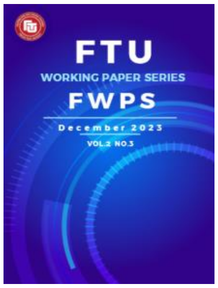

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TÁC ĐỘNG CỦA KINH TẾ SỐ ĐẾN GIẢM PHÁT THẢI CARBON Ở CÁC NƯỚC CHÂU Á VÀ GỢI Ý CHÍNH SÁCH CHO VIỆT NAM

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Trong bối cảnh Cách mạng Công nghiệp, lượng khí thải CO_2 tăng lên một cách nhanh chóng thông qua các hoạt động kinh tế mới, trong đó có tác động của nền kinh tế số đến việc giảm phát thải carbon ở các nước châu Á. Nghiên cứu này sử dụng mô hình tác động cố định với dữ liệu được trích xuất từ World Bank, UNCTAD và EDGAR từ năm 2010 đến năm 2022, tập trung vào việc sử dụng ba giả thuyết để tìm hiểu về mối quan hệ giữa nền kinh tế số và lượng khí thải carbon. Trong đó, ở giai đoạn đầu tiên của quá trình số hóa, lượng khí thải carbon tăng lên và đạt đỉnh, sau đó giảm xuống khi các hoạt động số hóa tiếp tục diễn ra. Ngoài ra, hai trong số những nguyên nhân làm tăng lượng khí thải carbon do nền kinh tế số là quá trình công nghiệp hóa kém hiệu quả và đô thị hóa ồ ạt. Do đó, dựa trên tình hình hiện tại của Việt Nam, chúng tôi đề xuất một số chính sách như thực hiện mô hình thành phố phát thải carbon thấp, cải thiện quy hoạch cơ sở hạ tầng và thúc đẩy lối sống xanh để đạt được mục tiêu hợp tác bảo vệ môi trường toàn cầu.

Từ khóa: kinh tế số; giảm phát thải carbon; châu Á; gợi ý chính sách cho Việt Nam

THE DIGITAL ECONOMY'S EFFECTS ON CARBON EMISSION REDUCTION IN ASIAN COUNTRIES AND POLICY IMPLICATIONS FOR VIETNAM

Abstract

The emissions of carbon dioxide rapidly increase as a result of human activities in the context of the Industrial Revolution. As a new economic model, the impact of the digital economy on carbon emission reduction in Asian countries is worth investigating. The research paper introduced the digital economy into the Fixed-effect model with the data used extracted from the World Bank, UNCTAD, and EDGAR spanning a 13-year period from 2010 to 2022. Our finding has primarily focused on formulating three specific hypotheses to explore the complex relationship between the digital economy and carbon emissions. It indicates that at the first stage of digitalization, carbon emissions increase and peak at the top of the curve before decreasing. In addition, two of the reasons for increasing carbon emissions due to the digital economy are ineffective industrialization and massive urbanization. Therefore, based on Vietnam's current situation, there are some policy implications for the Vietnam government, such as implementing a low-carbon cities model, improving infrastructure planning, and promoting green lifestyles to achieve the goal of global collaborative environmental protection.

Keywords: digital economy; carbon emission reduction; Asian countries; policy implications for Vietnam

1. Introduction

Climate change has a profound impact on the sustainable growth of human society. The establishment of The Paris Agreement has emphasized the critical importance and imperativeness of this global issue, and in order to achieve the long-term, ambitious goal of reducing global average temperature rise to no more than 2°C, carbon emissions reduction should be taken into utmost consideration to mitigate the influence of climate change, not only in the overall well-being of the society but also the sustainable development of the global economy.

Particularly, efficiency in carbon emissions reduction is among the most pressing issues that demand immediate prioritization, which allows an economy to achieve more growth with less energy and the same amount of carbon emissions, thereby giving rise to a complete low-carbon transformation in economic and social aspects. The digital economy, accordingly, has been gaining increasing attention recently as the key economic model in contributing to the betterment of both economic growth and the ecological environment.

To be more specific, while it is arguable that the digital economy can provide long-term benefits to economic development, its possible environmental implications have been discussed at length by experts to decide whether the digital economy has a positive influence on the reduction of carbon emissions. Essentially, in terms of theoretical and empirical studies, there is still a lack of direct discussion on the impact of the digital economy on the efficiency of carbon emissions, but relevant studies on the impact of the digital economy, especially on carbon emissions, provide references and inspirational implications for this paper.

