the stability and integrity of nature (Ainou et al., 2022; Silvestre & Țîrcă, 2019). Currently, the world is facing several kinds of challenges, amongst them, climate change, injustice, poverty, inequality are most prominent challenges that are also highlighted in SD goals (Bai et al., 2022; Thacker et al., 2019). The Brundtland Report from 1987 serves as the foundation for the existing concept of sustainability. The said concept also reflects the impacts of earlier twentieth-century ideas about forest administration and the environment. Due to the emergence of sustainable development goals, the focus has switched to future generations' economic progress, social advancement, and environmental sustainability for the upcoming generation. According to the UN 2030 Sustainability Agenda, the three pillars of sustainable development are the environment, economy, and society. Each pillar of sustainable development provides support to another (Chien, 2022a; Sharpley, 2020).

Greenhouse gas (GHG) emission is a big challenge to attain sustainable development as it degrades the environment and, thereby, destroys social welfare and creates problems for the economy. GHG emission is caused by human activities (social and particularly economic activities) such as energy generation, mining, transportation, infrastructure building, transportation, manufacturing, etc. Green finance, technological advancements, and energy efficiency are the factors that can be useful to reduce the GHG emissions and thereby, gives assurance of sustainable development (Leal Filho et al., 2020). Green finance means to enhance financial flows from financial institutions like banks, investment, insurance, and micro-credit firms at both public and private levels with the intention to encourage ecologically friendly activities. The eco-friendly projects, as a result of green financing, reduce GHG emissions without affecting human activities. So, sustainability can be created in human activities (Fonseca et al., 2020). GHG emissions are caused by energy consumption or harmful wastes. Technological advancement introduces better technologies for social and economic purposes. The use of eco-logical friendly technologies reduces energy consumption and causes no waste; it reduces GHG emissions and protects the environment. Hence, the country is likely to achieve sustainable development (Chien et al., 2022c; Shulla et al., 2021). Energy efficiency refers to the use of less amount of energy to fulfill the same task and consume the energy to leave no waste or the least amount of waste. Renewable energy output and renewable energy consumption are the two major components of energy efficiency. This reduces the usage of unclean energy and overcomes the overall use of energy for undertaking the same activities and minimizes the harmful result of energy consumption. So, there is a reduction in GHG emissions, which clears the way to achieve the desired goals (Chien et al., 2022b; Chien, 2022d).

Vietnam is counted among those economies which is famously known as fossil-fuel economy. The reason is that it derives approximately two-thirds of energy supply from non-renewable sources especially from coal and oil. As the demand for energy has been increasing continuously, thereby, it has made Vietnam a major coal importer (Duong et al., 2022; Huang et al., 2022). However, Vietnam is also rich in

renewable natural resources particularly in the category of wind power, biomass, solar power. Unfortunately, these areas remain untapped. It is reported that in 2015, 3.7 percent of energy supply came from non-renewable energy, hence, making the country relying on fossil fuels. This overreliance, however, is becoming the threat for economy. This obliges the country to gradually decrease the share of fossil fuel in energy mix and replace it with green initiatives and renewable energy resources (Dinh et al., 2022).

GHG emissions growth in Vietnam is highest all over the globe and the carbon intensity of this economy is considered second highest in Asian economies (Kamarudin et al., 2021; World Bank, 2015). As the energy intensity level is rising constantly, thereby, the predictions indicate that Vietnam will become highest GHG emission in the region as other economies of said region are exerting effort to reduce the harm emissions. Moreover, these projections, which are made based on coal usage growth, estimate that the share of coal will reach to 50% in energy mix by 2030. Nevertheless, Vietnam witnessed remarkable economic growth in last three decades. However, at the same times, the carbon emissions in particular region have increased four times during the time span. The stronger association of economic growth carbon emission made the country vulnerable in terms of environmental quality. Along with it, the statistics also indicate that Vietnam is ranked 8th among those 10 economies which are greatly affected by extreme weather conditions (German watch, 2017; Lan et al., 2022). Not only this, the country also experienced climate changes such as rising sea level, heavy floods and droughts, high temperature etc.

