Journal of Open Innovation: Technology, Market, and Complexity 9 (2023) 100100

Contents lists available at ScienceDirect

Journal of Open Innovation: Technology, Market, and Complexity

journal homepage: www.sciencedirect.com/journal/journal-of-open-innovation-technology-market-and-complexity

Nexus of innovation, renewable consumption, FDI, growth and CO2 emissions: The case of Vietnam

Pham Xuan Hoa [a,1], Vu Ngoc Xuan [b,*,2], Nguyen Thi Phuong Thu [c,3]

[a] Department of Public Finance, School of Banking and Finance, National Economics University, Viet Nam
[b] Department of Microeconomics, Faculty of Economics, National Economics University, Viet Nam
[c] Department of Public Economics, Faculty of Development Economics, National Economics University, Viet Nam

ARTICLE INFO

Keywords:
Innovation (IN)
Technology revolution (TR)
Foreign direct investment (FDI)
Economic growth (EG)

ABSTRACT

Governments around the world have enacted many policies to reduce environmental pollution and carbon dioxide (CO2) emission. This study aimed to determine and understand the relationship between innovation, renewable energy consumption, foreign direct investment inflows, economic growth and CO2 emission in Vietnam. Information was collected annually based on the annual data of the General Statistics Office of Vietnam and World Bank from 2000 to 2022. The authors use the unrestricted fixed effects to resolve the study problems and using panel data method. The results indicate that innovation positively affects environmental pollution in Vietnam. However, renewable energy consumption has a negative effect on environmental pollution in Vietnam. In addition, FDI inflows and economic growth have strongly positive effects on environmental pollution. This paper also provides some recommendations that can assist Vietnam in developing a green and sustainable economy in the technology revolution 5.0 to achieve the United Nations Sustainable Development Goals (SDGs) over a long-term period.

1. Introduction

The Fifth Industrial Revolution, or Industry 5.0, seeks a more balanced relationship between humans and smart technologies, and this is transforming the way we live, work and interacts with each other. It builds upon the digital revolution that began in the late 20th century and is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres. This revolution is expected to fundamentally alter the way we produce goods and services, creating new opportunities for growth and development across a range of sectors, optimizing production processes, reducing waste and increasing efficiency as a result of greater collaboration between smart technologies and humans (Ganesan et al., 2020; Melane-Lavado, 2020).

The relationship of innovation, renewable energy consumption, FDI inflows, economic growth and carbon dioxide emissions have not been studied in developing economies such as Vietnam, particularly in the context of collaborative technology and the fifth industrial revolution. Therefore, this paper refers to the relationship between these factors and how they affect each other in Vietnam. Both policymakers and scientists can benefit from understanding the factors affecting environmental pollution in order to maintain a sustainable economy (Shi et al., 2020) (An et al., 2023).

The motivation of the study is examined the relationship of innovation, renewable consumption, FDI inflows, economics growth and carbon dioxide emissions in Vietnam. The empirical results are the policy suggestions for the decision makers in protecting environment in Vietnam. The necessities for this study because the lack of research in carbon dioxide emissions in Vietnam. Furthermore, policy-level problem in this study is addressing that the Vietnam government are not care about the environmental pollution in the past time. The Vietnam government also is lacking the policies in protect the environment for the sustainable development goals.

The study is expected to provide the good solutions to resolve the problem of environment pollution in Vietnam. The policy makers can use the empirical results in this paper to have the good policies to protect the environment in Vietnam. How does the choice of sample is

* Corresponding author.
E-mail address: xuanvn@neu.edu.vn (V.N. Xuan).
[1] ORCID ID: 0009–0000-6406–2129
[2] ORCID ID: 0000–0003-4364–9785
[3] ORCID ID: 0000–0003-2011–6417

https://doi.org/10.1016/j.joitmc.2023.100100
Received 21 June 2023; Received in revised form 17 July 2023; Accepted 23 July 2023
Available online 29 July 2023
2199-8531/© 2023 The Author(s). Published by Elsevier Ltd on behalf of Prof JinHyo Joseph Yun. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

complementing that problem. The Vietnam government faced the trade-off between the environment pollution and economics growth, FDI inflows. The good choice may be the using more renewable energy to reduce the carbon dioxide emissions. The paper is focused on the innovation and renewable consumption to decrease the environmental pollution in Vietnam.

The results and policies generalizable in this study is the promoting of Vietnam government to change the policies just focus on the economic growth and FDI inflows to the green economy and green FDI inflows. The authors use the unrestricted fixed effects to resolve the study problems. A contribution of a study is using the panel data method. The paper employs the unrestricted fixed effects to resolve the problem of carbon dioxide emissions in Vietnam.

This paper includes the following sections: Section 1, Introduction; Section 2, Literature Review, Section 3, Data Collection and Research Methodology; and Section 4, Results. The final section presents this study's conclusions and recommendations.

2. Literature Review

2.1. Factors affecting CO_2 emission

2.1.1. Innovation affecting CO2 emission

The Industry Revolution 5.0 has brought about significant changes in the global economy, with an increasing focus on sustainability. To better understand the interplay of factors within this context, research questions should focus on the nexus of innovation, renewable energy consumption, foreign direct investment (FDI) inflows, economic growth, and CO2 emissions:

How does innovation in Industry 4.0 technologies (e.g., artificial intelligence, internet of things, robotics) impact carbon dioxide emissions and adoption in Industry 5.0?

How do FDI inflows in Industry 5.0 technologies affect carbon dioxide emissions in Vietnam?

What is the role of government policies and regulations in promoting innovation, renewable energy consumption, and FDI inflows, and in mitigating CO2 emissions in the context of Industry 5.0?

What are the potential synergies and trade-offs between innovation, renewable energy consumption, FDI inflows, and economic growth in the context of Industry 5.0? (Andersen et al., 2010). How can policymakers balance the objectives of economic growth, innovation, renewable energy consumption, and CO2 emission reduction in the context of Industry 5.0, while addressing potential negative externalities and ensuring social equity?

Investigating these research questions can provide valuable insights into the complex interrelationships between various factors in the Technology Revolution 5.0, and contribute to the development of effective strategies for promoting sustainable economic growth (Al Afif et al., 2023).

The existing scholarly literature has categorized the effects of income, growth, and trade on environmental quality into three distinct types: scale effects, technique effects, and composition effects. The scale effect is a result of economic activities such as manufacturing, assembly, and waste generation, which directly contribute to increased pollution levels in proportion to economic growth (Can et al., 2020). The technique effects become evident in later stages of economic development when the economy performs well and leads to significant technological advancements that reduce environmental pollutants. Lastly, the composition effects pertain to the production composition within the economy and its ambiguous effects on the environment. For example, a country engaged in open trade may have varying impacts on pollution concentration, depending on its comparative advantage, which is determined by factors such as endowment and pollution policies. The factor endowment hypothesis suggests that high-income countries with ample capital are more likely to export goods and services that are polluting in nature (Balsalobre-Lorente et al., 2023). This argument aligns with the Heckscher-Ohlin theory, which states that a country should design its manufacturing and export product portfolio based on its factor intensity in manufacturing (Can et al., 2020).

In recent years, environmental scientists and policymakers have been grappling with the need for environmental reforms to address climate issues stemming from the consumption of fossil fuels and non-renewable energy sources. Policymakers are particularly focused on reducing energy demand through product and process innovations (Shahzad, 2020; Shahzad et al., 2021). These efforts align with the research of Adam Smith and David Ricardo. Thus, this study aims to investigate the impact of three indicators of export diversification (export product diversification, extensive margin, and intensive margin) on carbon emissions in both developing and developed countries. Export diversification can occur through the expansion of the existing export basket (intensive margin) or an increase in the number of products being exported (extensive margin). The combination of these indicators reflects export product diversification. The expansion of exports is associated with manufacturing and the utilization of resources such as energy, fossil fuels, oil, and income (Balsalobre-Lorente et al., 2023). Therefore, an empirical examination of the relationship between export diversification indicators may yield new insights for developing and developed economies (Can et al., 2020).

Over the past three decades, there has been a significant increase in greenhouse gas emissions due to various economic and non-economic activities such as trade, income growth, industrialization, urbanization, and deforestation (Sarwar et al., 2019). Urbanization and the use of fossil fuel energy are particularly prominent contributors to environmental issues, as they generate waste and emit pollutants (Khan et al., 2020; 2019; Khan et al. 2019). Additionally, the relationship between income and pollution is supported by the Environmental Kuznets Curve Hypothesis (EKC) (Can et al., 2020; M. K. Khan et al., 2020; 2019; Khan et al., 2019). Efforts to mitigate global warming and reduce greenhouse gas emissions have become priorities in national and international climate policies, as highlighted by Haggar (2012). In line with these efforts, the United Nations Framework Convention on Climate Change, an internationally recognized agreement, was signed in 1992. The Kyoto Protocol, implemented in 1997, aimed to restrict and reduce greenhouse gas emissions. Similarly, the Paris Agreement of the United Nations Framework Convention (UNFCCC) in 2015 brought together 195 countries and marked a significant milestone in implementing environmental policies and regulations to tackle environmental challenges (Sarwar et al., 2019).

Therefore, we address the research gaps in analysing the factors affecting the environmental pollution in Vietnam for a sustainable economy. In this study, the authors use the regression model to estimating how innovation, renewable consumption, FDI inflows, economic growth affected CO2 emissions in the period from 2000 to 2022 in Vietnam. The findings presented in this research are significant for the long-term efforts of Vietnamese policymakers to grow the GDP and the whole economy as well as safeguarding the environment in the context of the industry revolution 5.0 (Huang et al., 2021).

Innovation can enable more efficient and sustainable production and consumption, which can help reduce environmental impact. In general, the innovation can encourage the investment of green technology and protect the environment, reduce carbon dioxide emission. However, innovation can be slowed down by a lack of investment and political will. Therefore, it is important for governments, businesses, and individuals to invest in research and development, promote innovation-friendly policies, and create an environment that encourages innovation (Aghasafari et al., 2021; Al Afif et al., 2023; Khan et al., 2022).

2.1.2. Renewable energy consumption affecting CO2 Emission

Renewable energy consumption is crucial for reducing carbon dioxide emissions and achieving environmental sustainability. Renewable energy is the green energy and sustainable energy. As the world transitions towards a low-carbon economy, the use of renewable energy

sources will become increasingly important. Therefore, governments, businesses, and individuals can play a role in promoting the use of renewable energy sources by investing in renewable infrastructure, incentivizing the development of renewable energy, and adopting renewable energy technologies in daily life (C. Chen et al., 2022) (Bassey Enya et al., 2022).

This section provides an overview of the relationship between per capita Carbon Dioxide (CO2) emissions, Economic Complexity Index (ECI), Renewable Energy, and Inward Foreign Direct Investment (FDI) based on significant research in the field. The BRICS countries, including fossil energy dependence, trade, renewable energy, and CO2 emissions, have been extensively studied (Chen et al., 2022), (Balsalobre-Lorente et al., 2023). CO2 emissions have received considerable attention in the research literature due to their impact on environmental degradation (Balsalobre-Lorente et al., 2023). Studies on BRICS countries and other developing economies have analyzed emissions from various perspectives, including electricity consumption, trade openness, financial development, renewable energy, and the Environmental Kuznets Curve (EKC) framework (Balsalobre-Lorente et al., 2023). These studies have often observed a U-shaped relationship between ecological degradation and economic growth, where degradation initially increases but then decreases after reaching a certain income level.