As a result, we chose the topic: **"The digital economy's effects on carbon emission reduction in Asian countries and policy implications for Vietnam"** for this study. By constructing an empirical model on the correlation between the digital economy and carbon emissions reduction in Asia, we leverage the data to test whether the digital economy had a positive impact on the reduction of carbon emissions. Through the study, we made an attempt to bridge the research gap by using data collected from 47 Asian countries within the period from 2010-2022, which would ensure the relevance of findings to the current situation in Vietnam. Hereby, we will apply the lessons learned from examples in the Asia region to the current situation in Vietnam, in which we focus on proposing policy recommendations to promote the development of infrastructure and regulations related to carbon emissions reduction in Vietnam.

2. Literature review

Based on previous research, there are many studies related to the impact of economic activities on the environment. According to the Environmental Kuznets Curve Hypothesis (EKC), the inverted U-shaped was first found in the relationship between environmental pollution and economic growth, environmental pollution rises with the increase in economic factors and then decreases after reaching the peak or threshold point. Besides, in compliance with *Abeydeera et al., 2019*, research on CO_2 emissions first began in 1981, and publications in the field have shown a rapid growth trend after some scientists found that the main cause of climate change is CO_2 emissions. Aside from the impact of overall economic growth on the environment, most studies about CO_2 emissions have examined the role of various factors, such as urbanization, industrialization, FDI, and electricity. First, some empirical evidence from a comprehensive study substantiates the existence of a correlation between heightened urbanization rates, elevated energy carbon emission coefficients, and increased energy intensity, culminating in a discernible upsurge in carbon emissions *(Wu et al., 2020).* As for the proliferation of digital technologies in emerging economies, especially their integration into energy-intensive sectors such as electricity generation is believed to be responsible for a spike in energy consumption, thereby contributing to increased carbon emissions *(Congqi Wang et al, 2023).* In addition, the impact of Foreign Direct Investment (FDI) on carbon dioxide emissions is different in different regions, the FDI in some countries increases CO_2 emissions, while the FDI in other countries inhibits CO_2 emissions *(H.Peng et al., 2016)*. Moreover, about the impact of industrialization, when industrial processes lack efficiency and environmental safeguards, they tend to consume larger quantities of energy and resources, leading to a substantial increase in carbon emissions *(Arjan Trinks et al., 2020).* Especially, in the context of the development of computer technology, the digital economy has a positive effect on the environment in China's developed regions and a negative effect in less developed regions *(Wu et al., 2006),* whereas following *Shvakov and Petrova, 2009,* digitization does not contribute to the development of a green or an energy-saving economy but hinders their development.

By analyzing the studies on the impact of the digital economy on the environment, the research team found that most of the studies at this stage are qualitative in nature. These previous studies investigate the impact of the digital economy on the environment mainly using descriptive analysis, which lacks theoretical and mathematical models. In addition, quantitative studies and empirical tests are only conducted on specific countries, lacking universality and generality.

Therefore, in this research paper, the team establishes a new partial equilibrium growth model of CO_2 emissions and draws out an EKC curve of CO_2 emissions and the digital economy by supposing three hypotheses. The team also uses country panel data to examine the U-shaped curve between CO_2 emissions and the digital economy and determine whether the impact of the digital economy on CO_2 emissions is heterogeneous among countries.

3. Theoretical framework

3.1. Digital economy and its components

3.1.1. Definition and characteristics of the digital economy

There are several variations of a digital economy definition, and since technological advancements are the backbone of the digital economy, the definition of the digital economy would continue to evolve alongside technological disruptiveness. The digital economy is defined as a data-driven economy that results from billions of everyday online connections among people, businesses, devices, data, and processes *(Deloitte, 2017).* In the meantime, it also reflects how digital technology affects production and consumption, "including how goods and services are marketed, traded, and paid for." *(The Conversation, 2020).* Overall, for the time being, the current digital economy focuses on the way digital technologies, services, products, techniques, and skills are integrated across economies in digitalization.

From a technological perspective, the digital economy is the result of the transformational effects of new General-Purpose Technologies (GPT) in the fields of information and communication (European Commission), which means the digital economy gives rise to a holistic revolutionization in different industries, such as retail, transport, financial services and manufacturing. The most profound and evident characteristic of the digital economy, therefore, is that it is driven by the Internet and other technological advancements. The Internet has a prerequisite role in the growth of the digital economy, revolutionizing every aspect of the digital economy, as it promotes new industries with information technology, or digitalizes and transforms business models.

Another key characteristic of the digital economy is hyperconnectivity, which means the growing interconnectedness of people, organizations, and machines that results from the Internet, mobile technology, and the Internet of Things (IoT). The digital economy transcends geographical boundaries and revolutionizes the way businesses operate. This means local businesses can access new opportunities for growth and expansion by tapping into previously untapped markets through the facilitation of the Internet. Specifically, businesses from Vietnam can easily conduct business transactions with foreign business partners, and vice versa. The advancement in technology and the infrastructure supporting transactions has facilitated the process of conducting business online and creating a frictionless experience for both business owners and consumers, through memory-optimized object storage and real-time analytics.