Besides, Vietnam is also experiencing rapid growth in population and industries that which also leads to excessive amount of waste generation that eventually increases the rate of GHG emissions. Along with it, the increase in middle-income population and rapid growth in technology also makes the consumption pattern unbalance due to which the country has been experiencing issues in terms of electronic waste, plastic waste, construction waste etc. It is reported that the amount of waste generated by households in 2018 was about 25.5 million tons. Moreover, the calculated predictions report that the waste will be increased by 10 to 16% each year (Lin et al., 2022; Liu et al., 2022). As it is understood that GHG emissions have a negative impact on the quantity and quality of the country's natural resources as well as on the health of living beings, including humans, which provides a basis for future economic growth. So, in Vietnam, the rising GHG emissions pose a danger to the country's ability to expand economically and socially sustainably. Because of this, it is a severe problem that needs to be addressed. Therefore, the current study seeks to resolve this social and economic issue that Vietnam has been facing (Moslehpour et al., 2022a, 2022b). It diverts the readers' attention toward the ways how to attain sustainable ways that are helpful for country to reduce ecological deficit. Thus, the study intends to analyze the influences of green finance, technological advancements, and energy efficiencies like renewable energy output and renewable energy consumption along with industrialization and population growth on the achievement of sustainable development.

In the previously conducted literature, many authors have paid heed to sustainable development achievement and its drivers. Many authors have made the debate on the

outlined constructs. But these authors have discussed these relations in different workouts (Moslehpour et al., 2022c; Nguyen et al., 2021). The present study, however examines them altogether, hence makes significant contribution to literature. Second, in the past literature, energy efficiency is usually measured by renewable energy consumption. Studies appears to be scarce which used renewable energy output as a proxy to energy efficiency for checking sustainable development. The paper makes an addition to the literature, as it examines energy efficiency with proxies of renewable energy output and consumption. Third, for GHG emissions, Vietnam is considered a highest emitter, and GHG emissions are a great challenge in achieving sustainable development. Still, limited research has been conducted on green finance, technological advancements, renewable energy output, and renewable energy consumption's role in reducing GHG and achieving sustainable development for Vietnam. The current study analyzing the relationship of these factors with GHG emissions and sustainable development for Vietnam is a distinction.

The paper is structured in to following parts: the second part, next to the introduction, checks the previous studies related to the outlined constructs. Next section spills a procedure of gathering required data and analysis techniques. After analyzing the data, the results are then compared with prior studies. Finally, the study is concluded in short where limitations and implications are mentioned.

2. Literature review

All the high-quality natural living and non-living resources, the nature of the atmosphere, and human capital are necessary for economic progress. Despite the fact that they can currently be arranged for economic practices, with regular use, these fundamental factors sooner or later collapse. Moreover, the falling quality of these factors because of the environmental destruction and weak social system is a great challenge in developing consistency in economic development (Goralski & Tan, 2020; Phuoc et al., 2022). Contrary to this, sustainable development is the economic condition where different resources are utilized to address the present requirements without creating issues for the future generation in meeting their needs (Huang et al., 2021; Quynh et al., 2022). GHG emissions are the pollutants caused by the increasing and inappropriate use of energy and technological resources. These gases destroy the climate balance and natural resources, whether they are living or non-living, and disturbs the health of humans. So, GHG emissions are a threat to economic resources and can put break in sustainable economic development. But then, initiatives like green finance, technological advancements, and energy efficiency can reduce the GHG emissions from economic practices. Therefore, they are helpful in creating sustainability in economic development (Fonseca et al., 2020; Sadiq et al., 2022a). In the existing literature, there has been debate on the relationship of these constructs. In further paragraphs, the relation of green finance, technological advancements, renewable energy output, renewable energy consumption, and industrialization and population growth to GHG emission and sustainable development in the light of past study arguments (Rahman et al., 2020).

2.1. Green finance and sustainable development

Green finance offers support to the global fight against climate change because of GHG emissions, and therefore it is a great contributor to sustainable development (Sadiq et al., 2022b, 2022c). Mohd and Kaushal (2018), investigate green finance and sustainable development. In order to empirically analyze and establish a relation between the factors, the information was acquired from the existing literature, making sure that the literature is about the Indian economy. The study pinpointed the three broader problems that are related to current global economy; “environmental change, energy shortages, and financial emergencies”. Green finance, in this regard, appears to be a perfect solution that can mitigate such issues. It provides a financial based support to green agendas which can restrict the harmful emissions. Moreover, in order to maintain sustainability at national level, factors such “green funds in horticulture, green constructions, green security” must be evaluated and they are positively linked with sustainability. Debrah et al. (2022), examine the relation between green finance, GHG emissions, and sustainable development. This study is based on the review of literature that systematically and quantitatively examines 995 relevant publications from Scopus and validated with Google Scholar, Web of Science, and ScienceDirect. The six types of green finance, like a green bond, green credit, carbon investment, green banking, market stress, green finance, and climate finance, were taken. The study claims that manufacturing and trading activities, because of the use of involved technologies, cause gases that cause greenhouse effects. But, green finance in any of its forms provides finances to mitigate GHG emissions and, with a balanced climate and preserved resources, contributes to sustainable development. Similarly, Cui et al. (2020) explores the role of green finance in the mitigation of GHG emissions and achieving sustainable development. This study posits that green finance enhances an investment in ecological-friendly practices, and the success of these practices results in GHG reduction. Therefore, the country can attain sustainable development.