CO2 emissions per capita are considered a relevant variable in the context of the EKC hypothesis, encompassing policy indicators, income differences, energy intensity, and the consequent rise in CO2 emissions per capita (Balsalobre-Lorente et al., 2023). Fossil fuel dependence has been identified as a significant contributor to environmental degradation, leading to increased CO2 emissions due to fossil fuel consumption and production (Chen et al., 2022) (Doğan et al., 2022).

The concept of Industry 4.0 represents a new era in industrial development characterized by enhanced production efficiency through technologies such as the Internet of Things (IoT), Big Data Analytics, Cloud Computing, 3D Printing, Augmented Reality, and Robotic Systems. The implementation of Industry 4.0 aims to achieve economic, automation, and safety improvements, along with greater environmental protection. However, the impact of Industry 4.0 on the environment, job market, and other factors is still uncertain, and studies on its environmental implications are limited (Esmaeili et al., 2023).

The BRICS countries, comprising a significant portion of the global population, exhibit diverse economic structures. For example, Russia relies on fossil energy sources, while South Africa specializes in highly polluting industries such as mining, metallurgy, automobile, chemical, and fertilizer industries. The relationship between Industry 4.0 and CO2 emissions must consider these unique contexts and realities (Balsalobre-Lorente et al., 2023).

The paradigm of sustainable development is based on three pillars: environmental protection, social justice, and economic development. Achieving Society 5.0 requires harmonizing the results of Industry 4.0 with the 17 Sustainable Development Goals proclaimed by the UN (Balsalobre-Lorente et al., 2023).

2.1.3. FDI inflows affecting CO2 Emission

In addition, FDI inflows can bring in new technology and expertise to a country, which can lead to innovation and economic growth. Nowadays, the multinational corporation care about the protect environment and reduce the carbon dioxide emission. However, FDI inflows can also have negative impacts on the environment if the investments are not made in a sustainable manner. Therefore, it is important for governments to implement policies that encourage sustainable practices and ensure that FDI inflows are aligned with environmental and social sustainability goals (Banerjee, 2022).

The Economic Complexity Index (ECI) is utilized to predict countries' expected income levels, economic growth, and greenhouse gas emissions (Leitão, 2021). The ECI measures an economy's capacity based on data linking locations with the activities present in them, incorporating production, exports, knowledge, and quality. Studies have examined the impact of ECI on environmental degradation, highlighting the long-run reduction of environmental degradation in relation to environmental quality, culture, and GDP (Leitão et al., 2023). Lower levels of the ECI have been associated with a greater presence of CO2 emissions, higher energy consumption, and greenhouse gas emissions, indicating lower economic complexity.

Inward Foreign Direct Investment (FDI) has been shown to play a significant role in CO2 emissions, as suggested by the Pollution Haven Hypothesis (PHV). Some nations with less stringent environmental regulations attract FDI, resulting in higher pollution levels, while others accepting FDI with stricter environmental regulations experience environmental improvements, known as the Pollution Halo Hypothesis (PHH) (Leitão et al., 2022).

Various econometric approaches have been employed to study the selected panel of countries. These include ARDL cointegration, Westerlund's cointegration, PMG - Pooled Mean Group, second-generation panel, heterogeneity panel, FMOLS, DOLS, and ARDL methods to measure long-run elasticity and analyze different sets of countries and variables (Leitão et al., 2023; Leitão et al., 2022; Sinha et al., 2022). The empirical findings regarding the impact of FDI on CO2 emissions do not always align with expectations, as the relationship can exhibit non-linear behavior and differ across countries.

2.1.4. Economic growth affecting CO2 Emission

Economic growth can provide a pathway towards poverty reduction and improvement in quality of life. However, economic growth can also lead to increased energy consumption and higher carbon dioxide emissions if sustainable practices are not implemented. Many developing countries just care about the economic growth and don't focus on the environmental protection. Therefore, it is important for economic growth to be decoupled from environmental degradation. This can involve implementing sustainable production and consumption practices, investing in renewable energy infrastructure, and promoting circular economy principles (Le et al., 2022).

Furthermore, addressing carbon dioxide emissions is crucial for mitigating the impacts of climate change. This can involve implementing policies and strategies that promote renewable energy and sustainable practices, increasing public awareness and engagement, and promoting international cooperation and collaboration (Chen et al., 2022).

The nexus of innovation, renewable energy consumption, FDI inflows, and economic growth and carbon dioxide emissions is complex and interconnected. A comprehensive and coordinated approach is necessary to address these factors and create a sustainable and equitable future for all (Al Afif et al., 2023; An et al., 2023; Andersen et al., 2010; Ashizawa et al., 2022).

Developing countries most frequently preference strategies for increasing the export of goods and services and attracting foreign direct investment (FDI) to promote economic growth. However, the Sustainable Development Goals (SDGs) require strategies geared towards actions that reduce environmental pollution, such as taking urgent action to combat climate change and ensuring access to affordable, reliable, sustainable, and modern energy for all. The relationship between exports, FDI, and carbon dioxide emissions has been demonstrated by empirical evidence in countries such as those in the Middle East and North Africa (Aghasafari et al., 2021).

Foreign direct investment inflows can increase work in the economy and economic growth in Vietnam. However, Vietnam has consistently attracted polluted FDI in recent years (Banerjee, 2022). Multinational companies and international corporations want to put capital into Vietnam because the labor costs are cheap and the law does not place strict regulations on production technology, meaning that they can use old technology causing environmental pollution (Fadly, 2020).

Economic growth coupled with environmental protection has been the main goal of the Vietnamese government in recent years. For example, farmers are interested in using more organic fertilizers so that

they can label their products as clean vegetables and sell them at a higher price, in turn helping to reduce CO_2 emissions (Fiori and Foroni, 2019). Policymakers in Vietnam have taken actions to reduce environmental pollution such as building solid waste treatment plants (Le et al., 2022).

Xuan et al. examined the influence of foreign direct investment (FDI) on economic growth and environmental pollution in Vietnam (Xuan, 2020a, 2020b; Xuan et al., 2020a; 2020b). The majority of exports from Vietnam are produced by FDI businesses, particularly those of electronic goods, where phone and component exports make up 99.1% of total exports [6]. Based on this relationship, the Vietnamese government is therefore concerned about the problem of environmental contamination. The Vietnamese government announced its commitment to decreasing carbon emissions to zero by 2050 during the COP26 meeting in the United Kingdom.

As is evident from this pledge, Vietnam's government places a high value on creating jobs and GDP growth and attracting the inflows of foreign direct investment capital while also working to reduce CO_2 emissions in order to achieve sustainable development. Thus, economic growth, technical advancement, and the use of renewable energy sources are the elements that significantly influence Vietnam's ability to reduce pollution and combat climate change (Phan, 2022; Phan et al., 2022).

In addition, China's CO_2 emission has risen because of the export of products and services. This means that China's export of products creates more pollution. Numerous research papers have discussed the connection between economic growth, FDI, and environmental pollution. Joe et al. demonstrated a positive correlation between FDI and economic growth. They found that the more FDI attraction there was, the better the economic growth occurred (Usman et al., 2022). They also discovered that differences in the characteristics of the host nation had an impact on economic expansion.

Nguyen also demonstrated that regional characteristics have an impact on Vietnam's capacity to attract FDI. He just focused on the attraction of FDI inflows in each province in Vietnam (Nguyen, 2022; Nguyen Thi Ngoc, 2016; Nguyen and Nguyen, 2021). Thu et al. investigated the factors that contribute to environmental pollution in Asia and Vietnam. They found that the greater the renewable consumption is, the better the environmental condition has in Vietnam and Asia (Thu et al., 2022; 2022). Raihan et al. referred to the connections that exist between green electricity consumption, the industrialization of the economy, forest area coverage, and CO_2 in the Russian context (Raihan and Tuspekova, 2022a; 2022b).

Fadly et al. discussed greening industry in Vietnam; environmental management standards and resource efficiency in small and medium-sized businesses were highlighted (Fadly, 2020). In addition, Liem et al. demonstrated that organic fertilizers can cut down on carbon dioxide emissions in Vietnam (Li et al., 2019; Liem et al., 2022).

Nguyen et al. investigated the relationship between financial development and renewable energy in Southeast Asian nations where organic waste materials serve as the primary raw materials. Overall, there is still a research gap regarding the connection between innovation, the consumption of renewable energy, and carbon dioxide emissions in Vietnam (Nguyen, 2022; Nguyen Thi Ngoc, 2016; Nguyen and Nguyen, 2021).

Le et al demonstrated that environmental pollution and FDI boost Vietnam's GDP. Le et al. demonstrated the connection between environmental pollution, economic expansion, and foreign direct investment. The non-linear ARDL co-integration approach provided them with these insights (Le et al., 2022; Li et al., 2019; Liem et al., 2022).

Andersen et al referred CO_2 emissions from the transport of China's exported goods. They noted that the transport of China's export goods and services increase the carbon dioxide emissions (Aghasafari et al., 2021; Al Afif et al., 2023; Andersen et al., 2010; Ashizawa et al., 2022). Ashizawa et al studied CO_2 emissions and economy of co-firing carbonized wood pellets at coal-fired power plants: the case of overseas production of pellets and use in Japan. They concluded that the production of wood pellets decrease the CO_2 emissions in Japan (Ashizawa et al., 2022).

Wu et al researched the carbon-neutral energy consumption and emission volatility: the causality analysis of ASEAN region. They found that the green consumptions decrease the CO_2 emissions in Asean countries (Wang and Wang, 2023; X. Wang et al., 2022; W. Wang et al., 2022; 2022; X. Wang et al., 2022; Wu et al., 2021). Fernandes et al referred urban metabolism-based approaches for promoting circular economy in buildings refurbishment. They noted that the circular economy needs to reduce the carbon dioxide emissions (Fernandes and Ferrão, 2023; Fiori and Foroni, 2019; Firth et al., 2022; Flammini et al., 2020).

Firth et al research the dynamics of soil organic carbon and CO_2 flux under cover crop and no-till management in soybean cropping systems of the Mid-South United State of America (Firth et al., 2022). Hu et al studied effects of cover crops and soil amendments on soil CO_2 flux in a Mississippi corn cropping system on upland soil (Hu et al., 2023; Huang et al., 2021).

Visconti et al noted the spontaneous plants improve the inter-row Soil fertility in a citrus orchard but nitrogen lacks to boost organic carbon. They found that the organic fertilizer could reduce the carbon dioxide emissions (Van Thanh, 2022; Visconti et al., 2022). Zickgraf studied political factors of immobility and climate change. He found that the political could reduce the carbon dioxide emissions and climate change.

Banerjee et al. conducted research on FDI flows in the energy industry with respect to the subregional links between the BCIM, BIMSTEC+ 1, and ASEAN+ 4 (Banerjee, 2022; Bassey Enya et al., 2022; Borg et al., 2022). According to the findings of this study, renewable energy for sustainable development receives the majority of FDI in these nations' energy sectors. Using empirical evidence from energy-intensive nations, Huang et al. observed an inverse relationship between renewable energy and CO_2 emissions (Huang et al., 2021). Fadly et al. highlighted Vietnam's green industry development. Environmental management standards and resource efficiency in small and medium-sized businesses were discussed (Fadly, 2020).