Last but not least, the digital economy can offer continuous access to services and products to customers, through the assistance of the Internet, thereby enhancing their productivity and customer reach. This aspect of the digital economy opens up diverse opportunities for entrepreneurs and promotes globalization. Digital economy encourages access to global markets and interaction with global audiences, in a much more cost-effective and timely approach compared to traditional economy. For example, digital technologies such as AI, cloud storage, and other digital platforms have become over 50% cheaper than they were a few years ago *(Estevão, M., 2021).* Furthermore, they increase the efficiency of businesses by up to 40 - 50%, thereby significantly reducing operating costs *(Bendor-Samuel, 2020).*

3.1.2. Key components driving the digital economy

The vast range of economic activities that use digital information and knowledge as primary production inputs collectively referred to as the "digital economy" are driven by a number of essential elements, including Digital infrastructure, E-commerce, Data, and Regulations.

First, digital infrastructure is the foundation of any connected business. which enables success, powers transformation, and connects people around the world. It also includes the production, storage, and distribution of digital material and other digital platforms such as fast internet, cloud computing, etc. Additionally, as the demand for digital skills rises, so does the size of the digital economy. This encompasses both hard skills like digital literacy and online communication as well as soft skills like technical abilities like coding and data analysis. With awareness of this situation, many universities, even in Vietnam, have been offering more and more courses that train students' digital skills. VinUni, a university founded by innovation-oriented VinGroup, offers multiple courses about Big data, AI, Object-oriented programming, Computer systems programming, etc *(Thuy M. Ha et al., 2023)*. Employers have also been more interested in candidates with excellent digital skill sets. According to US News and World Report in 2023, information security analysts, software developers, data scientists, and statisticians ranked among the top jobs in terms of pay and demand.

Second, the way we buy and sell services has definitely been changed by online markets, commonly known as e-commerce. They give companies a way to interact with clients on a worldwide scale, fostering economic expansion and opening up new job opportunities. Since the epidemic, the adoption of online commerce has been rapidly increasing, and more customers and businesses are turning to the internet for all kinds of transactions. Consumer behavior has been significantly impacted by this quick change, which has increased the desire for convenience, customization, and options while purchasing online. As a result, established online merchants are switching to the marketplace model. In 2022, global e-commerce retail sales were $4.2 trillion, or 17.8% of all retail sales worldwide. By 2023, this percentage is anticipated to be 21%, and by 2053, it will be 24.5% *(Dan Ikenson, 2022).* Therfore, the emergence of online markets is reshaping the world economy by encouraging economic growth and creating new job opportunities.

Third, data is a valuable resource that businesses leverage to gain insights into customer behavior, improve products and services, and strategize for the future. Thanks to Big Data, giant firms such as Google, Meta, X, etc. are growing their business and expanding at an impeccable speed. As the world has moved further into the digital age, the importance of data in driving business decisions and innovation continues to increase. In the digital age, data's role in shaping business decisions and spurring innovation is growing. It is considered the "new oil" of the digital economy, which is a renewable resource that expands with use. In particular, making informed decisions and maximizing corporate growth are made possible by the insights and patterns it offers. However, it's important to consider the data's quality because it can influence judgments in the wrong way.

Regulations in the digital economy are crucial to ensure fair and contestable markets. The European Union's Digital Markets Act (DMA), introduced in 2022, aims to prevent large companies such as Google, Facebook and Amazon from abusing their market power and allowing new players entering the market can participate in adjusting the power of those giants. The firm sets obligations for these digital 'gatekeepers' to ensure fair competition, including not favoring their own services, sharing data with third parties, and obtaining consent for tracking user data. On the other hand, the Organization for Economic Cooperation and Development (OECD) is committed to developing policies that ensure security and privacy in the digital world, fostering economic and social prosperity with the aim to build trust in an open and interconnected digital world, promoting respect for privacy as a fundamental value.

3.2. Carbon emission reduction and environmental concerns

3.2.1. The role of carbon emission reduction

Moving further into the digital age, the importance of data in driving business decisions and innovation continues to increase. The International Energy Agency (IEA) reported that global energy-related to CO_2 emissions grew by 0.9% or 321 Mt in 2022, reaching a new high of over 36.8 Gt1. This growth was much slower than 2021's rebound of more than 6%, following two years of exceptional oscillations in energy use and emissions caused in part by the COVID-19 pandemic. The decrease in carbon emissions is crucial to combating climate change. Global ecosystems and human societies are at serious risk from climate change, which is primarily caused by rising atmospheric carbon dioxide (CO_2) levels. With human activities like deforestation and the combustion of fossil fuels, the amount of CO_2 in the atmosphere has significantly increased, amplifying the greenhouse effect and causing global warming.