2.2. Technological advancement and sustainable development

The technological advancements begin eco-innovation within the country and assist in overcoming environmental concerns like GHG emissions. The environment and resources saved from GHG emissions move the country towards sustainable development (Sadiq et al., 2023a, 2023b; Yuan & Zhang, 2020). Suki et al. (2022), examines technological advancement and its impacts on the environmental condition. The study claims that technologies are being employed to transform to manufacture or process of products and services. Traditional methods produce GHG emissions because of the fossil fuels’ combustion for high voltage power. However, the innovative technologies with the use of recycling energy let to perform business processes without GHG emissions. So, the company applying innovative technologies supports sustainable growth. Silvestre and Țîrcă (2019), analyzes the technological innovation’s role in reducing GHG emissions and achievement of sustainable development. The articles on innovation, environmental quality, and SED were analyzed to establish relations between technological innovation, GHG emissions, and sustainable

development. The study indicates that the tendency of business organizations to maintain technological innovation enhances the effectiveness of different business processes and removes their environmental impacts. There is mitigation of GHGs emissions, and a clean environment assures healthy and active human resources for sustainable development. Thereby, technological advancement is negatively related GHG emissions. Zhang et al. (2021), checks the relationship of eco-technology innovation, eco-efficiency, and eco-well-being performance with sustainable development. A two-stage Super-slack-based measure (SBM) model and the relationship between eco-technology innovation, eco-efficiency, GHG emissions, and sustainable development was analyzed in 102 economies. The study explains that economic activities like building infrastructure, manufacturing, construction, chemicals processing, energy generation, and transportation emits GHGs deteriorating nature's functioning. In a country where there is high technological advancement, economic entities implement eco-efficiency, and the reduction of GHG clears the way to sustainable development. So, technological advancement is positively connected with sustainable development (Tan et al., 2021; Zhang et al., 2023).

2.3. Energy efficiency and Sustainable development

The output of renewable energy contributes to clean and affordable energy supplies and also reduces the polluting environmental factors. The GHG emissions, which deplete the ozone layer, disturb the climate, and affect the naturally occurring resources, could be overcome. The availability of living and non-living resources enables the firms to sustain the economic development (Majid, 2020; Zhao et al., 2022). Bishoge et al. (2018) examines the role of REO in achieving SD. The study exposes that GHG emission, the worst environmental polluting factor, is caused by domestic and economic human activities, including fossil fuel usage in energy mix. The projects for renewable energy production provide large supplies of renewable, affordable, and clean energy. In this situation, it is in the hand of humans to replace fossil fuels energy and fight against GHG emissions. The resources are preserved, and a sustainable work environment assures sustainable development. It shows a positive relation between REP and SD. Güney (2019), examines the relation between non-renewable energy, REP, and SED. The data from 73 developing and 40 developed countries were analyzed for non-renewable energy and renewable energy production's role in sustainable development. The study points out non-renewable energy usage for meeting the energy requirements creates many environmental issues by GHG emissions. So, the increasing renewable energy output helps to overcome GHG emissions contributing to sustainable development (Van Hoa et al., 2022; Zhao et al., 2021).

Fossil fuel is considered a traditional source of energy is not safe for the environment and humanity because its consumption is responsible for producing high amount of GHGs. Opposite this, the use of renewable energy is proven to be safe for not releasing GHG emissions. So, renewable energy consumption is better to preserve environmental quality (Chang et al., 2022; Yousaf et al., 2021). Lyeonov et al. (2019), examines the green investment and green renewable energy impacts on GHG emissions and SD. The focus of research is on the EU countries over the time 2008–2016.