Using empirical research, Khan et al. examined innovation ability, green electricity use, and CO_2 emissions in African countries (H. Khan et al., 2022). Moreover, Nguyen studied Vietnam's export of goods and services and CO_2 emissions. With contextual evidence from both developing countries and developed countries, Shahzad also investigated CO_2 emissions and export diversification (Shahzad et al., 2020).

2.2. *The rise of smart factories*

Within the Fourth Industrial Revolution, the development of smart factories has become one of its key aspects. These innovative facilities, characterized by advanced technology, automation, and data exchange, are transforming traditional manufacturing processes and revolutionizing the industry landscape. In this article, we will explore the concept of smart factories, their key features, and the advantages they offer in driving the next phase, i.e., the Industry 5.0 revolution.

What is a Smart Factory? a smart factory refers to a highly digitized and connected production facility that relies on modern technologies such as the Internet of Things (IoT), artificial intelligence (AI), machine learning, big data analytics, and robotics to optimize manufacturing processes. By integrating these technologies, smart factories are able to achieve greater flexibility, efficiency, and adaptability, which enables them to respond to market changes and customer demands more effectively (Chen et al., 2023).

Key Features of Smart Factories are described below:

Interconnectivity: smart factories rely on seamless communication between machines, devices, and systems through IoT, enabling real-time data exchange and collaboration. This interconnectivity allows for better decision-making and process optimization (Kuo and Wu, 2023).

Data-driven decision-making: By harnessing the power of big data analytics, AI, and machine learning, smart factories can analyze vast amounts of data to optimize operations, predict potential problems, and improve overall efficiency.

Automation and robotics: Smart factories utilize advanced robotics and automation technologies to perform tasks with minimal human intervention. This not only enhances productivity but also reduces the chances of human error and ensures consistent product quality.

Adaptive manufacturing: by leveraging digital technologies, smart factories can quickly adapt to changes in demand, customer requirements, and market conditions. This enables them to produce customized products with shorter lead times and lower costs.

Enhanced supply chain management: smart factories can monitor and control their entire supply chain through real-time data exchange, which leads to better coordination, reduced lead times, and improved inventory management.

2.3. Advantages of Smart Factories in Industry 5.0

Increased productivity: with advanced automation and real-time data analysis, smart factories can optimize their processes and eliminate bottlenecks, resulting in higher productivity levels [44–46].

Improved product quality: the use of AI, machine learning, and robotics helps ensure consistent product quality by minimizing human errors and detecting defects early in the production process.

Cost reduction: the efficiency and adaptability of smart factories lead to reduced operational costs, energy consumption, and waste generation.

Enhanced competitiveness: by embracing digital technologies and developing smart factories, companies can stay ahead of the competition in the fast-paced, ever-evolving new Industry 5.0 landscape (Noh et al., 2023).

Sustainability: smart factories promote sustainable practices by optimizing resource use, minimizing waste, and reducing environmental impacts.

The development of smart factories has paved the way for a more efficient, adaptive, and sustainable manufacturing landscape within the collaborative Industry 5.0 revolution. As companies continue to invest in advanced technologies and embrace the smart factory concept, they can unlock new opportunities for growth, innovation, and competitiveness in the global market (Schweitzer et al., 2023) that embodies greater collaboration between smart technologies and humans.

2.4. CO_2 Emissions and Climate Change

A substantial body of literature has focused on the relationship between CO2 emissions and climate change, emphasizing the role of greenhouse gas emissions in global warming and the need for mitigation strategies (IPCC, 2014; Stern, 2007) (Stjepanovic et al., 2022). Researchers have investigated the sources of CO_2 emissions, including energy production, industrial processes, and transportation, and their impacts on the environment (Friedlingstein et al., 2019; Peters et al., 2017). These studies have laid the groundwork for understanding the significance of reducing CO_2 emissions in addressing climate change.

Another strand of literature has examined the impact of fiscal decentralization on environmental outcomes, with mixed findings. Some studies suggest that fiscal decentralization can lead to better environmental outcomes due to increased local autonomy, accountability, and innovation (Oates, 1999; Sigman, 2003). In contrast, others argue that fiscal decentralization might exacerbate environmental problems due to inter-jurisdictional competition, free-riding, and weak regulatory capacity at the local level (Banzhaf & Oates, 2013; Lockwood, 2006). This inconsistency in the literature highlights the need for further research to better understand the relationship between fiscal decentralization and environmental outcomes, particularly CO_2 emissions.

Some studies have explored the potential nonlinear relationship between fiscal decentralization and CO_2 emissions, finding evidence of a U-shaped relationship. For instance, Wang et al. (2018) argue that there is a critical point at which the impact of fiscal decentralization on CO_2 emissions switches from positive to negative. Similarly, Akhmetova et al. (2021) find that decentralization initially increases CO2 emissions, but after a certain threshold, further decentralization led to a decrease in emissions.

A few studies have also examined the role of regulatory factors in shaping the relationship between fiscal decentralization and CO2 emissions. For example, Shen et al. (2019) investigate the moderating effect of environmental regulations on the decentralization-emissions relationship and find that stringent environmental regulations can reduce the adverse impact of decentralization on emissions.

While the existing literature has provided valuable insights into the relationship between CO_2 emissions and fiscal decentralization, several gaps remain. First, there is a need for more empirical studies examining the U-shaped relationship between fiscal decentralization and CO_2 emissions, as the evidence is still limited and inconclusive. Second, research on the regulatory effect on this relationship remains sparse, and a more comprehensive analysis of various regulatory factors, such as environmental policies, market-based mechanisms, and institutional quality, is warranted.

By addressing these gaps, this paper aims to contribute to the literature by providing a more nuanced understanding of the impact of fiscal decentralization on carbon emissions, considering both the U-shaped relationship and the regulatory effect. This study will enable policymakers to better design and implement fiscal decentralization policies that promote environmental sustainability and mitigate climate change.

Therefore, the paper seeks to understand the determinants of CO_2 emission in the fifth industry revolution for a sustainable economy. The section below describes how the relationship between renewable consumption, FDI inflows, economic growth, and environmental pollution is complex and can vary depending on the specific context and conditions.

Renewable Consumption and Economic Growth: The use of renewable energy sources can lead to reduced dependence on non-renewable energy sources, such as fossil fuels, which can contribute to sustainable economic growth. Moreover, renewable energy technologies are becoming more cost-effective, which can create new opportunities for economic development and job creation in the renewable energy sector (Shang et al., 2022).

FDI Inflows and Economic Growth: FDI inflows can contribute to economic growth by bringing in capital, technology, and expertise, which can create new industries, expand existing ones, and increase productivity. This can lead to job creation, higher wages, and increased consumption, which can further stimulate economic growth (Thu et al., 2022).

FDI Inflows and Renewable Consumption: FDI inflows can also contribute to the development of renewable energy by providing the necessary capital, technology, and expertise. This can lead to increased investment in renewable energy projects and the adoption of new renewable energy technologies (Thu et al., 2022).

Environmental Pollution: Economic growth and FDI inflows can increase environmental pollution, particularly if there is a heavy reliance on non-renewable energy sources. However, the use of renewable energy sources can help reduce environmental pollution and promote sustainable development (Tsai et al., 2021).

In addition, the relationship between renewable consumption, FDI inflows, economic growth, and environmental pollution is complex and depends on a range of factors. However, the adoption of renewable energy technologies can contribute to sustainable economic growth and

Table 1
Analysis of the variables in the regression model.

Variable	Obs	Mean	Std. Dev	Min	Max
Country	Vietnam				
Code	VNM				
Year	23	2011	6.78233	2000	2022
CO_2 million tons	23	151.1594	69.23378	52.601	269.7901
Innovation	23	3.67×10^{10}	4.38×10^{10}	1.83×10^{10}	1.34×10^{11}
Renewable Consumption	23	124.723	77.68318	40.419	288.9172
FDIUS	23	9.39×10^{9}	7.34×10^{9}	1.30×10^{9}	2.80×10^{10}
GDPUS	23	1.52×10^{11}	1.05×10^{11}	3.12×10^{10}	3.88×10^{11}

(Source: compiled by authors)

help reduce environmental pollution (Usman et al., 2022).

Innovations in technology and business practices can help reduce carbon dioxide emissions by making production and consumption more efficient and sustainable. For example, the development of renewable energy technologies such as solar, wind, and hydro power, can help reduce the reliance on fossil fuels and reduce emissions (Van Thanh, 2022).

Renewable consumption refers to the use of renewable energy sources in daily life, such as using solar panels to generate electricity for homes or driving electric cars. Increased renewable consumption can help reduce carbon dioxide emissions by reducing the demand for fossil fuels (Visconti et al., 2022).

Carbon dioxide emissions are a major contributor to climate change and global warming. They are produced by burning fossil fuels such as coal, oil, and gas, as well as through industrial processes and land use changes. Therefore, reducing carbon dioxide emissions is crucial for mitigating the impacts of climate change (Wang and Wang, 2023).

The nexus of innovations, renewable consumption, and carbon dioxide emissions is important because it highlights the interconnectedness of these factors and the need for coordinated efforts to address them. By promoting and investing in innovative technologies and encouraging the use of renewable energy sources, we can reduce carbon dioxide emissions and create a more sustainable future (W. Wang et al., 2022; X. Wang et al., 2022).

Innovations can play a key role in reducing carbon dioxide emissions. For example, new technologies can make production processes more efficient, reduce waste, and optimize energy use. In addition, innovations in transportation can help reduce emissions by increasing the efficiency of vehicles and encouraging the use of low-emission alternatives like electric cars or public transportation (Khan et al., 2022).

Furthermore, the increasing use of renewable energy sources can have a significant impact on reducing carbon dioxide emissions. Renewable energy sources are sustainable and produce minimal greenhouse gases, making them an excellent alternative to fossil fuels. The deployment of renewable energy technologies has been growing rapidly in recent years, with solar and wind power being two of the fastest growing sources of electricity in the world. As more countries and companies shift towards renewable energy, the reduction of carbon dioxide emissions is becoming more achievable (Wei et al., 2023).

Another way to reduce carbon dioxide emissions is by promoting sustainable consumption patterns. This includes encouraging the use of products that are made with renewable materials, are energy-efficient, and have a low carbon footprint. Consumers can also make a difference by reducing their use of products that produce large amounts of carbon dioxide emissions, such as meat, dairy, and processed foods. By choosing to consume sustainably, individuals can contribute to reducing their own carbon footprint and encouraging others to do the same (Wu et al., 2021).

Thus, this paper used the linear model to study a connection between environmental pollution and renewable consumption, FDI inflows, economic growth, innovation. The following section details the data and research methods.

3. Data and research methodology

3.1. Data Collection

We categorized data based on the World Bank and Vietnam General Statistics Office indicators from 2000 to 2022, such as the following:

Vietnam's environmental pollution is calculated by its CO_2 emissions, which are measured as a unit in millions of tons annually and by capital. In spite of the fact environmental pollution can affected by air pollution, water pollution, waste material from individuals and firms, pollution from the industrial zone. However, in this paper there is the assumption that the greater the CO_2 emission is, the greater the environmental pollution has (Thu, Huong et al., 2022).