Additionally, the decrease in carbon emissions has a crucial influence on economic expansion both directly and indirectly. In direct ways, reducing carbon emissions often involves transitioning to cleaner, more efficient technologies. The transition to clean energy is expected to generate 10.3 million net new jobs globally by 2030, offsetting the 2.7 million jobs expected to be lost in fossil fuel sectors *(Wallach, O., 2022)*. Most of these job gains are anticipated to be in electrical efficiency, power generation, and the automotive sector. By indirect touchpoint, lower carbon emissions can mitigate the harmful effects of climate change, which can have substantial economic costs. In particular, greenhouse gases emitted by one country can cause warming in another, depressing economic growth. Moreover, five national emitters of greenhouse waste caused $6 trillion in global economic losses through warming from 1990 to 2014.

Furthermore, as the air is becoming more polluted these days, the cost per extreme weather event has increased by nearly 77% over the past five decades *(World Economic Forum, 2023)*. For instance, floods across Germany, Belgium, Luxembourg, and the Netherlands generated an estimated $43 billion per year in damages, being summed up with other nations' data, causing a loss in the global economy of more than $520 billion annually of the cost due to extreme weather event *(World Economic Forum, 2023)*. It led to the fact that lowering carbon emissions can help to reduce the financial toll that extreme weather events have on society. Therefore, carbon emissions contribute to both an improved economy and a better quality of life for people.

Moreover, health care has also benefited from lessened air pollution. According to WHO, lung cancer is the most common disease caused by polluted air, with almost 11% of lung cancer deaths in adults linked to exposure to carcinogens from home air pollution brought on by using kerosene or solid fuels like wood, charcoal, or coal. Moreover, air pollution contributes to 11.65% of deaths globally with 107,000 premature deaths are caused every year in the United States, costing the country $820 billion in healthcare bills *(World Economic Forum, 2021)*. This number is approximately 1.6 million per year for China *(Washington, 2018)*. All these data have suggested that the more carbon emission is reduced, the more health problems will be solved.

3.2.2. Opportunities and challenges of carbon emission reduction in the context of the digital economy

Opportunities

Digital technologies have indeed enabled a shift towards remote work and online shopping, which can significantly lower emissions related to transportation. This shift in work and shopping habits has been particularly noticeable during the COVID-19 pandemic, with more people working online and an increase in online activity contributing to the global economy. In fact, the percentage of people working from home in the U.S. alone rose from 5% to 37% during the height of the pandemic *(Ganga Shreedhar and co-workers, 2022).*

Moreover, the digital economy also fuels low-carbon technology innovation. Digital channels can facilitate financing for sustainable energy initiatives, making it easier for these projects to get off the ground. The integration of science, technology, and innovation in national development strategies is a major instrument in building up STI policy-making capacity in both developed and developing countries, through the potential of digital technology to enhance energy efficiency across various industries. One of the most breakthrough innovations in energy efficiency is Smart Grids, according to Statista *(2021)*, Smart Grids in China are a key component in the country's plan to reduce its national energy consumption to 13.5% per unit of GDP by 2025; The market size of China's smart grid industry was almost 80 billion yuan in 2020, and it was estimated to grow to around 85.5 billion yuan by the end of 2021.

Challenges

The development and use of digital technology indeed require a substantial amount of energy. Data centers, in particular, are significant consumers of electricity. These facilities house computer systems and associated components, such as telecommunications and storage systems. With the increasing reliance on digital technologies in various sectors, the demand for data centers has grown exponentially, leading to increased energy consumption. Moreover, the energy used by data centers often comes from non-renewable sources, contributing to carbon emissions. Therefore, while digital technologies offer numerous benefits, their energy consumption poses significant environmental challenges. It is crucial to develop and implement strategies for improving energy efficiency in data centers and transitioning to renewable energy sources. Due to the rapid pace of technological advancement and the frequent replacement of digital equipment, there is a significant amount of electronic waste, often referred to as e-waste. In 2021, 57.4 million metric tonnes (Mt) of e-waste was generated globally, and this total is growing by an average of 2 Mt per year.

Inequality in the digital economy is a significant concern. The benefits of the digital economy may not be distributed equally, leading to a widening divergence in growth rates between advanced economies and emerging and developing economies. On the other hand, as the economy becomes more digital, concerns about data privacy and cybersecurity may hinder the adoption of digital solutions for carbon reduction, in which, cybercrime cost the global economy just under USD 1 trillion in 2020, indicating an increase of more than 50% since 2018 *(Frank Cremer, 2022)*. Therefore, ensuring data privacy and enhancing cybersecurity are crucial for fostering trust and promoting the adoption of digital solutions.