In order to address the relationship among the abovementioned factors, panel unit root test, Padroni panel co-integration tests, and FMOLS and DOLS co-integration techniques were applied. The findings show that the firm's tendency to utilize renewable energy in performing their routine functions reduces GHG emissions, and higher environmental well-being contributes to the country's sustainable development. Vasylieva et al. (2019), investigates the impacts of renewable energy on GHG emissions and SD. This investigation is based on Environmental Kuznets Curve hypothesis. The data were taken from Ukraine and EU countries for years during 2000–2016 from the Eurostat database. The study posits that the economy has destructive impact on the environment. Renewable energy consumption in place of fossil fuels does not cause GHGs, and the preservation of the environment leads the country towards sustainable development.

2.4. Industrialization, population growth and sustainable development

Industrialization and population growth also play a crucial role in mitigating GHG emissions. The research of Wang et al. (2022) was about industrialization, trade openness, renewable energy, GHG emissions, and sustainable development. Having applied the STIRPAT model, the empirical data was acquired from G-7 countries for the period 1990–2020. The study pin points that industrialization has the capability to reduce GHG emissions. Tien et al. (2019), claims that industrialization causes GHG emissions and creates issues for social and economic development. The expansion in industrialization gives progress to eco-friendly technologies, which sustains economic functioning without releasing GHGs. Hence, sustainable development can be achieved with industrialization development. Fang et al. (2019), states that a place receives more attention from the government and authorities as its population grows. As a result, activities for environmental and human development are created. This aids in lowering GHG emissions and safeguards the resources for later use, both of which are essential for sustainable growth. Abid et al. (2022), investigates the impacts of population growth on green growth and sustainable development. With a grey relational analysis model, relevant data were acquired from the Pakistani economy. The results showed that when there is increasing population growth, the country is making green growth where eco-friendly technologies and clean resources are utilized, and the wastes of economic practices are properly handled. So, there is minimum GHG emission.

3. Methodology

The paper investigates the role of green finance, technology advancement, REO, REC, industrialization, and population growth on sustainable development in Vietnam. Secondary data was extracted from the WDI along with OECD from 1991 to 2020. The study formulated the model with understudy constructs given as under:

$$SD_t = \alpha_0 + \beta_1 GF_t + \beta_2 TAD_t + \beta_3 REO_t + \beta_4 REC_t + \beta_5 IND_t + \beta_6 PG_t + e_t \quad (1)$$

Where;

SD = Sustainable Development

t = Time Period

GF = Green Finance

TAD = Technology Advancement

REO = Renewable Energy Output

REC = Renewable Energy Consumption

IND = Industrialization

PG = Population Growth

From Table 1 we can see that sustainable development was used as the dependent variable. Moreover, three predictors such as green finance, technology adoption and energy efficiency were used in the study. The article has also taken two control variables, such as population growth and industrialization.

The present study checks the details of the constructs via descriptives. Moreover, the present article also investigates the correlation or multicollinearity using a correlation matrix. Furthermore, the current article assessed unit root among the constructs. The study used the Phillips–Perron test and augmented Dickey-Fuller (ADF) test for this purpose. The equation is mentioned below:

$$d(Y_t) = \alpha_0 + \beta t + \gamma Y_{t-1} + d(Y_t(-1)) + \varepsilon_t \quad (2)$$

In addition, the present article also checks the co-integration that is also necessary for the application of the model via Westerlund and Edgerton (2008) approach. The expressions are stated below:

$$LM_\varphi(i) = T\hat{\varphi}_i (\hat{\sigma}_i/\hat{\sigma}_i) \quad (3)$$

$$LM_\tau(i) = \hat{\varphi}_i/SE(\hat{\varphi}_i) \quad (4)$$

Where,

$\hat{\varphi}_i$ = estimate beside standard error

$\hat{\sigma}_i^2$ = long-run measured variance. Moreover, $\varphi_i(L) = 1 - \sum \varphi_{ij}L^j$ represents “scalar polynomial” with L lag length, and ρ_i indicates loading parameters vector.

Finally, the current study investigates the connections among understudy constructs using the ARDL approach. It is an appropriate approach when the variables have no unit root at I(0) and I(1) (Zaidi & Saidi, 2018). Furthermore, it regulates heteroscedasticity effects and autocorrelation on the estimations (Nazir et al., 2018). The expression developed for it is stated below:

Table 1. Measurements of variables.