Innovation or high technology export value uses US dollar to measure the export of high-tech goods. In general, the greater the investment of technology is, the greater the export of goods has. This paper is assumed that the export of goods measure the innovation in spite of the fact that there are some limitation of this assumption.

The quantity of green energy produced annually, such as from wind electricity, water electricity, and solar electricity sources, is referred to as renewable consumption (TWh). Renewable consumption is also measured in relation to total energy consumption in percentage.

FDI inflows are measured by the US dollar.

GDP is measured US dollar and presented the economic growth.

An analysis of the independent and dependent variables in the linear model and panel data method are presented in Table 1. The paper uses the STATA software 16.0 for analysis and regression (Thu et al., 2022).

There were 23 observations compiled as data that were collected in Vietnam in the period from 2000 to 2022. CO_2 emissions (dependent Y) had an average value of 151.1594 million tons per one year, the minimum value of 52.601 million tons in 2000, and the maximum value of 269.7901 million tons in 2022. The ratio of CO_2 emissions to total energy was 19.2% on average, with the lowest ratio of 12.8% in 2004 and the highest of 24.2% in 2017.

Innovation (as measured by the high-tech export of goods and services) composed independent variable X_1 with a mean value of USD 36.7 billion, the lowest value of USD 18.3 billion in 2000, and the highest value of USD 134 billion in 2022.

Independent variable X_2 was the consumption of renewable energy with a mean of 124.723 TWh, a lowest value of 40.419 TWh in 2000, and a highest value of 288.9172 TWh in 2022.

Independent variable X_3 was the FDI inflows with a mean of 9.39 billion US dollars, a lowest value of 1.3 billion US dollars in 2000, and a highest value of 28 billion US dollars in 2022.

Independent variable X_4 was the GDP of Vietnam with mean of 152 billion US dollars, a lowest value of 31.2 billion US dollars in 2000, and a highest value of 388 billion US dollars in 2022.

3.2. Research Methodology

The research model employed in this study is as follows:
$Y = f(X_1, X_2, X_3, X_4\ldots)$, where the variables are defined as follows:
Y: CO2 emissions, serving as a measure of environmental pollution;.

X_1: innovation;.
X_2: renewable energy consumption;.
X_3: FDI inflows;.
X_4: Economic growth;.

This paper focuses on CO2 emissions as the dependent variable, with explanatory variables consisting of innovation, renewable energy consumption, FDI inflows and economic growth.

Previous studies, including An and other recent works, have explored energy consumption as an explanatory variable for CO2 emissions using an emissions-energy-output (EEO) model (An et al., 2023). However, some recent studies have highlighted econometric issues associated with using energy consumption as a determinant of carbon emissions. It argues that the use of energy consumption distorts the parameters' interpretation and exaggerates the estimation of the carbon Kuznets curve (CKC). Jahanger et al extend critique, pointing out that the energy variable is redundant and introduces systematic volatility in the model's parameters, potentially leading to an overestimation of the turning point of the Kuznets curve (Jahanger et al., 2023; Johnathon et al., 2023). Taking these critiques and recent works into consideration, this research adopts three approaches to draw more robust and valid conclusions, while also considering the "carbon intensity" interpretation of the model.

Following the recent literature, panel data methods are employed to investigate the relationships between the studied factors. Panel data methods help address issues related to relatively short time series data and enable a better understanding of the energy-environment nexus. The use of panel data allows for the consideration of heterogeneity across regions and control for region-specific effects. The sample is limited to Vietnam based on the classification provided by the World Development Bank (2022).

To estimate the relationships, this paper employs the Cobb-Douglas function and utilizes ordinary least squares (OLS). This method is straightforward to apply and allows for the determination of the independent variables that influence CO2 emissions in Vietnam (Balsalobre-Lorente et al., 2023; Balsalobre-Lorente et al., 2023; Balsalobre-Lorente et al., 2023).

The research assumes the CO2 emissions function using the Cobb-Douglas function, which is represented by Eq. (1a):

$$Y = AX_1\text{^}aX_2\text{^}bX_3\text{^}cX_4\text{^}d + e(i,t) \quad (1a)$$

As an alternative, the study also considers the logarithmic transformation of both sides of the equation, resulting in Eq. (1b):

$$Ln(Yi,t) = A + aLn(X1i,t) + bLn(X2i,t) + cLn(X3i,t) + dLn(X4i,t) + ei,t \quad (1b)$$

This paper also used the function of equation (1c) as follows:

$$Y = Bo + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + \varepsilon \quad (1c)$$

Specifically, this research had the following hypotheses:

H_1. : Innovations or high-technology exports positively influence carbon dioxide (CO_2) emissions.

H_2. Renewable energy consumption negatively influences carbon dioxide (CO_2) emissions.

H_3. : FDI inflows positively influence carbon dioxide (CO_2) emissions.

Table 2
Description of variables in the linear regression model.

Variable	Definition	Expectation
X_1	Innovations or high-technology exports	+
X_2	Renewable energy consumption or green energy	-
X_3	FDI inflows	+
X_4	Economic Growth	+

(Source: compiled by authors)

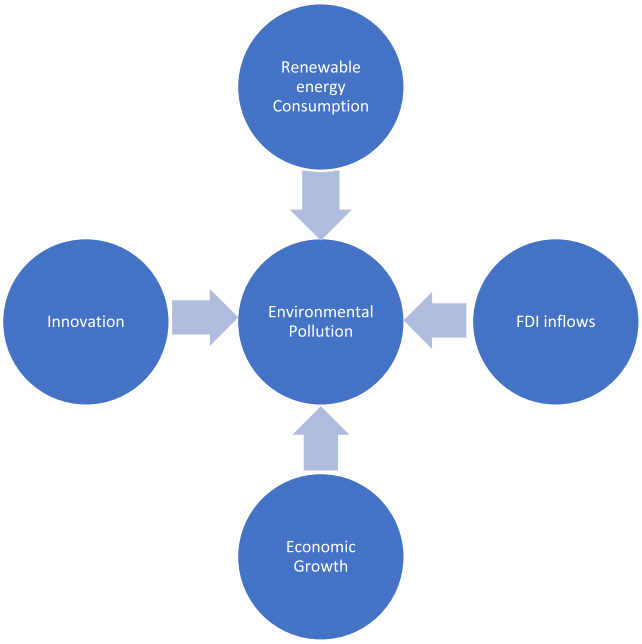

Fig. 1. Nexus between innovation, renewable energy consumption, FDI inflows, economic growth regarding environmental pollution. (Source: compiled by authors).

H_4. : Economic growth positively influences carbon dioxide (CO_2) emissions.

The independent variables of the research model are presented in Table 2.

The definition and symbol + /- in the Table 2 means that the innovation positively affects to the environmental pollution; the renewable energy consumption negatively affects to environmental pollution; the FDI inflows positively affect to environmental pollution and economic growth positively affects environmental pollution.

The research model used in this study is shown below in Figure 1.

The study model used is detailed in the following section.

The function $Y = f(X_1, X_2, X_3, X_4\ldots)$ was used, in which the dependent and independent variables were the following:

Y: the CO_2 emissions measured by the million tons, which present environmental pollution; these data were collected based on the World Bank reports. This study assumed that the higher the CO2 emissions, the higher the environmental pollution in Asian countries. Although environmental pollution can be caused by various other sources, such as waste material, industrialization, and water pollution, this paper only collected data on CO_2 emissions to measure environmental pollution.

X_1: the independent variable of innovation or high-technology export value, which measured by trillions US dollars; perhaps, there is many ways to measure the innovation. In this paper, the article is assumed that the greater the technology export value is, the greater the innovation in Vietnam has.

X_2: the independent variable of renewable energy consumption, which measured by TWh;.

X_3: the independent variable of FDI inflows, which measured by trillions US dollars; the study is assumed that the simple standards about the environment in Vietnam. Therefore, Vietnam will be the heaven for the polluted FDI inflows from the developed countries. In conclusion, the greater the FDI inflows are, the greater the environment pollution has in Vietnam.

X_4: the independent variable of economic growth, which measured by trillions US dollars;.

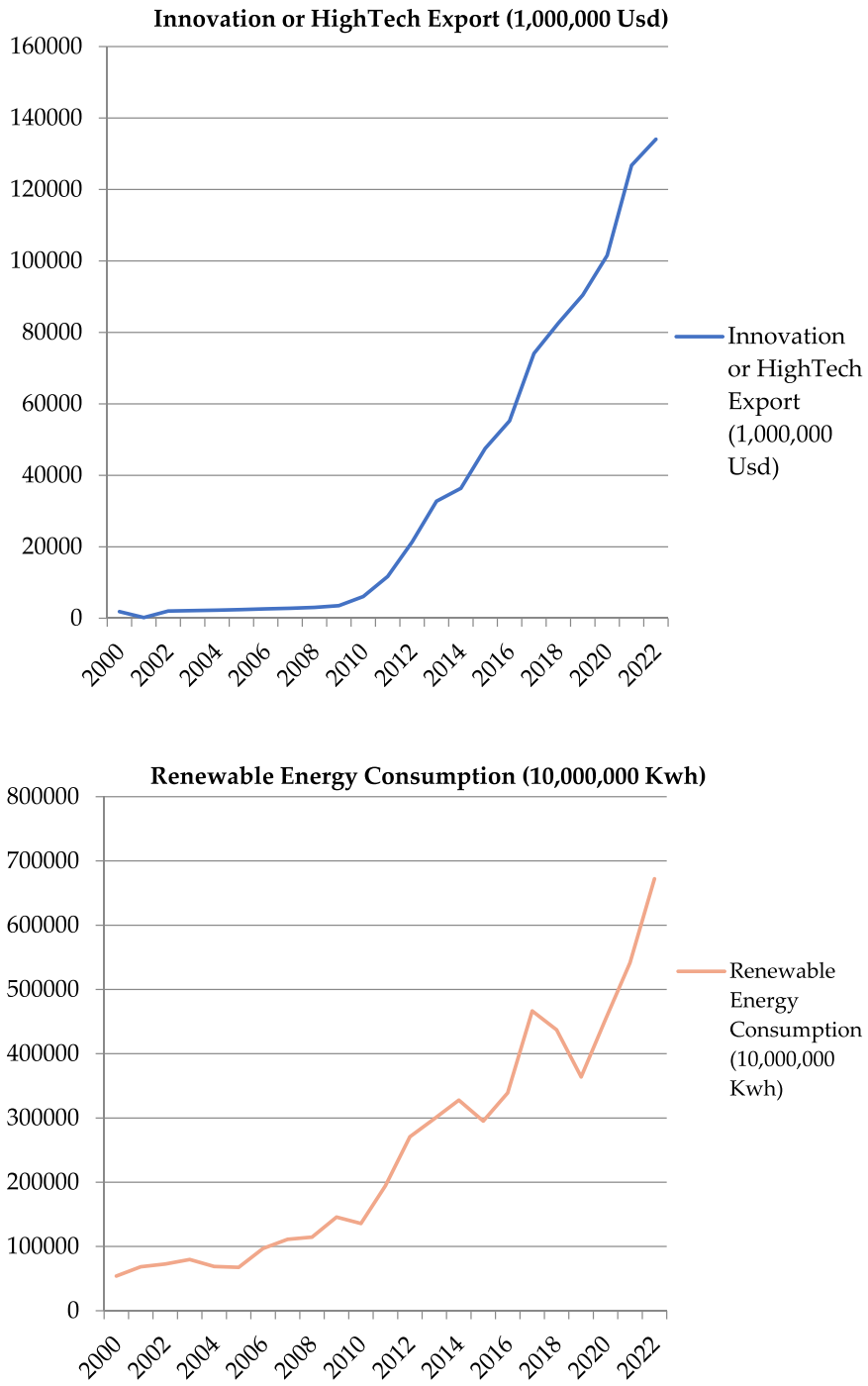

Fig. 2. The innovations (X_1) and green electricity (renewable energy consumption) (X_2) for the period from 2000 to 2022 in Vietnam. (Source: compiled by authors).