4. The digital economy's effects on carbon emission reduction in asian countries

4.1. Hypotheses about the link between the digital economy and carbon emissions

The region's attempts to reduce carbon emissions are projected to be significantly and in a variety of ways impacted by the expansion of the digital economy in Asian nations, which is characterized by greater adoption of digital technologies, e-commerce, and digital services. This effect may be linked to a number of connected causes, including Improved Energy Efficiency, Enhanced Resource Allocation, Promotion of Sustainable Practices, Data-driven Decision Making, and Facilitation of Green Innovation.

The research team has refined its focus to develop **three specific hypotheses** that investigate the intricate relationship between the digital economy and carbon emissions.

Hypothesis 1: The digital economy and CO_2 emissions are correlated in an inverted U-shaped. CO_2 emissions increased to the peak during the early stages of the digital economy's development, then decreased as the digital economy continued to grow.

The relationship between digitalization and CO_2 emissions is a complex and multifaceted one, with both positive and negative aspects to consider. Following the Environmental Kuznets Curve hypothesis, the two subjects in the relationship are economic output per capita (international trade of digitally delivered services per capita) and a measure of environmental quality (carbon dioxide emissions per capita) *(David I. Stern, 2018)*. Then the two variables will have an inverted U-shaped relationship. With another measurement of digitalization, international trade of ICT services per capita, it also was concluded that having the inverted U-shaped correlation with CO_2 emissions.

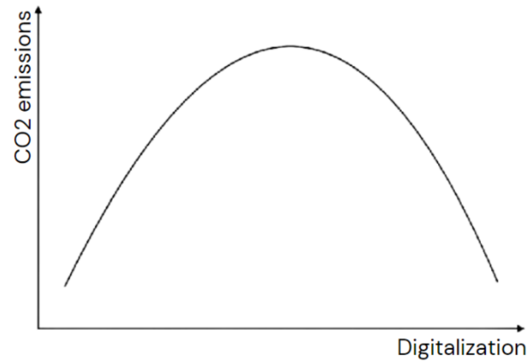

Figure 1: Digitalization and CO_2 emissions' relationship following EKC hypothesis

On the positive side, digitalization has the potential to reduce CO_2 emissions through various mechanisms. Firstly, it enables greater energy efficiency in various sectors of the economy, such as manufacturing, transportation, and buildings, through the implementation of smart technologies and data analytics. Additionally, digitalization can facilitate the optimization of supply chains, reducing unnecessary transportation and energy consumption. However, it is important to note that digitalization is not without its own environmental costs. The production and disposal of electronic devices, data centers, and the energy consumption of the digital infrastructure contribute to electronic waste and carbon emissions. The increasing demand for data storage and processing power also puts pressure on energy-intensive data centers, potentially leading to a rise in CO_2 emissions. Therefore, the period between the start of the digital economy's growth and its maturity is a crucial time when CO_2 emissions are at their peak before digitalization encourages sustainable behavior and the decrease of emissions, which eventually causes CO_2 emissions to trend downward.

Hypothesis 2: The digital economy promotes carbon emissions through ineffective industrialization.

When industrial processes lack efficiency and environmental safeguards, they tend to consume larger quantities of energy and resources, leading to a substantial increase in carbon emissions. Such inefficiencies can manifest in several ways, including outdated technologies, poor maintenance practices, and inadequate waste management systems. Furthermore, industries that prioritize short-term gains over long-term sustainability often rely on fossil fuels as their primary energy source, further exacerbating carbon emissions. The ramifications of this nexus are wide-ranging and extend beyond environmental concerns, as carbon emissions are a principal driver of climate change, precipitating adverse environmental consequences and socio-economic challenges globally.

After that, the proliferation of digital technologies in emerging economies, especially their integration into energy-intensive sectors such as electricity generation, is believed to be responsible for a spike in energy consumption, thereby contributing to increased carbon emissions *(Congqi Wang et al, 2023)*. The specificity of this hypothesis centers on the emerging economies' context and highlights the pivotal role played by ineffective industrialization processes in fostering carbon emissions. This precision elucidates the exact scope and relevant factors entailed within the hypothesis.

Hypothesis 3: The digital economy promotes carbon emissions through massive urbanization.

As urban areas expand rapidly to accommodate a burgeoning global population, the construction and maintenance of the requisite infrastructure place substantial demands on energy and resources, often sourced from fossil fuels. Moreover, urbanization is often associated with increased private vehicle usage due to sprawling metropolitan layouts and inadequate public transportation systems. Urban growth also amplifies the demand for heating, cooling, and electricity, intensifying carbon emissions. Empirical evidence from a comprehensive study substantiates the existence of a correlation between heightened urbanization rates, elevated energy carbon emission coefficients, and increased energy intensity, culminating in a discernible upsurge in carbon emissions *(Wu et al., 2020)*. It delineates not only the precise context of developing megacities but also elucidates the intricate causal mechanisms through which urbanization amplifies the influence of the digital economy on carbon emissions.