S#	Variables	Measurement
01	Sustainable Development	Total greenhouse gas emission (% change from 1990)
02	Green Finance	The ratio of green finance to total finance.
03	Technology Advancement	High technology exports (% of manufactured exports)
03	Energy Efficiency	REO (percentage of total energy output) REC (percentage of total energy output)
05	Industrialization	Industry value added (% of GDP)
06	Population Growth	Population growth (annual percentage)

Source: WDI & OECD.

$$\begin{aligned}
\Delta GHGE_t = & \alpha_0 + \sum \delta_1 \Delta GHGE_{t-1} + \sum \delta_2 \Delta GF_{t-1} + \sum \delta_3 \Delta TAD_{t-1} \\
& + \sum \delta_4 \Delta REO_{t-1} + \sum \delta_5 \Delta REC_{t-1} + \sum \delta_6 \Delta IND_{t-1} + \sum \delta_7 \Delta PG_{t-1} \\
& + \varphi_1 GHGE_{t-1} + \varphi_2 GF_{t-1} + \varphi_3 TAD_{t-1} + \varphi_4 REO_{t-1} \\
& + \varphi_5 REC_{t-1} + \varphi_6 IND_{t-1} + \varphi_7 PG_{t-1} + \mathcal{E}_t
\end{aligned} \tag{5}$$

Furthermore, the ongoing article also examines the association between the variables using the DARDL model. This approach was developed by Jordan and Philips (2018). This approach can handle all the shortcomings that exist in the ordinary ARDL model. Moreover, the current article has applied 5000 simulations for parameters vector by applying the multivariate normal distributions for the dynamic ARDL simulations model. The equation of the approach is mentioned below:

$$\begin{aligned}
\Delta GHGE_t = & \alpha_0 + \sum \delta_1 \Delta GHGE_{t-1} + \sum \delta_2 \Delta GF_t + \sum \delta_3 \Delta GF_{t-1} \\
& + \sum \delta_4 \Delta TAD_t + \sum \delta_5 \Delta TAD_{t-1} + \sum \delta_6 \Delta REO_t + \sum \delta_7 \Delta REO_{t-1} \\
& + \sum \delta_8 \Delta REC_t + \sum \delta_9 \Delta REC_{t-1} + \sum \delta_{10} \Delta IND_t + \sum \delta_{11} \Delta IND_{t-1} \\
& + \sum \delta_{12} \Delta PG_t + \sum \delta_{13} \Delta PG_{t-1} + \mathcal{E}_t
\end{aligned} \tag{6}$$

Finally, the current article has also used the Bayesian inference analysis for robustness that assumed that assessment parameters are random and the observed data is fixed. The Bayesian inference analysis operates based on Bayes's rule regarding the prior distribution results using posterior data related to model parameters from observed data (Salakpi et al., 2022). Hence, the Bayesian linear model regression is mentioned below:

$$Y_t \sim N + \beta^T X_t, \delta^2 I \tag{7}$$

In equation (7) Y_t shows the dependent variable like GHGE drawn from Gaussian distribution. In contrast, in equation (7) X_t shows the matrix of predictors. Moreover, in this equation, β^T shows the transposed weight matrix, δ^2 shows the variance, and I show the identity matrix. Finally, the adaptive random-walk Metropolis-Hastings algorithm has also been applied to avoid spurious convergence.

4. Findings

The present study checks the details of the constructs, such as minimum value, average value, standard deviation, and maximum value using descriptive statistics. The results indicated that the GHGE average value was recorded 120.283 percent, while GF mean value was 15.201 percent. In addition, the outcomes revealed that the TAD average value was 30.558 percent, while the REO mean value was 18.715 percent. Finally, the outcomes revealed that the REC average value was 20.804 percent, while

the IND mean value was 44.395 percent, and the PG mean value was 0.725 percent. These values are given in [Table 2](#).

Moreover, the present article also investigates the correlation or multicollinearity using a correlation matrix. The results revealed that green finance, technology advancement, REO, REC, industrialization, and population growth have a significant along with positive nexus with sustainable development in Vietnam. These values are given in [Table 3](#).

Furthermore, the current article checks the unit root among the variables to apply the appropriate model. The study has used the PP and ADF tests for this purpose. The findings exposed that the GHGE, GF, TAD, IND, and PG have no unit root at level while REO and REC have no unit root at first difference. These values are given in [Table 4](#).

In addition, the present article also checks the co-integration that is also necessary for the application of the model using the (Westerlund & Edgerton, 2008) approach. The outcomes exposed that the t-values are higher than 1.64 and the p-values are less than 0.05. These findings exposed co-integration exists. These values are given in [Table 5](#).

Furthermore, the ongoing article also examines the association between the variables using the DARDL model. The results revealed that green finance, technology advancement, REO, REC, industrialization, and population growth have a significant along with positive nexus with sustainable development in Vietnam. These values are given in [Table 6](#).