4. Results

The renewable consumption and high technology export value or innovation is presented in Figure 2.

A graph of X_3 – FDI inflows, X_4 – GDP of Vietnam from 2000 to 2022 is shown in Figure 3.

The renewable consumption compared to the total energy consumption is presented in Figure 4.

Table 3 displays the regression analysis results of the innovation (X1) renewable energy (X2), FDI inflows (X3), Gross Domestic Product (X4) and CO2 emission (Y) for the period from 2000 to 2022 in Vietnam. According to the adjusted R-squared value of 0.8762, the CO_2 emission can be explained by 87.62% of the independence variable change.

The nexus of the innovation and CO_2 emission is demonstrated by the *p-value* of 0.000. Therefore, hypothesis 1 is not rejected.

We used the following Equation (2) to determine the elasticity of CO_2 emission to innovation in 2022 as follows:

$$Ex_1 = 1{\cdot}47\times10^{-11} \text{ x } 1{\cdot}34\times10^{11}/2{\cdot}950 = 0{\cdot}6677 \quad (2)$$

According to these findings, CO_2 emissions will rise by 0.68% if high-technology goods and services exports increase by 1%. The empirical results suggest that Vietnam policymakers should place their focus on the export of environmentally friendly high-technology goods and services. The nexus of CO_2 emissions and the high-tech export of goods and

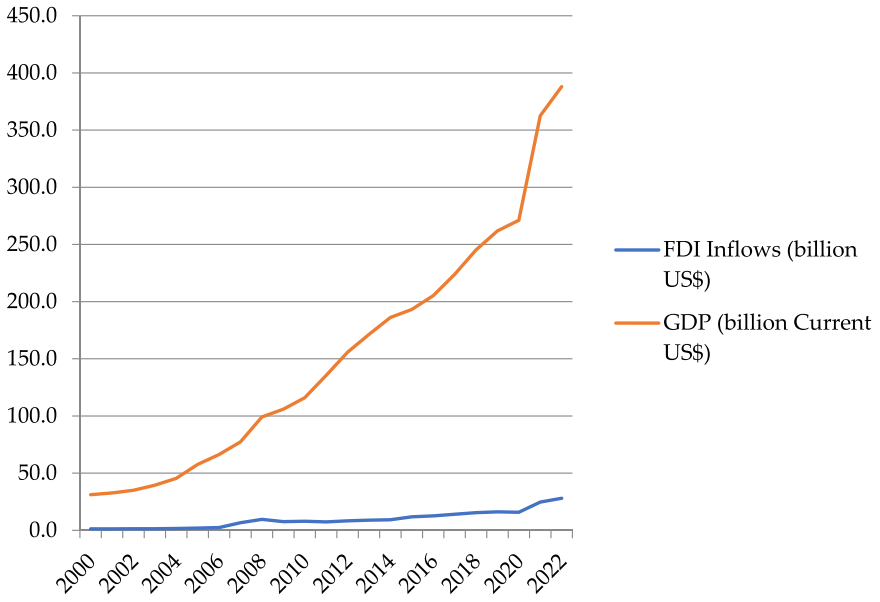

Fig. 3. The FDI inflows (X_3) and GDP (X_4) for the period from 2000 to 2022 in Vietnam. (Source: compiled by authors).

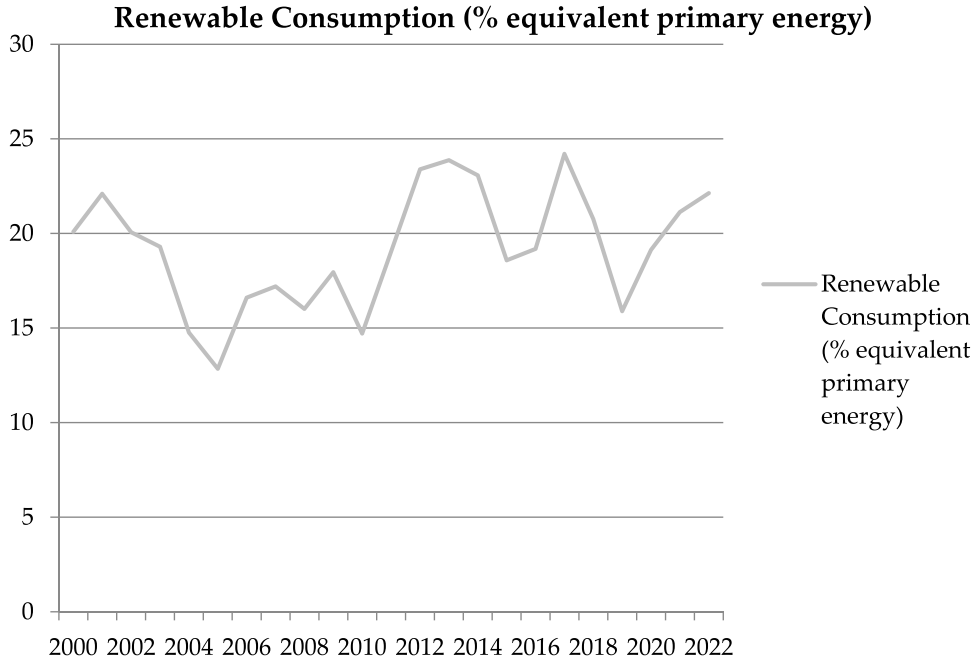

Fig. 4. Renewable consumption (% equivalent primary energy) for the period from 2000 to 2022 in Vietnam. (Source: compiled by authors).

services will become negative as developed countries implement this strategy long term, and the more goods and services are exported, the lower CO_2 emissions will be. The nexus of CO_2 emissions and innovations will perhaps remain greater than zero for a short period due to the attraction of old, cheap technology that pollutes the environment.

Table 3 displays the regression analysis results for carbon dioxide (CO_2) emissions (Y) and renewable consumption (X_2). The relationship between green energy consumption and CO_2 emissions is shown by the *p-value* of 0.000. Therefore, the hypothesis 2 is not rejected.

Equation (3) allowed us to determine the elasticity of CO_2 emissions to green energy consumption in 2022.

$$Ex_2 = -0{\cdot}0677 \times 22{\cdot}1/2{\cdot}95 = -0{\cdot}51 \quad (3)$$

According to these findings, the CO_2 emissions per capita in Vietnam would decrease by 0.51% if renewable consumption were to increase by 1%. These figures demonstrate that Vietnam's environmental pollution has been significantly reduced over time by renewable consumption. The findings suggest that these issues should be re-examined. Vietnam devoted more than two decades to expanding its use of renewable energy. Taking the environment into account and contributing to a cleaner environment are necessary actions. The analysis and empirical results of this paper denote the recommendation that Vietnamese policymakers place great emphasis on green energy consumption for long-time development. The nexus between CO_2 emissions and green energy consumption is significantly negative.

To achieve sustainable development, Vietnam needs to continue

Table 3
Regression analysis model of innovation (X_1), renewable energy (X_2), FDI inflows (X_3), Gross Domestic Product (X_4) and CO_2 emission (Y) for the period from 2000 to 2022 in Vietnam.

R-squared:						
Within = 0.8745						
Between = 0.7473						
Overall = 0.7453						
corr(u_i, Xb) = 0.4800	Prob > F	=	0			
Ln CO2 emissions	Coefficient	Std. err.	t	P > t	[95% conf.	interval]
Ln Innovation	0.6677801	0.0695059	9.7	0.000 * **	0.5372553	0.8109048
Ln Renewable Energy	0.5127071	0.0879156	2.32	0.021 * *	0.0306422	0.376772
Ln FDI inflows US	1.3942662	0.027156	2.23	0.047 * *	0.1077238	0.0008086
Ln GDP Current US	1.2611127	0.0379642	1.74	0.083 *	-0.008621	0.1408465
Constant	3.0594665	1.064255	1.23	0.000 * **	4.04167	2.851628
Source	*SS*	*df*	*MS*	*Number of obs*	*= 23*	
Model	9.13958587	1	9.13958587	Prob > F	= 0.0000	
Residual	1.22515668	21	0.058340794	R-squared	= 0.8818	
				Adj R-squared	= 0.8762	
Total	10.3647426	22	0.471124662	Root MSE	= 0.24154	
CO_2 per capital ton	Coef.	Std. Err.	t	P > |t|	[95% Conf. Interval]	
Innovation	1.47×10^{-11} * **	1.18×10^{-12}	12.52	0.000	1.23×10^{-11}	1.72×10^{-11}
Renewable Energy	-0.0677523 * **	0.0119065	-5.69	0.000	-0.0925888	-0.0429159
FDI inflows US	1.34×10^{-8} * **	8.62×10^{-10}	15.56	0.000	1.16×10^{-8}	1.52×10^{-8}
GDP Current US	8.83×10^{-10} * **	3.89×10^{-11}	22.69	0.000	8.03×10^{-10}	9.64×10^{-10}
_Cons	3.0628472	0.0663579	17.01	0.000	0.9904733	1.266471

* , * *, * ** represent 10%, 5% and 1% significance, respectively
(Source: computed by Stata 16.0 software)

developing more renewable energy to reduce CO_2 emissions per capita and maintain a clean environment. The Vietnamese government has had success in the development of green energy and protecting environmental sustainability.

Table 3 also displays the regression analysis results for carbon dioxide (CO_2) emissions (Y) and FDI inflow (X_3). The relationship between FDI inflows and CO_2 emissions is shown by the *p-value* of 0.000. Therefore, the hypothesis 3 is not rejected.

Equation (4) allowed us to determine the elasticity of CO_2 emissions to FDI inflows in 2022.

$$Ex_3 = 1{\cdot}34\times10^{-8} \times 28\times10^{9}/269{\cdot}79 = 1{\cdot}39 \quad (4)$$

The empirical results show that the relationship between the FDI inflows and environmental pollution is positive. If the FDI inflows up 1% then the environmental pollution up 1.39%. It means that the Vietnamese government should attract more the green FDI to protect the environment in the future. In the past, Vietnam attract so much the polluted FDI inflows with low technology and increase the CO_2 emission.

Table 3 also displays the regression analysis results for carbon dioxide (CO_2) emissions (Y) and GDP (X_4). The relationship between GDP and CO_2 emissions is shown by the *p-value* of 0.000. Therefore, the hypothesis 4 is not rejected.

