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Impact of Digital Economy Development on Carbon Emissions an Empirical Study based on 15 RCEP Countries

Senquan Kong[1*] ,Yi Wu[2], Xinyu Wang[3], Wenpei Cui[4]

[1 2 3 4]Universiti Putra Malaysia,School of Business and Economics,Serdang Selangor, 43400,Malaysia

[4]Lvliang university,department of economic management,Lvliang 033000,Shanxi,China

Email:

[1*]hnsbyxksq@163.com.,[2]1049071517@qq.com.,[3]1246150613@qq.com.,[4]569047067@qq.com

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Abstract

The environmental problems caused by global warming have made low-carbon development a focus of attention worldwide. At the same time, the digital economy based on the Internet, big data, cloud computing, and other new technologies have become an important force in driving the country's economic development. Can the digital economy contribute to low-carbon development while driving the computing infrastructure? This paper selects 210 sample data points from 15 RCEP countries from 2005 to 2018 and uses OLS robust standard error regression to study the impact of the digital economy on carbon emissions and its mechanism of action. It is found that there is a significant inverted U-shaped relationship between the digital economy and carbon emissions, while the dual effects of the digital economy and the level of information infrastructure have a suppressive effect on carbon emissions. Based on the above research results, the following insights are proposed: strengthen the dual development of the digital economy and information infrastructure in RECP countries; enhance the research and development of digital economy products; and improve technological support capabilities.

Keywords：RCEP, Digital Economy,Carbon Emissions,Level of Information Infrastructure.

1.Introduction

After the third technological revolution, the world entered the information age, and various information products began to be marketed. The digital economy is a new economic form that has emerged from this situation, a trend in economic development and the result of various technological impulses. The digital economy and the information economy are both economic forms with modern service industries as their main structure. When the information economy has reached a certain stage of development, it evolves into the digital economy, which is an advanced stage of the information economy.(Xu,2022) The digital economy mainly uses the Internet, big data, artificial intelligence, and other technologies to communicate with each other across different countries, reflecting the characteristics of data diversity, wide dissemination, ease of use, and rapid flow. All countries and peoples were equal before the digital age. At present, there is no consensus on the definition and scope of the digital economy, and there is no unified international standard for accounting methods. The following three methods are commonly used to measure the scale of the digital economy, such as using the production method, using regression models, and using the growth function framework.(Xian&Wang,2022)Based on the measurement results, the current situation and development trend of the core industries of the digital economy are further analyzed through structural analysis to observe the characteristics of the industrial structure of the digital economy, realize the status and contribution of the core industries of the digital economy in the macroeconomy, and provide numerical support to clarify the development goals of the core industries of the digital economy.

As the digital economy continues to rise in global economic development, many of its problems are becoming increasingly apparent: for example, uneven regional development, a gradually deepening digital divide, a severe shortage of information and communication facilities, and growing social polarisation. At present, only by strengthening international cooperation, activating the creative potential of the digital economy, and promoting digital sharing to create greater value can we achieve

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the effect of making full use of the digital chain and be more helpful in dealing with serious problems such as ecological changes, public health, and information security in various countries. Some studies have suggested that the rapid development of ICT and industry has led to a rapid increase in electricity consumption, which has led to an increase in carbon emissions; others have suggested that ICT development will improve environmental quality by reducing greenhouse gas emissions.(Xu et al.,2022)Based on the RCEP-15 countries, this paper aims to address the outstanding issues in the economy such as carbon emissions, information infrastructure, GDP per capita, urbanization levels, etc., by forming multilateral and equal consultations, to promote the early achievement of actionable and enforceable goals for the digital economy and the development of the regional digital economy. Using a richer and multi-layered digital economy to strengthen the economies of member countries, promote a balanced, diversified, and secure development of the digital economy in the countries of the region, and achieve a harmonious growth of the social-ecological environment and socio-economic systems, thus contributing to the promotion of the global digital economy.

2. Theoretical Analysis and Hypothesis Study

Although existing studies suggest that the digital economy may affect energy consumption and carbon emissions, there is relatively little literature directly exploring the relationship between the digital economy and carbon emissions, and the mechanisms involved have not yet been systematically explained. The analysis of the theoretical mechanism of the impact of the digital economy on carbon emissions is the key to the subsequent research. Therefore, after combing through a large amount of literature, this study starts the analysis of the mechanism of the impact of the digital economy on carbon emissions based on the following aspects:

2.1The Impact of The Digital Economy on Infrastructure

Digital infrastructure is an important foundation and prerequisite for the in-depth development of the digital economy, and it is also fundamental for the digital economy to exert an environmental improvement effect. On the one hand, the wide coverage of access facilities and the low threshold for