Finally, the current article has also used the Bayesian inference analysis for robustness. The results revealed that green finance, technology advancement, REO, REC, industrialization, and population growth have a significant along with positive nexus with sustainable development. Moreover, the acceptance rate is than standard threshold. In addition, the Monte Carlo chain standard errors (MCSE) are close to one that exposed Bayesian inference is valid. These values are given in [Table 7](#).

4.1. Discussions

The results showed that green finance has a negative association with GHG emissions and positively influences sustainable development. These results are in line with X. Wang and Wang (2021), which checks the role of green finance in sustainable development. The study implies that to reduce GHG emissions while business operations are being performed, organizations bring changes in the resources and processes.

Table 2. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
GHGE	30	120.283	92.391	3.662	268.353
GF	30	15.201	22.841	41.879	128.109
TAD	30	30.558	0.612	29.364	32.124
REO	30	18.517	2.199	15.037	23.927
REC	30	20.804	8.414	11.340	33.258
IND	30	44.395	2.901	37.843	47.557
PG	30	0.725	0.277	0.238	1.364

Source: Author Estimation.

Table 3. Matrix of correlations.

Variables	GHGE	GF	TAD	REO	REC	IND	PG
GHGE	1.000						
GF	-0.926	1.000					
TAD	-0.473	0.434	1.000				
REO	-0.604	0.569	0.193	1.000			
REC	-0.935	-0.858	-0.437	-0.404	1.000		
IND	-0.561	-0.495	-0.216	-0.735	0.299	1.000	
PG	-0.807	-0.856	-0.458	-0.220	0.844	0.299	1.000

Source: Author Estimation.

Table 4. Unit root test.

ADF PP				
Series	Level	First difference	Level	First difference
GHGE	-3.092***	-	-2.622***	-
GF	-4.902***	-	-3.829***	-
TAD	-2.883***	-	-2.029***	-
REO	-	-5.883***	-	-4.902***
REC	-	-6.102***	-	-4.001***
IND	-2.553***	-	-3.732***	-
PG	-3.812***	-	-3.192***	-

Source: Author Estimation.

Table 5. Co-integration test.

Model	No shift		Mean shift		Regime shift	
	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value
LM_{τ}	-3.092	0.000	-3.711	0.000	-4.873	0.000
LM_{ϕ}	-3.927	0.000	-3.888	0.000	-4.914	0.000

Source: Author Estimation.

Table 6. Dynamic ARDL model.

Variable	Coefficient	t-Statistic	Prob.
ECT	-3.732***	5.322	0.000
GF_{t-1}	-3.565***	4.611	0.000
GF	-0.673**	4.653	0.000
TAD_{t-1}	-2.771*	3.774	0.022
TAD	-3.994***	4.993	0.000
REO_{t-1}	-4.892***	2.192	0.042
REO	-0.353***	2.871	0.031
REC_{t-1}	-0.553**	3.992	0.019
REC	-0.291**	4.183	0.000
IND_{t-1}	-0.092**	3.097	0.029
IND	-1.772**	4.661	0.000
PG_{t-1}	-1.688***	3.773	0.022
PG	-3.546**	2.897	0.031
Cons	-3.773**	2.837	0.033

R square = 56.223 Stimulation = 5000.

Source: Author Estimation.

Green finance strengthens the organization's financial position to bring innovation, and GHG emissions reduction becomes possible for them. As a result, improved environmental sustainability leads to the achievement of sustainable development. These results are supported by Lee (2020), which states that while the business functions are being performed for the production of goods and services, there may be the

Table 7. Bayesian analysis results.

Variables	Mean	Std. Dev.	MCSE	Prob. of mean > 0	Interval
GF	-3.893	0.432	0.031	0.911	-2.512, -1.102
TAD	-5.662	0.352	0.055	1	-2.902, -0.091
REO	-5.448	0.266	0.061	0.985	-1.643, -0.662
REC	-3.902	0.233	0.055	1	-2.165, -0.001
IND	-2.291	0.543	0.051	0.892	-2.125, -1.221
PG	-6.772	0.528	0.064	1	-3.176, -1.632
Intercept	-52.547	6.232	0.511	1	-2.188, -0.092
e.ME Sigma2	0.655	0.155	0.005		1.119, 2.726
					Acceptance rate = 0.332

Source: Author Estimation.

creation of toxic wastes causing GHG emissions. By employing green finance in the business, the wastes from the production processes are minimized, and thereby, the control of GHG emissions increases the organization's contribution to the sustainable development of the country.