Equation (5) allowed us to determine the elasticity of CO_2 emissions to GDP in 2022.

$$Ex_4 = 8{\cdot}83\times10^{-10} \text{ x } 388\times10^{9}/269{\cdot}79 = 1{\cdot}26 \quad (5)$$

The empirical results show that the relationship between the GDP and environmental pollution is positive. If the GDP is up 1% then the environmental pollution is up 1.26%. The results in this paper show that the economic growth much affects the environment pollution in Vietnam for a long time. The Vietnam government focused on the economic growth for more than 40 year and make the environment are more polluted. Nowadays, Vietnam need the green growth and sustainable development.

Based on the regression above, the articles have the function in Eqs. (6a) and (6b) as follows:

$$Ln(Yi,t) = 3{\cdot}06 + 0{\cdot}667Ln(X1i,t) - 0{\cdot}51Ln(X2i,t) + 1{\cdot}39Ln(X3i,t) + 1{\cdot}26Ln(X4i,t) + ei,t \quad (6a)$$

$$Y = 3{\cdot}06 + 1{\cdot}47\times10^{-11}X_1 - 0{\cdot}0677523X_2 + 1{\cdot}34\times10^{-8}X_3 + 8{\cdot}83\times10^{-10}X_4 + ei,t \quad (6b)$$

The Eqs. (6a) and (6b) show that if X_1= 0, X_2= 0, X_3= 0 then the CO_2 emission = 3.06 million ton. This equation also shows the slope of Y to X_1= 1.47, the slope of Y to X_2= −0.067, the slope of Y to X_3= 1.37, the slope of Y to X_4= 8.83;.

These results help to compute the elasticity. Therefore, the results show that if the innovation up 1% then the CO_2 emission up 0.67%; if the renewable energy consumption up 1% then the CO_2 emission down 0.51%; if the FDI inflows up 1% then the CO_2 emission up 1.39%; if the GDP up 1% then the CO_2 emission up 1.26%;.

5. Conclusions and Recommendations

Open innovation is a concept that emphasizes the importance of looking beyond a country's internal resources for innovation and ideas. Open innovation has the potential to play a crucial role in reducing carbon dioxide emissions and addressing climate change. Tackling this global challenge requires innovative solutions that go beyond the capabilities of individual companies or industries. Open innovation can foster collaboration, share knowledge, and leverage diverse expertise to accelerate the development and implementation of sustainable technologies and practices. How open innovation can contribute to reducing carbon dioxide emissions:

Open innovation encourages collaboration between industries that may not traditionally work together. For example, energy companies can collaborate with transportation companies, technology firms, and research institutions to develop integrated solutions that reduce emissions across sectors. Through open innovation, companies and organizations can openly share their successful strategies for reducing carbon emissions. This sharing of best practices allows others to learn from each other and implement effective measures more rapidly.

Open innovation can bridge the gap between academic research and practical implementation. By collaborating with universities and research institutions, companies can access cutting-edge research on renewable energy, carbon capture, and other emission-reduction technologies. Open-source projects can drive innovation in sustainable technologies. By openly sharing data, algorithms, and software related to carbon capture, energy efficiency, and renewable energy, developers

and organizations worldwide can contribute to and benefit from collective knowledge.

Open innovation can foster the creation of startups focused on sustainability. Large companies can provide resources, mentorship, and funding to these startups, enabling the development of disruptive technologies that can significantly impact carbon emissions. Climate change is a global challenge that requires international cooperation. Open innovation allows companies from different countries to collaborate, share ideas, and collectively address the issue on a global scale. Open innovation involves engaging customers and communities in the innovation process. Understanding their needs and concerns related to carbon emissions can lead to the development of more sustainable products and services.

Open innovation can help companies and policymakers work together to design effective regulations and incentives that promote sustainable practices and technologies. Open innovation can also support the development of carbon offset projects, such as reforestation initiatives or carbon capture and storage projects, by facilitating partnerships and investments.

It's important to acknowledge that open innovation in reducing carbon dioxide emissions comes with challenges, including intellectual property concerns, competitive dynamics, and the need for effective communication and collaboration among stakeholders. However, by embracing open innovation principles, companies and organizations can unlock new opportunities for sustainable development and contribute to the global efforts to combat climate change.

The nexus between innovation, renewable energy, FDI inflows, economic growth, and carbon dioxide emission is a complex web of interrelated factors that shaped the sustainable development of countries during the fifth industrial revolution. A detailed discussion of this nexus involves understanding how each component interacts with the others, and the implications for sustainable growth, climate change, and policy interventions.

Collaboration between humans and technological innovations, particularly in Industry 5.0, can drive the development and adoption of renewable energy sources, energy-efficient processes, and sustainable practices. Innovations such as smart grids, energy storage systems, and advanced materials can improve the efficiency and effectiveness of renewable energy generation, transmission, and distribution. Moreover, innovation can lead to new business models and market opportunities, fostering economic growth while contributing to the reduction of CO2 emissions.

The increased adoption of renewable energy sources, such as solar, wind, hydro, and bioenergy, is vital for mitigating climate change and reducing CO2 emissions. Renewable energy can help countries diversify their energy mix, reduce dependency on fossil fuels, and enhance energy security. The growth of renewable energy sectors can also create new jobs and stimulate economic growth (Balsalobre-Lorente et al., 2023).

Foreign direct investment (FDI) can play a crucial role in promoting innovation and renewable energy adoption. FDI inflows can facilitate technology transfer, provide financial resources for research and development, and support the construction and expansion of renewable energy infrastructure. FDI can also contribute to economic growth by generating employment opportunities and fostering the development of local industries (Balsalobre-Lorente et al., 2023).

The relationship between economic growth and CO2 emissions is complex. Traditional economic growth has often been associated with increased energy consumption and emissions. However, with the transition to a sustainable economy, the focus is on decoupling economic growth from CO2 emissions. This involves promoting energy efficiency, renewable energy adoption, and low-carbon technologies to achieve sustainable growth (Balsalobre-Lorente et al., 2023).

CO2 emissions are the primary driver of climate change, and reducing these emissions is critical for mitigating its impacts. The nexus between innovation, renewable energy, FDI inflows, and economic growth is essential in understanding how countries can transition towards low-carbon development and achieve carbon neutrality. Effective policy interventions and incentives can encourage the adoption of low-carbon technologies, stimulate investment in renewable energy, and promote sustainable economic growth (Balsalobre-Lorente et al., 2023).

To leverage the nexus effectively within the fifth Industrial Revolution, policymakers need to consider the following aspects:

Governments need to implement policies that promote innovation, renewable energy adoption, and FDI inflows while addressing CO2 emissions. These policies can include R&D support, feed-in tariffs, tax incentives, and carbon pricing mechanisms (Balsalobre-Lorente et al., 2023).

Building and upgrading infrastructure for renewable energy generation, transmission, and distribution is crucial for increasing renewable energy adoption and achieving sustainable growth (Balsalobre-Lorente et al., 2023; Can, Balsalobre-Lorente et al., 2023; Can et al., 2020).

Developing human capital and skills in renewable energy technologies and green innovation is essential for fostering a sustainable economy.

International cooperation, technology transfer, and knowledge sharing among countries can help accelerate the adoption of renewable energy sources and low-carbon technologies.

Continuous monitoring and evaluation of the nexus between innovation, renewable energy, FDI inflows, economic growth, and CO2 emissions can help identify potential synergies and trade-offs, and inform evidence-based policy decisions.

According to the statistical results of CO_2 emissions data, several nations have maintained stable CO_2 emission levels. However, from 2020 to 2022, CO_2 levels in Vietnam continued to rise. This demonstrates that the Vietnamese government has not yet successfully implemented long-term policies for green electricity and a green economy as have developed countries with low carbon emissions. However, other nations have placed great emphasis on and succeeded in developing a green economy. These countries will help Vietnam to learn lessons in the future. Vietnam has grown its economy by exporting high-tech goods, attraction of the FDI inflows, economic growth that pollute the environment. Increasing the consumption of renewable energy sources has the potential to preserve the environment (Thu et al., 2022).

The statistical analysis of CO2 emissions data reveals that several countries have achieved stable levels of emissions. However, Vietnam has experienced an increasing trend in CO2 emissions from 2020 to 2022. This indicates that while other countries have successfully focused on and implemented policies towards a green economy, Vietnam, as a low-carbon developed economy, has not effectively pursued such strategies. The country has developed its economy by attracting FDI with high pollution potential and placing a strong emphasis on increasing GDP without adequate environmental protection measures (Thu et al., 2022).

In the case of Vietnam, the continuous rise in CO2 emissions in recent years suggests a tendency to import industries that heavily rely on fossil energy, such as thermal power, with outdated technologies. This also implies that the utilization of clean energy sources in Vietnam is less effective compared to other countries in the region. Given the abundant availability of fossil fuel resources in Vietnam, there is a tendency to fully exploit these resources without a sense of urgency for promoting clean energy development.

This study demonstrates that CO2 emissions have a positive impact on the rate of economic growth. The findings suggest that green growth will have long-term implications for the country's economic growth. Additionally, the study confirms that heavy reliance on fossil energy (coal, gas) or heavy industries will lead to economic decline in the future. Furthermore, the impact of CO2 emissions is observed to occur after a lag of 1 year, meaning that the released CO2 affects the economy with a time delay, and there is no immediate impact of CO2 emissions on the economy.

Moreover, the research results indicate that FDI has an immediate

impact on economic growth, and this impact persists after 1 year. The rapid implementation of FDI in the host country is observed within one year, leading to increased promotion of construction materials and equipment for project development. The study highlights the importance of FDI for economic growth; however, it emphasizes the need to carefully select investment partners and develop policies and solutions to enhance the attraction and efficiency of FDI. This involves improving the legal framework, revising investment incentive policies in a favorable direction, ensuring consistency, transparency, and public participation. It is also crucial to adjust and supplement mechanisms and policies to encourage domestic and foreign private investors to invest in infrastructure development and to attract suitable and high-tech projects from other countries, especially developing nations like Vietnam.

Vietnam should implement policies to attract FDI as a means to stimulate domestic growth, as this source of capital not only has an immediate positive impact on economic development but also provides sustained growth for at least one year. Additionally, to boost future GDP growth, the government should reconsider the reliance on fossil fuels and prioritize sustainable economic development rather than solely promoting economic production activities at any cost.

Vietnam's exports from industries that rely heavily on fossil fuels (e.g., thermal power) have increased in recent years as CO_2 levels have continued to rise in using technology that is out of date. This also suggests that Vietnam's use of clean energy is not as effective as its use in developed countries. Vietnam has many advantages with respect to the develop of clean energy such as wind, water, and solar electricity compared with other countries in the region. However, it is simpler to make full use of abundant fossil fuel resources because of their benefits. Therefore, there has been no immediate need to promote the development of clean energy.

This study demonstrates that Vietnam's FDI inflows, economic growth and export of high-tech goods make the CO_2 emissions increase and as a results, it make the environment in Vietnam is much polluted. Similar to the findings of Le et al. (Le et al., 2022), our findings suggest that the country's economic expansion will be impacted over the long term by green growth. At the same time, research confirms that heavy industry or high fossil fuel consumption will hurt the economy over a long-term period. Moreover, when CO_2 is released into the environment, it only has an effect on the economy after one year. Thus, CO_2 emissions have no immediate effect on the economy, and the economy has not shown any signs of being affected.