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the use of devices have narrowed the digital access divide and promoted the formation of informal environmental regulation. On the other hand, the goal of a digital economy for sustainable development is achieved by linking digital infrastructures. For example, it supports the implementation of government policies to promote green, low-carbon, and sustainable urban development based on sensors, smart devices, communication platforms, and other facilities to connect urban elements.(Zhang&Ji, 2019)

2.2The Impact of The Digital Economy on Structural Optimisation

The effect of the digital economy on the optimization of the industrial structure is mainly due to technological penetration and industrial convergence. In the context of the rapid development of information technology, the Internet and the Internet of Things, with their characteristics of openness, collaboration, sharing, and connectivity are gradually becoming important production application tools and integrating with traditional production factors and resources, penetrating the industry and thus promoting industrial upgrading. (Ivus&Boland, 2015)

2.3The Impact of The Digital Economy on Technological Innovation

There are two main pathways through which the digital economy affects carbon emissions through technological innovation. On the one hand, through the penetration of technologies such as big data, cloud computing, Internet of Things, and industrial Internet into the industry, the pollution management strategy, and energy management mode of the industry can be optimized and upgraded in multiple dimensions. On the other hand, digital technologies can also enhance the city's innovation environment through talent clustering and the supply of technology and finance, accelerate the city's digital transformation and innovation, and facilitate technological innovation to have an abatement effect. (Lu et al.,2021).

2.4The Impact of The Digital Economy on Resource Allocation

In essence, the conflict between economic development and the environment for resources is determined by the pattern of allocation and combination of the various factors of production and the efficiency of their use. Related studies also point to resource allocation as a major factor influencing carbon productivity. The digital economy uses the network effect to increase effective supply and demand information, improve price mechanisms, match supply and demand, change transactions and distribution activities, and improve resource allocation efficiency. (Jing et al.,2019)

2.5Literature Review

The impact of the digital economy on environmental pollution or carbon emissions is receiving increasingly widespread academic attention. In recent years, the digital economy has been used on a large scale and in-depth. In the early 1990s,(Grossman&Krueger,1995)Grossman and Krueger proposed: “an environmental Kuznets curve for the relationship between the level of economic development and environmental pollution”. This is based on the theory of the EKC curve, which states that there is an "inverted u-shaped" relationship between the level of income per capita and environmental pollution.

In addition to the above points, there are two other "single pathway" views in academia. Usama and Che, for example, (Al-Mulali&Sab, 2012). provide empirical evidence that economic growth increases carbon emissions when the wealth and scale effects of finance outweigh the technological and structural effects of economic. This is because when there is less pressure on firms to raise finance, they invest heavily in energy-intensive industries in pursuit of profits, and the high pollution caused by their energy consumption seriously affects the quality of the environment.The energy consumption associated with increased production also raises carbon emissions. Economic development, on the other hand, stimulates consumption by increasing household credit, which increases consumer purchases of energy-intensive goods while also increasing carbon emissions.

3.Research Design

3.1Factor Analysis

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Table 1:Seven Secondary Indicators of Information Infrastructure

Indicators at Level 1	Indicators at Level 2
Information Infrastructure	The number of subscribing to fixed broadband
	Individuals using the Internet as a percentage of the total population
	The number of subscribing to Landline
	The number of subscribing to Landline (Thousands of people in units)

Source :The World Bank

Table 2:KMO and Bartlett's Feasibility Test Results

KMO test		0.581
Bartlett's sphericity test	Chi-square	681.030
	Degrees of freedom	6
	P-value	0.000

Table 3:Factor Analysis

Factor	Variable Eigenvalues	Contribution of Variance	Contribution of Cumulative Variance
Factor1	2.61952	0.6549	0.6549
Factor2	1.01157	0.2529	0.9078

IFOR=F1*0.6549/0.9078+F2*0.2529/0.9078

Table 1:A factor analysis of the secondary indicators related to information infrastructure is conducted to synthesize a comprehensive indicator for information infrastructure.

Table 2: Before doing the factor analysis by performing KMO and Bartlett's test of sphericity (where the KMO test value is between 0 and 1), the KMO value is close to 1 when the sum of squared simple correlation coefficients between all variables is much greater than the sum of squared partial

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correlation coefficients. At the same time, the closer the KMO value is to 1, the stronger the correlation between the variables and the more suitable the original variables are for factor analysis. The KMO test here has a test value of 0.581, indicating that it is suitable for factor analysis; it also has a p-value of less than 1%, thus rejecting the original hypothesis and making it suitable for factor analysis.