The results showed that technological advancement has a negative association with GHG emissions and positively influences sustainable development. These results are in line with [Tabrizian \(2019\)](#), which shows that the processing of material into goods and services depends on the use of technologies. The traditional technologies need higher voltage power that is acquired from using fossil fuels, and therefore, these technologies cause GHG emissions. But the innovation in technologies sterilizes the production processes from GHG emissions, and the organization releasing the least amount GHGs contributes to sustainable development. These results are supported by [Abbasi et al. \(2022\)](#), which highlights that the firms which intend to benefit from technological advancements within the economy maintain innovation in the business processes. Technical innovation reduces the negative consequences of resources and processes. As a result, the reduction of toxic gases like GHGs improves the environmental performance of the firms. These firms succeed in achieving sustainable development.

The results showed that renewable energy output has a negative association with GHG emissions and positively influences sustainable development. These results are in line with the previous study of [Meng et al. \(2022\)](#). According to this previous study, human activities, mostly those including the use of energy, cause GHG emissions and degrade the environment. The increasing supply of clean energy, as a result of increasing renewable energy output, minimizes these negative impacts of human activities on the environment and natural resources. The preservation of nature and its productivity assures an economy is making sustainable development. These results also match with the study of [Cerqueira et al. \(2021\)](#), which throws light on the nexus between technological advancement and sustainable development. The study claims that with innovation in technological processes, the use of resources can be reduced to attain higher production. Thus, firms face environmental concerns like GHG emissions in rare cases and can have sustainable development.

The results showed that renewable energy consumption has a negative association with GHG emissions and positively influences sustainable development. These results are supported by [Sharma et al. \(2022\)](#). This study proclaims that the use of energy is essential to carry the economic activities, but it is also a big cause of environmental

pollution as it releases GHGs. But the environmental consequences of economic practices can be overcome with the change in energy patterns by employing renewable resources. These firms play an active role in the country's sustainable development. These results are in line with the study of Cantarero (2020) and Kurniawan et al. (2022), which reveals that renewable energy does not release chemicals or gases while being used and leaves no waste. So, the use of renewable energy does not cause GHG emissions giving the same product just like fossil fuels. With the reduced GHG emissions, environmental sustainability adds to sustainable development.

The results showed that industrialization has a negative association with GHG emissions and positively influences sustainable development. These results are in line with Samour et al. (2022). This study examines the role of industrialization in improving sustainable development. To some extent, industrialization, because of the use of fossil fuel energy, creates GHG emissions and environmental deterioration. But, as there is constant progress in industrialization, it introduces innovation in technologies, resources, and business techniques. This innovation is useful for overcoming GHG emissions and climate change. So, with the protection of the environment and natural resources, economic development can be sustainable. These results are supported by the previous study of Solangi et al. (2021) Van Hoa et al. (2022), which highlights that industrialization is a suitable way to develop environmental awareness, technological innovation, and the preparation of human capital. So, there are more chances of carrying on eco-friendly projects, and with the reduction of pollutants like GHG emissions, the natural environment can be preserved. This leads the economy towards sustainable development.

The results showed that population growth has a negative association with GHG emissions and positively influences sustainable development. These results are in line with Agyekum et al. (2020) and Sriyakul et al. (2022). It highlights that the increase in population is a natural source of GHG emissions. But the increase in population brings expansion in economic practices and brings the economy to develop in machines, technologies, infrastructure, and logistics. Such economic development encourages eco-friendly changes like the reduction of GHG emissions. The sustainability of the environment and the natural resources available add to sustainable development. These results are supported by Thitinan and Chankoson Khunanan (2022) and Zamora-Polo et al. (2019), which indicates that the increase in the population in an area diverts the attention of government and regulators towards the area. Consequently, human development and environmental development activities come into existence. This is helpful in reducing GHG emissions and protects the resources for future use, which are necessary for sustainable economic development.

4.2. Theoretical implications

The present study has made a significant contribution to literature, and future authors can learn much. The current study examines the influences of green finance, technological advancements, energy efficiencies such as renewable energy output, and renewable energy consumption with the factors like industrialization and population growth on sustainable development. The simultaneous analysis of these factors for

determining sustainable development saves a distinctive position of the current study in literature. This study also makes a contribution to the literature because it uses GHG emissions as the measurement of sustainable development for a country. In earlier literature, the consumption of renewable energy is typically used to quantify energy efficiency and assess its contribution to sustainable development. The current study adds to the body of literature as it investigates energy efficiency using proxies of renewable energy output and renewable energy consumption for sustainable development. The present study also makes an addition to the literature reason it examines green finance, technological advancements, renewable energy output, and renewable energy consumption's role in reducing GHG and achieving sustainable development for Vietnam.