Additionally, the findings of this research indicate that the lower the consumption of renewable energy sources, the greater the CO_2 emissions per person. Wind, solar, and water electricity are examples of clean energy sources that are advantageous in Vietnam. Vietnam needs to protect the environment and decrease carbon dioxide (CO_2) emissions. Empirical findings demonstrate that the Vietnamese government should increase its investments in renewable electricity. Over the past two decades, renewable energy development has reduced environmental impacts. In the future, the Vietnamese government must concentrate on the growth of green energy. To promote green energy, the government must take actions to establish a competitive electricity market. Additionally, in order to lay a solid foundation for the growth of the green energy market, the government must implement policies that encourage private investment in the construction of power transmission infrastructure.

Vietnam ought to enact policies that will encourage the green industry to attract FDI inflows, economic growth and export high-tech goods and services. Vietnam has been successful in attracting multinational corporations like Samsung, Apple, and Intel to innovate and export high-tech goods to other nations in recent years. To help stabilize the economy, Vietnam also uses foreign currency. However, the expansion of high-tech product exports results in an increase in CO_2 emissions. Green innovation and green industry ought to be the primary focus. As a result, investing in businesses that use a lot of energy is also not a good idea for long-term economic growth.

The nexus of renewable consumption, foreign direct investment (FDI) inflows, economic growth, innovation, and carbon dioxide emissions refers to the relationship between these factors and how they interact with one another.

Renewable consumption, as mentioned earlier, refers to the use of renewable energy sources such as solar, wind, and hydropower. FDI inflows refer to the investment by foreign entities in domestic companies and infrastructure. Economic growth refers to the increase in production and consumption of goods and services in a country. Innovation refers to the development and implementation of new technologies and processes that can improve efficiency and reduce environmental impact.

The nexus of these factors is important because they all play a role in shaping the path of a country's economic development and environmental sustainability. Renewable consumption can contribute to reducing carbon dioxide emissions and improving environmental sustainability. FDI inflows can bring in new technology and expertise to a country, which can lead to innovation and economic growth. Economic growth can provide a pathway towards poverty reduction and improvement in quality of life. Innovation can enable more efficient and sustainable production and consumption, which can help reduce environmental impact.

However, these factors are also interconnected and can have unintended consequences. For example, economic growth can lead to increased energy consumption and higher carbon dioxide emissions if sustainable practices are not implemented. FDI inflows can lead to environmental degradation if the investments are not made in a sustainable manner. Renewable consumption can be limited by the availability of resources and infrastructure. Innovation can be slowed down by a lack of investment and political will.

Therefore, it is important to have a comprehensive and coordinated approach to address the nexus of renewable consumption, FDI inflows, economic growth, innovation, and carbon dioxide emissions within Industry 5.0. This can involve policies and strategies that promote sustainable practices, encourage investment in renewable energy and innovation, and provide incentives for companies to reduce their carbon footprint. It is also important to have public awareness and engagement in order to create a sustainable and equitable future.

The positive nexus found between innovations and environmental pollution in Vietnam within Industry 5.0 represents a new contribution of this research. This study's empirical findings are opposite results of Khan et al. (H. Khan et al., 2022). The paper stated innovation and carbon neutrality relationship as hypothesis 1, the previous publication of modeling the effect of green technology innovation and renewable energy on carbon neutrality in N-11 countries: evidence from advance panel estimations. The previous paper refers to the green technology innovation and renewable energy on carbon neutrality in N-11 countries. In our paper, we referred to the relationship between innovation and renewable energy to CO_2 emission in Vietnam. In general, the difference of these issues in Vietnam is the positive relationship between innovation and carbon dioxide emission. The similar empirical results are the negative relationship between renewable energy and CO_2 emission in both Vietnam and N-11 countries. In future studies, Vietnam can be compared to other nations with respect to FDI inflows, economic growth and carbon dioxide (CO_2) emission in industry 5.0. The nexus of those factors and environmental pollution in developed and developing nations could also be studied through additional research in the future.

In conclusion, understanding the nexus between innovation, renewable energy, FDI inflows, economic growth, and CO_2 emissions can provide valuable insights for policymakers to design and implement effective strategies for promoting sustainable development and mitigating climate change within Industry 5.0.

Funding Statement

This research is funded by National Economics University Hanoi, Vietnam.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Declaration of Competing Interest

The authors declare no conflict of interest.

Data Availability

Not applicable.

References

Aghasafari, H., Aminizadeh, M., Karbasi, A., Calisti, R., 2021. CO_2 emissions, export and foreign direct investment: empirical evidence from Middle East and North Africa Region. J. Int. Trade Econ. Dev. 30 (7), 1054–1076. https://doi.org/10.1080/09638199.2021.1934087.

Al Afif, R., Ayed, Y., Maaitah, O.N., 2023. Feasibility and optimal sizing analysis of hybrid renewable energy systems: a case study of Al-Karak, Jordan. Renew. Energy 204, 229–249. https://doi.org/10.1016/j.renene.2022.12.109.

An, Y.-S., Kim, J., Joo, H.-J., Han, G.-w, Kim, H., Lee, W., Kim, M.-H., 2023. Retrofit of renewable energy systems in existing community for positive energy community. Energy Rep. 9, 3733–3744. https://doi.org/10.1016/j.egyr.2023.02.055.

Andersen, O., Gössling, S., Simonsen, M., Walnum, H.J., Peeters, P., Neiberger, C., 2010. CO_2 emissions from the transport of China's exported goods. Energy Policy 38 (10), 5790–5798. https://doi.org/10.1016/j.enpol.2010.05.030.

Ashizawa, M., Otaka, M., Yamamoto, H., Akisawa, A., 2022. CO_2 emissions and economy of co-firing carbonized wood pellets at coal-fired power plants: the case of overseas production of pellets and use in Japan. Energies 15 (5). https://doi.org/10.3390/en15051770.

Balsalobre-Lorente, D., Contente dos Santos Parente, C., Leitão, N.C., Cantos-Cantos, J. M., 2023. The influence of economic complexity processes and renewable energy on CO_2 emissions of BRICS. What about industry 4.0? Resour. Policy 82, 103547. https://doi.org/10.1016/j.resourpol.2023.103547.

Balsalobre-Lorente, D., Nur, T., Topaloglu, E.E., Evcimen, C., 2023. Assessing the impact of the economic complexity on the ecological footprint in G7 countries: fresh evidence under human development and energy innovation processes. Gondwana Res. https://doi.org/10.1016/j.gr.2023.03.017.

Balsalobre-Lorente, D., Shahbaz, M., Murshed, M., Nuta, F.M., 2023. Environmental impact of globalization: the case of central and Eastern European emerging economies. J. Environ. Manag. 341, 118018 https://doi.org/10.1016/j.jenvman.2023.118018.

Banerjee, K., 2022. FDI flow in energy sector among BCIM, BIMSTEC+1 and ASEAN+4 sub-regional alignments. J. Environ. Sci. Econ. 1 (3), 33–50. https://doi.org/10.56556/jescae.v1i3.226.

Bassey Enya, N., James, H.T., Friday Bassey, A., 2022. Autoregressive distributed lag approach (ARDL) to corruption and economic growth nexus in Nigeria. J. Environ. Sci. Econ. 1 (3), 8–14. https://doi.org/10.56556/jescae.v1i3.181.

Borg, E., Kits, I., Junttila, J., Uddin, G.S., 2022. Dependence between renewable energy related critical metal futures and producer equity markets across varying market conditions. Renew. Energy 190, 879–892. https://doi.org/10.1016/j.renene.2022.03.149.

Can, M., Dogan, B., Saboori, B., 2020. Does trade matter for environmental degradation in developing countries? New evidence in the context of export product diversification. Environ. Sci. Pollut. Res. 27 (13), 14702–14710. https://doi.org/10.1007/s11356-020-08000-2.

Can, M., Balsalobre-Lorente, D., Adedoyin, F.F., Mercan, M., 2023. The impact of trade openness, export concentration and economic complexity on energy demand among G7 countries, 0958305×231177740 Energy Environ.. https://doi.org/10.1177/0958305×231177740.

Chen, C., Pinar, M., Stengos, T., 2022. Renewable energy and CO_2 emissions: new evidence with the panel threshold model. Renew. Energy 194, 117–128. https://doi.org/10.1016/j.renene.2022.05.095.

Chen, K.-S., Wu, C.-F., Tsaur, R.-C., Huang, T.-H., 2023. Fuzzy evaluation and improvement decision-making model for machining operation performance. Appl. Sci. 13 (3) https://doi.org/10.3390/app13031430.

Doğan, B., Chu, L.K., Ghosh, S., Diep Truong, H.H., Balsalobre-Lorente, D., 2022. How environmental taxes and carbon emissions are related in the G7 economies? Renew. Energy 187, 645–656. https://doi.org/10.1016/j.renene.2022.01.077.

Esmaeili, P., Balsalobre Lorente, D., Anwar, A., 2023. Revisiting the environmental Kuznetz curve and pollution haven hypothesis in N-11 economies: fresh evidence from panel quantile regression. Environ. Res. 228, 115844 https://doi.org/10.1016/j.envres.2023.115844.

Fadly, D., 2020. Greening industry in Vietnam: environmental management standards and resource efficiency in SMEs. Sustainability 12 (18). https://doi.org/10.3390/su12187455.

Fernandes, J., Ferrão, P., 2023. Urban metabolism-based approaches for promoting circular economy in buildings refurbishment. Environments 10 (1). https://doi.org/10.3390/environments10010013.

Fiori, A., Foroni, I., 2019. Reservation forecasting models for hospitality SMEs with a view to enhance their economic sustainability. Sustainability 11 (5). https://doi.org/10.3390/su11051274.

Firth, A.G., Brooks, J.P., Locke, M.A., Morin, D.J., Brown, A., Baker, B.H., 2022. Dynamics of soil organic carbon and CO_2 flux under cover crop and no-till management in soybean cropping systems of the mid-south (USA). Environments 9 (9). https://doi.org/10.3390/environments9090109.

Flammini, A., Brundin, E., Grill, R., Zellweger, H., 2020. Supply chain uncertainties of small-scale coffee husk-biochar production for activated carbon in Vietnam. Sustainability 12 (19). https://doi.org/10.3390/su12198069.

Ganesan, M., Kor, A.-L., Pattinson, C., & Rondeau, E. (2020). Green Cloud Software Engineering for Big Data Processing. 12(21), 9255.

Hu, J., Miles, D.M., Adeli, A., Brooks, J.P., Podrebarac, F.A., Smith, R., Moorhead, R.J., 2023. Effects of cover crops and soil amendments on Soil CO_2 flux in a mississippi corn cropping system on upland soil. Environments 10 (2). https://doi.org/10.3390/environments10020019.

Huang, Y., Kuldasheva, Z., Salahodjaev, R., 2021. Renewable energy and CO_2 emissions: empirical evidence from major energy-consuming countries. Energies 14 (22). https://doi.org/10.3390/en14227504.

Jahanger, A., Ali, M., Balsalobre-Lorente, D., Samour, A., Joof, F., Tursoy, T., 2023. Testing the impact of renewable energy and oil price on carbon emission intensity in China's transportation sector. Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-023-28053-3.