4.2. Empirical model, variable description, and data

4.2.1. Variable description and data

According to research by Sainan Cheng and his colleagues *(2023)*, there are some factors, such as Digitalization, Urbanization level, Industrialization level, Government, and Education, having a direct impact on reducing carbon emissions in the digital economy. In particular, after examining the data the research also shows the result that these variables lnDIG, Urban, Industry, Government, and lnEdu all exhibit positive signs. Some other studies show that the GDP per capita contributed unfavorably to carbon dioxide emissions *(Halkos and Gkampoura, 2021)*; the FDI on carbon dioxide emissions is different in different regions *(H.Peng et al., 2016).* Based on these studies, the previous research paper, the determined factors CO_2, GDP, FDI, Digitalization, Urbanization level, Industrialization level, and power supply level were chosen.

Table 1: Variables and Data Description

Variables	Meaning	Unit	Expectation of sign	Source
$lnCO_2$	Carbon dioxide emission per capita	tons		World Bank EDGAR
lnDIG *lnDIG2*	The export and import of digitally delivered services per capita	USD	+ -	UNCTAD

lnFDI	The inflows and outflows of foreign direct investment per capita	USD	+	World Bank
Industry	Industrialization level - % industrial value	% of GDP	+	World Bank
Urban	Urbanization level - % urban population	% of Population	+	World Bank
Elec	Power supply level - % population access to electricity	% of Population	+	World Bank

Source: The author's compilation

The observations came from 47 Asian countries from different continents and economic backgrounds that demonstrated minimal rates of missing data, spanning 13 years the period from 2010 to 2022. However, there are some cases where a country doesn't have specific data for that category.

Table 2: Data summary

Variables	Obs	Mean	Std. Dev.	Minimum	Maximum
$lnCO_2$	582	1.141175	1.296671	-1.804047	3.678378
lnDIG2	579	32.9895	24.31103	1.125973	10.90225
lnDIG	579	5.356272	2.075399	1.061119	10.90225
lnFDI	563	5.36876	2.144208	-2.577192	10.53074
Industry	611	31.51451	14.61756	2.758632	74.81215
Urban	611	60.59061	25.95569	16.768	100
Elec	611	94.53491	11.81978	31.1	100

Source: The author's calculation by STATA

4.2.2. Empirical model setting

According to the theoretical regression model in the economy, the reesearch team developed the following model in order to determine the digital economy's effects on the factors above on carbon emission reduction.

$$lnCO_2 = \beta_0 + \beta_1 lnDIG^2 + \beta_2 lnDIG + \beta_3 lnFDI + \beta_4 Industry + \beta_5 Urban + \beta_6 Elec + \varepsilon_{it}$$

In which: β_0 : the intercept of the regression model

β_j (j = (1;6)): the regression coefficients

ε_{it} is the error term country i in year t, which represents other factors that are not in the model but still have impacts on the dependent variables

4.2.3. Research Method

By using the Stata program, during the analysis, the research team conducted a Hausman test to select the most suitable model for our research, the Fixed effects model.

Table 3: Results of the Hausman test

Variables	Fixed Coefficient	Random Coefficient	Difference	S.E.
lnDIG2	-0.0176278	-0.019568	0.0019402	0.0015556
lnDIG	0.2558869	0.2929106	-0.0370237	0.0167772
lnFDI	0.0320537	0.0309511	0.0011027	0.0036689
Industry	0.0062438	0.008785	-0.0025412	0.0008578
Urban	0.038993	0.0304655	0.0085274	0.0060454
Elec	0.0107006	0.0116455	-0.0009449	0.0005849
chi2(6) = 48.81		Probability > chi2= 0.000		

Source: The author's calculation by STATA

This method assumes that individual-specific effects are correlated with independent variables. If the random effects assumption holds, then the random effects estimator will be more efficient than the fixed effects estimator. After that, the team applied the Robust standard error (HAC) to remove defects in the model, including heteroscedasticity and autocorrelation. Finally, a robustness test was used in order to check the reliability of the result.

4.3. Empirical results

4.3.1. Key Findings

The results of the fixed-effects regression show that the explanatory variables all had significance at a threshold of 10%, proving that the variables are meaningful and have an impact on CO_2 emissions. Besides, they also affect the explained variable in the same direction as the expected signs predicted by the study. In addition, the research team conducted Wooldridge and Breusch-Pagan tests to check whether the model contained hidden defects such as heterogeneity and autocorrelation. The results appear p-value lower than 0.05, indicating that the model contains defects. Therefore, the team used Robust Standard Errors (HAC) to fix the model's defects, and the final results are shown in the table below.