4.3. Empirical implication

The present study has considerable significance in Vietnam and other similar countries for it addresses GHG emissions, the common issue of all countries, restricting the achievement of sustainable development. It has many empirical implications in these countries. It provides a guideline to government, economists, and environmental regulatory authorities on how GHG emissions can be overcome, and sustainable development can be achieved. This study guides them that they must struggle to encourage green integration into financial services like investment, loans, credit, insurance, etc., so that GHG emissions can be controlled, and sustainable economic development can be acquired. This piece of literature also guides that the policymakers must pay heed to technological advancements within the country to reduce the GHG emissions, which causes complexity in getting sustainable development. The study also suggests that government must formulate economic and fiscal policies to encourage energy efficiency by increasing renewable energy development. This will reduce GHG emissions leading the state towards getting sustainable development. Likewise, energy efficiency must also be encouraged through renewable energy consumption for firms to be able to overcome GHG emissions, and thereby, sustainable development can be assured. The study also suggests that industrialization must be promoted and regulated to minimize environmental concerns like GHG emissions and make it a convenient way to achieve sustainable development. The study guides the regulators in establishing regulations related to sustainable development through the adoption of green finance, energy, and technology. The study also highlights that population growth must be managed properly to mitigate GHG emissions and ensure the achievement of sustainable development.

5. Conclusion

The aim of the study was to examine the influences of green finance, technological advancements, and energy efficiencies like renewable energy output and renewable energy consumption on the achievement of sustainable development. It was also to the role of factors like industrialization and population growth in achieving sustainable development. Vietnam was selected for the analysis, and empirical data were

collected for green finance, technological advancements, renewable energy output, renewable energy consumption, industrialization, population growth, GHG emissions, and sustainable development. The study results indicated that green finance, technological advancements, renewable energy output, renewable energy consumption, industrialization, and population growth, have a negative relation to GHG emissions but positive relation to sustainable development. The results showed that access to green finance enables organizations to form and execute eco-logical friendly business strategies. It minimizes the total amount of GHG emissions and continues to operate a business. Hence, sustainable development is achieved. The results also showed that in the country, making advancements in the technological field allows individuals and firms to employ modern, environmentally friendly technologies for carrying on the practices. Innovative technologies reduce the use of energy required for business processes, and the reduction of GHG emissions leads to sustainable development achievement. The results highlighted that the increasing output of renewable energy like biomass, biofuel, solar power, hydroelectric power, etc., enhances the firms' access to clean energy. Consequently, the fall in fossil fuel energy reduces the total GHG emissions, and a clean environment provides support to sustainable development. Likewise, energy efficiency, as a result of increasing renewable energy use, brings a fall in GHG emissions, and the preservation of the natural environment enhances sustainable development. The results also suggested that the expansion in industry enhances the manufacturing of technological instruments, innovation in infrastructure, renewable energy generation, and development awareness. The resultant decrease in GHG emissions helps develop sustainability in economic development. The study also concluded that with the increasing population, the human capital formation and excessive demand for clean overcome GHG emissions and help attain sustainable development.

6. Limitations & future recommendations

The present study has some specific limitations. The future authors may remove this limitation by making some additions or amendments. A few variables like green finance, technological advancements, and energy efficiency with renewable energy output and renewable energy consumption have been examined as contributors to sustainable development. Many other variables, like energy transition, corporate social responsibility, and human capital, are also appropriate for achieving sustainable development. The study is limited to missing these appropriate factors of sustainable development. Future authors must also examine these factors to conduct a comprehensive study on sustainable development. The relationship between green finance, technological advancements, and energy efficiency with renewable energy output, renewable energy consumption, industrialization, population growth, and sustainable development with empirical evidence from the Chinese economy alone. Vietnam is a developing country with a huge population and causing a large amount of GHG emissions. But this study may not be appropriate in developed economies. So, both developed and developing economies must be examined for collected information on these factors' relationship. Moreover, the current study uses GHG emissions in order

to predict sustainable development in a country. It is recommended that CO₂ emission would be a better predictor of sustainable development.

Disclosure statement

No potential conflict of interest was reported by the authors.

Ethical approval

The authors declare that they have no known competing financial interests or personal relationships that seem to affect the work reported in this article.

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