Johnathon, C., Agalgaonkar, A.P., Planiden, C., Kennedy, J., 2023. A proposed hedge-based energy market model to manage renewable intermittency. Renew. Energy 207, 376–384. https://doi.org/10.1016/j.renene.2023.03.017.

Khan, H., Weili, L., Bibi, R., Sumaira, Khan, I., 2022. Innovations, energy consumption and carbon dioxide emissions in the global world countries: an empirical investigation. J. Environ. Sci. Econ. 1 (4), 12–25. https://doi.org/10.56556/jescae.v1i4.288.

Khan, M.K., Teng, J.-Z., Khan, M.I., 2019. Effect of energy consumption and economic growth on carbon dioxide emissions in Pakistan with dynamic ARDL simulations approach. Environ. Sci. Pollut. Res. 26 (23), 23480–23490. https://doi.org/10.1007/s11356-019-05640-x.

Khan, M.K., Teng, J.-Z., Khan, M.I., Khan, M.O., 2019. Impact of globalization, economic factors and energy consumption on CO_2 emissions in Pakistan. Sci. Total Environ. 688, 424–436. https://doi.org/10.1016/j.scitotenv.2019.06.065.

Khan, M.K., Khan, M.I., Rehan, M., 2020. The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan. Financ. Innov. 6 (1), 1 https://doi.org/10.1186/s40854-019-0162-0.

Kuo, Y.-H., Wu, E.H.-K., 2023. Advanced, innovative AIoT and edge computing for unmanned vehicle systems in factories. Electronics 12 (8). https://doi.org/10.3390/electronics12081843.

Le, T.T.H., Nguyen, V.C., Phan, T.H.N., 2022. Foreign direct investment, environmental pollution and economic growth—an insight from non-linear ARDL co-integration approach. Sustainability 14 (13). https://doi.org/10.3390/su14138146.

Leitão, N.C., 2021. Testing the role of trade on carbon dioxide emissions in Portugal, 9 (1), 22.

Leitão, N.C., Koengkan, M., & Fuinhas, J.A. (2022). The Role of Intra-Industry Trade, Foreign Direct Investment, and Renewable Energy on Portuguese Carbon Dioxide Emissions. 14(22), 15131.

Leitão, N.C., Dos Santos Parente, C.C., Balsalobre-Lorente, D., Cantos Cantos, J.M., 2023. Revisiting the effects of energy, population, foreign direct investment, and economic growth in Visegrad countries under the EKC scheme. Environ. Sci. Pollut. Res. 30 (6), 15102–15114. https://doi.org/10.1007/s11356-022-23188-1.

Li, M., Chen, H., Huang, Y., Huang, M., 2019. The rise of border areas in an integrated Region of China. Sustainability 11 (20). https://doi.org/10.3390/su11205692.

Liem, L.T.T., Tashiro, Y., Tinh, P.V.T., Sakai, K., 2022. Reduction in greenhouse gas emission from seedless lime cultivation using organic fertilizer in a province in Vietnam Mekong Delta Region. Sustainability 14 (10). https://doi.org/10.3390/su14106102.

Melane-Lavado, A., Álvarez-Herranz, A., 2020. Cooperation networks as a driver of sustainability-oriented innovation. Sustainability 12 (7), 2820.

Nguyen, P.T., 2022. Carbon emissions versus value-added in export-driven countries: case of Vietnam. J. Econ. Struct. 11 (1), 12 https://doi.org/10.1186/s40008-022-00272-w.

Nguyen, T.T., Nguyen, V.C., 2021. Financial development and renewables in southeast asian countries—the role of organic waste materials. Sustainability 13 (16), 8748.

Nguyen Thi Ngoc, A., 2016. Regional determinants of FDI location in Vietnam. J. Econ. Dev. 19–37. https://doi.org/10.33301/2016.18.01.02.

Noh, C.-M., Jang, J.-G., Kim, S.-S., Lee, S.-S., Shin, S.-C., Lee, J.-C., 2023. A study on the optimization of the coil defect detection model based on deep learning. Appl. Sci. 13 (8) https://doi.org/10.3390/app13085200.

Phan, T.H., 2022. Working conditions, export decisions, and firm constraints-evidence from vietnamese small and medium enterprises. Sustainability 14 (13). https://doi.org/10.3390/su14137541.

Phan, T.H., Stachuletz, R., Nguyen, H.T.H., 2022. Export decision and credit constraints under institution obstacles. Sustainability 14 (9). https://doi.org/10.3390/su14095638.

Raihan, A., Tuspekova, A., 2022a. The nexus between economic growth, renewable energy use, agricultural land expansion, and carbon emissions: new insights from Peru. Energy Nexus 6. https://doi.org/10.1016/j.nexus.2022.100067.

Raihan, A., Tuspekova, A., 2022b. Nexus between energy use, industrialization, forest area, and carbon dioxide emissions: new insights from Russia. J. Environ. Sci. Econ. 1 (4), 1–11. https://doi.org/10.56556/jescae.v1i4.269.

Sarwar, S., Shahzad, U., Chang, D., Tang, B., 2019. Economic and non-economic sector reforms in carbon mitigation: empirical evidence from Chinese provinces. Struct. Change Econ. Dyn. 49, 146–154. https://doi.org/10.1016/j.strueco.2019.01.003.

Schweitzer, F., Bitsch, G., Louw, L., 2023. Choosing solution strategies for scheduling automated guided vehicles in production using machine learning. Appl. Sci. 13 (2) https://doi.org/10.3390/app13020806.

Shahzad, U., 2020. Environmental taxes, energy consumption, and environmental quality: theoretical survey with policy implications. Environ. Sci. Pollut. Res. 27 (20), 24848–24862. https://doi.org/10.1007/s11356-020-08349-4.

Shahzad, U., Ferraz, D., Doğan, B., Aparecida do Nascimento Rebelatto, D., 2020. Export product diversification and CO_2 emissions: contextual evidences from developing and developed economies. J. Clean. Prod. 276 https://doi.org/10.1016/j.jclepro.2020.124146.

Shahzad, U., Fareed, Z., Shahzad, F., Shahzad, K., 2021. Investigating the nexus between economic complexity, energy consumption and ecological footprint for the United States: new insights from quantile methods. J. Clean. Prod. 279, 123806 https://doi.org/10.1016/j.jclepro.2020.123806.

Shang, Y., Han, D., Gozgor, G., Mahalik, M.K., Sahoo, B.K., 2022. The impact of climate policy uncertainty on renewable and non-renewable energy demand in the United States. Renew. Energy 197, 654–667. https://doi.org/10.1016/j.renene.2022.07.159.

Shi, L., Cai, Z., Ding, X., Di, R., & Xiao, Q. (2020). What Factors Affect the Level of Green Urbanization in the Yellow River Basin in the Context of New-Type Urbanization?, 12(6), 2488.

Sinha, A., Balsalobre-Lorente, D., Zafar, M.W., Saleem, M.M., 2022. Analyzing global inequality in access to energy: developing policy framework by inequality decomposition. J. Environ. Manag. 304, 114299 https://doi.org/10.1016/j.jenvman.2021.114299.

Stjepanovic, S., Tomic, D., Skare, M., 2022. A new database on green GDP; 1970-2019: a framework for assessing the green economy. Oeconomia Copernic. 13 (4), 949–975. https://doi.org/10.24136/oc.2022.027.

Thu, N.T.P., Huong, L.M., Xuan, V.N., 2022. Factors affecting environmental pollution for sustainable development goals—evidence from asian countries. Sustainability 14 (24). https://doi.org/10.3390/su142416775.

Thu, N.T.P., Xuan, V.N., Huong, L.M., 2022. Analysis of the factors affecting environmental pollution for sustainable development in the future—the case of Vietnam. Sustainability 14 (23). https://doi.org/10.3390/su142315592.

Tsai, J.-F., Nguyen, P.-H., Lin, M.-H., Nguyen, D.-V., Lin, H.-H., Ngo, A.-T., 2021. Impacts of environmental certificate and pollution abatement equipment on SMEs' performance: an empirical case in Vietnam. Sustainability 13 (17). https://doi.org/10.3390/su13179705.

Usman, O., Alola, A.A., Akadiri, S.S., 2022. Effects of domestic material consumption, renewable energy, and financial development on environmental sustainability in the EU-28: Evidence from a GMM panel-VAR. Renew. Energy 184, 239–251. https://doi.org/10.1016/j.renene.2021.11.086.

Van Thanh, N., 2022. Optimal waste-to-energy strategy assisted by fuzzy MCDM model for sustainable solid waste management. Sustainability 14 (11). https://doi.org/10.3390/su14116565.

Visconti, F., Peiró, E., Baixauli, C., de Paz, J.M., 2022. Spontaneous plants improve the inter-row soil fertility in a citrus orchard but nitrogen lacks to boost organic carbon. Environments 9 (12). https://doi.org/10.3390/environments9120151.

Wang, B., Wang, C., 2023. Green finance and technological innovation in heavily polluting enterprises: evidence from China. Int. J. Environ. Res. Public Health 20 (4). https://doi.org/10.3390/ijerph20043333.

Wang, W., Liu, L., Yang, Y., 2022. Spatial matching analysis and development strategies of county night-time economy: a case of Anning County, Yunnan Province. Sustainability 14 (9). https://doi.org/10.3390/su14094891.

Wang, X., Xu, Z., Wang, X., Skare, M., 2022. A review of inflation from 1906 to 2022: a comprehensive analysis of inflation studies from a global perspective. Oeconomia Copernic. 13 (3), 595–631. https://doi.org/10.24136/oc.2022.018.

Wei, X., Liu, D., Ye, S., Chen, F., Weng, J., 2023. Optimal sizing of energy storage in generation expansion planning of new power system with high penetration of renewable energies. Energy Rep. 9, 1938–1947. https://doi.org/10.1016/j.egyr.2023.04.190.

Wu, S., Alharthi, M., Yin, W., Abbas, Q., Shah, A.N., ur Rahman, S., Khan, J., 2021. The carbon-neutral energy consumption and emission volatility: the causality analysis of ASEAN region. Energies 14 (10). https://doi.org/10.3390/en14102943.

Xuan, V.N., 2020a. Determinants of business performance in firms: evidence in vietnam technology and manufacturing enterprises. Int. J. Adv. Appl. Sci. 7 (7), 95–101. https://doi.org/10.21833/ijaas.2020.07.012.

Xuan, V.N., 2020b. Factors affecting foreign direct investment: evidence at foreign technology enterprises in Vietnam. Int. J. Adv. Appl. Sci. 7 (4), 21–28. https://doi.org/10.21833/ijaas.2020.04.004.

Xuan, V.N., Thu, N.T.P., Anh, N.T., 2020a. Factors affecting support services in small and medium enterprises: evidence from Vietnam small and medium information technology enterprises. Manag. Sci. Lett. 303–312. https://doi.org/10.5267/j.msl.2019.9.001.

Xuan, V.N., Thu, N.T.P., Anh, N.T., 2020b. Factors affecting the business performance of enterprises: evidence at Vietnam small and medium-sized enterprises. Manag. Sci. Lett. 865–870. https://doi.org/10.5267/j.msl.2019.10.010.