Table 4: Final regression result

Variable	1	2	3	4	5

lnDIG2	-0.053***	-0.056***	-0.031***	-0.032***	-0.024***
	(0.007)	(0.007)	(0.006)	(.005)	(0.052)
lnDIG	1.075***	0.896***	0.633***	0.486***	0.386***
	(0.088)	(0.086)	(0.072)	(0.066)	(0.052)
lnFDI		0.237***	0.183***	0.100***	0.097***
		(0.034)	(0.026)	(0.023)	(0.022)
Industry			0.034***	0.030***	0.029***
			(0.002)	(0.002)	(0.002)
Urban				0.023***	0.018***
				(0.002)	(0.002)
Elec					0.024***
					(0.002)
_constant	-2.881***	-3.088***	-3.280***	-3.274***	-4.941***
	(0.254)	(0.219)	(0.185)	(0.158)	(0.175)

Notes: Applying robust standard errors (HAC) to solve heteroskedasticity and autocorrelation. Standard errors in parentheses. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Source: The author's calculation by STATA

To ensure the reliability of empirical findings, the robustness test was carried out and shown in Table 5. First, we added the factor international trade of ICT services per capita, which replaces the variable DIG (UNCTAD). Replacing this core explanatory variable is the first step to check the robustness of the model, the results are shown in column 1. The results show that there is also an inverted U-shaped relationship between ICT and CO2 emission, consistent with the regression results with the DIG variable.

Table 5: Robustness tests of CO_2 emissions and the digital economy

	1	**2**	**3**
Variable	**lnCO_2**	**lnPCO_2**	**lnPCO_2**
lnDIG2		-0.055***	
		(0.013)	
lnDIG		0.728***	
		(0.166)	
lnICT2	-0.029***		-0.105***

	(0.004)		(0.016)
lnICT	0.261***		0.656***
	(0.038)		(0.116)
lnFDI	0.116***	-0.237***	-0.097
	(0.021)	(0.075)	(0.065)
Industry	0.028***	0.040***	0.041***
	(0.002)	(0.006)	(0.006)
Urban	0.024***	0.020***	0.028***
	(0.002)	(0.006)	(0.005)
Elec	0.025***	0.029***	0.031***
	(0.002)	(0.007)	(0.007)
_constant	-4.572***	11.786***	11.836***
	(0.164)	(0.652)	(0.615)

Notes: Applying robust standard errors (HAC) to solve heteroskedasticity and autocorrelation. Standard errors in parentheses. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Source: The author's calculation by STATA

With the second robustness test, we use the country's total annual CO_2 emissions (PCO_2) to replace the originally explained variable CO_2 emissions per capita. The regression results in columns 2 and 3 indicate an inverted U-shaped relationship between PCO_2 and the digital economy. The results are shown by the sign of both digitally delivered services per capita traded and ICT services per capita traded variables when square terms remained negative and were significant at a threshold of 1%. This series of regression results also supports the robustness of the above regression result.

4.3.2. Discussion

By developing a mathematical model and empirical testing, we determined a nonlinear relationship between CO_2 emissions and the level of digitalization, resembling an inverted U-shaped. To specify, the coefficient value of lnDIG2 lower than 0 demonstrates the inverted U-shaped relationship between digitalization and CO_2 emissions. Hence, the results accepted the relationship between CO_2 emissions and digitalization is true following Hypothesis 1. Besides, the industrialization and urbanisation levels demonstrate a positive regression coefficient, indicating that the digital economy promotes CO_2 emissions through ineffective industrialization and massive urbanisation. Then Hypotheses 2 and 3 were accepted. The data indicate that regions experiencing rapid digitalization often exhibit higher carbon emissions due to the growth of industries that are inadequately regulated in terms of environmental standards. Additionally, the expansion of urban areas driven by the digital economy appears to contribute significantly to increased carbon emissions, as urbanisation leads to higher energy consumption and transportation-related emissions. These findings underscore the need for policy interventions that address the environmental consequences of the digital economy, with a focus on both industrial practices and urban development, in order to achieve a more sustainable future.

This study had some limitations. Firstly, the variables' observations just cover 13 years, from 2010 to 2022, so they do not comprehensively represent the long-term situation as economies progress toward digitalization. For future research, it would be valuable to extend our theoretical model to encompass the interactive effects of diverse criteria on CO_2 emissions. Additionally, the research has a limitation of missing value in the dataset. According to the variable description, each variable is supposed to have 611 observations. However, there are different observations in some independent variables such as the export and import of digitally delivered services per capita due to the lack of data in some countries for these categories.

5. Policy recommendations on reducing carbon emission in the context of Vietnam digital economy

Sustainable urban development

Low-carbon urban development – and particularly the idea of low-carbon cities – is receiving greater attention from policymakers, an increasing amount of literature has started to look at the theoretical concepts, tools methods, and case studies of low-carbon city development. In 2009, the State Council announced a target of reducing the carbon intensity of its GDP by 40–45% by 2020 compared to the 2005 level *(Xinhua, 2009)*. This emissions mitigation target was incorporated into the national 12th Five Year Plan (FYP) for the very first time with the setting of a binding target of 17% reduction in CO_2 emissions per unit of GDP from 2011 to 2015 *(National People's Congress, 2011)*. However, because low-carbon development is a relatively new concept and policies have only been introduced within the last few years, there is very little academic literature evaluating the policy-driven low-carbon urban development efforts being implemented in China. The strategies and plans are being considered and adopted by multiple cities in order to achieve the national goal of becoming low-carbon cities. Moreover, while there is ample literature on the theory and motivation behind low-carbon cities, existing literature has very limited analysis of the actual progress and challenges facing Chinese cities seeking a path of low-carbon urban development. Through this case study, policymakers in Vietnam should probably consider the idea of low-carbon cities and make plans for the upcoming changes in large cities, such as Ha Noi or Ho Chi Minh, whose carbon emission levels are at rather high grade.

Foreign Direct Investment Selection Policy

In recent decades, the impact of FDI inflows on the environmental quality of receiving countries has become a concern for many national governments. The reason is that the economic benefits that FDI brings can be eliminated at the expense of future environmental costs caused by FDI, and Vietnam is one of these countries that are receiving FDI. Additionally, trade liberalization makes environmentally polluting goods tend to move to poorer countries, turning these places into "pollution hiding places". Overall, Vietnam's government should provide grants and tax incentives policy for FDI projects related to clean energy and green technology, and the development of clean public transportation systems. Moreover, the policy that encourage the reduction of green trade barriers is needed, for example, eliminating trade barriers for products and services related to reducing carbon emissions, eventually promoting the export of products and technology green. Besides, competitive policies to attract FDI with countries in the region need to shift from relaxing environmental regulations to improving infrastructure conditions, human resource quality, and developing other investment support services. In addition, the government should not consider expanding or extending operations for FDI projects that use outdated technology, pose a potential risk of environmental pollution, and are resource-intensive. Domestic businesses must also make efforts, seek connection opportunities, and proactively provide information about business capabilities such as technology, scale, strengths, and products and services to seek connections with FDI businesses.

Green Industrialization

In many provinces and cities across the country, many industrial areas want to deploy green production but are facing problems with policies. Among them, the biggest obstacles affecting the symbiotic process of businesses are waste circulation in production, investment in rooftop solar power projects to have renewable energy sources for production, and lack of green capital with preferential interest rates for businesses to borrow to invest in machinery, reduce fuel consumption, reduce emissions, etc. In the trend of production and export, many foreign partners have a roadmap requiring factories to apply green production processes. Therefore, the Government needs to encourage green production, in which, green industrial policy (GIP) is an effective tool to achieve fundamental and long-term transformations. GIP helps to minimize negative impacts from all forms of environmental pollution and develop the country towards long-term sustainability in the future. It does this by effectively using legal tools to establish access rights and quotas for resource use and minimize pollutants or "environment tax" policies, which directly reflect social costs from pollution to prices, causing short-term changes in consumer behavior and moving towards the development of a clean and sustainable industry.

6. Conclusion

In conclusion, the digital economy does have a positive effect on the reduction of carbon emissions. For the first hypothesis, we have proved that the digital economy and CO_2 emissions are correlated in an inverted U-shaped according to the Environmental Kuznets Curve hypothesis, indicating that at the initial stages of digitalization, CO_2 emissions would rise and peak at the top of the U-shaped curve before digitalization encourages sustainable behavior and the decrease of emissions, thereby decreasing carbon emissions. Similarly, both ineffective industrialization and massive urbanization from digitalization cause the increasing of carbon emissions, particularly because both industrialization and urbanization require significant energy consumption, thereby leading to high carbon emissions.

In the meantime, although the Vietnamese government has proposed some effective policies that help facilitate environmental protection, as well as programs that promote the leverage of renewable energy, we also recognize there have been few policies that directly regulate the reduction of carbon emissions. As a result, based on the preceding findings, we would initiate extensive policy recommendations, covering urban development and transportation, FDI, renewable energy adoption, to green industrialization. Specifically, from the case study of China, we recommend that the government should adopt a low-carbon cities model and implement it first with large cities such as Hanoi or Ho Chi Minh City, whose carbon emissions are quite high. For transportation, Vietnamese authorities should take population density in large cities into consideration, thereby establishing better infrastructure plans, for example, by building multinational corporations' branches far from residential areas. Additionally, policymakers should promote green lifestyles across different government channels to signify the urgency of the situation, thereby accelerating the adoption of sustainable consumption among the nationals.

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