Table 3:Using regression by factor analysis to derive factors whose eigenvalues were greater than one and whose cumulative variance contribution was found to be greater than 90%, and then by predicting Factor 1 and Factor 2 and finally calculating the composite factor as IFOR.

3.2The Basic Model

This paper first develops ordinary OLS multiple regression models and performs OLS robust standard error regressions to empirically analyze the impact of digital economic development on carbon emissions. Considering the large fluctuation of data with different magnitudes, this paper takes logarithmic treatment for some variables, and the base model is set as follows:

$lnTCO_{2it}=\alpha_0+\alpha_1 lnPDIG_{it}+\alpha_2 lnPGDP_{it}+\alpha_3 Urban_{it}+\delta_{jt}$ （1）

3.3 Intermediary Model

Based on the previous analysis, "the development of the digital economy will further affect carbon emissions by influencing the construction of information infrastructure, and the impact of the digital economy on the construction of information infrastructure has a non-linear relationship." To verify the above inference, this paper uses a mediation model for validation, specifically drawing on the approach of Wen Zhonglin and Ye Baojuan (Wen & Ye, 2014) below, which uses a distributional regression approach. Firstly, regression estimation based on the impact of digital economy development on carbon emissions is carried out as follows:

$lnTCO_{2it}=\theta_0+\theta_1 lnPDIG_{it}+\theta_2(lnPDIG_{it})^2+\theta_3 lnPGDP_{it}+\theta_4 Urban_{it}+\varphi_{it}$ （2）

Among them, lnTCO2it represents the logarithmic CO2 emissions of a country i in year t; lnPDIGit and lnPDIGit are the digital economy index and its squared term, respectively; lnPGDPit represents

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the level of development in a country i in year t; Urbanit represents the level of urbanization in a country i in year t, and φ_{it} is a random disturbance term.

Second, regressions were estimated with the quality of information infrastructure as the explanatory variable and the digital economy as the core explanatory variable:

$IFOR_{it}=\beta_0+\beta_1 lnPDIG_{it}+\beta_2(lnPDIG_{it})^2+\beta_3 lnPGDP_{it}+\beta_4 Urban_{it}+\varepsilon_{it}$ (3)

Finally, carbon emissions as the explanatory variable, the digital economy as the core explanatory variable, and the quality of information infrastructure as the mediating variable were put into the same model for regression estimation:

$lnTCO_{2it}=\gamma_0+\gamma_1 lnPDIG_{it}+\gamma_2(lnPDIG_{it})^2+\gamma_3 IFOR_{it}+\gamma_4 lnPGDP_{it}+\gamma_5 Urban_{it}+\eta_{it}$(4)

3.4The Cross Items of Intermediary Variables and The Digital Economy

Adding mediating variables, the cross items of intermediary variables and the digital economy to model (1) for regression analysis.

$lnTCO_{2it}=\lambda_0+\lambda_1 lnPDIG_{it}+\lambda_2 IFOR_{it}+\lambda_3 lnPDIG_{it}*IFOR_{it}+\lambda_4 lnPGDP_{it}+\lambda_5 Urban_{it}+ \nu_{it}$(5)

3.5 Definition of Variables

Table 4:Definition of Variables

Name of The Variable	Category of The Variable	Symbols for Variables	Definition and Calculation of Variables
Carbon Emission	Explained Variable	$lnTCO_2$	Total CO2 Emissions in ACountry i (metric tonnes) Take Logarithm
The Digital Economy	Explaining Variable	lnPDIG	Total Exports and Imports of Digitally Delivered Services in ACountry i (US dollars)/Population of ACountry i (number of people)Take Logarithm
The Square Side of The		$(lnPDIG)^2$	Total Exports and Imports of Digitally Delivered Services in ACountry i (US

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Digital Economy			dollars)/Population of ACountry i (Number of People)Take The Square of The Logarithm
Information Infrastructure	Intermediate Variable	IFOR	Calculated from Factor Analysis
Per Capita GDP	Controlled Variables	lnPGDP	Total GDP (current dollars)/Total Number of People(Number of People)Take Logarithm
Urbanization Level		Urban	The proportion of the urban population in the total population

Source :Data on carbon emissions、information infrastructure、per capita GDP、urbanization level are from the World Bank；Data on total imports and exports of digital delivery services (USD) are from UNCTAD.

3.6 Data Sources

The data sources for the indicators selected in this paper are mainly from the World Bank and UNCTAD and relate to 15 RCEP countries, including "Australia, Brunei, Cambodia, China, Indonesia, Japan, Laos, Malaysia, Myanmar, New Zealand, Philippines, Singapore, South Korea, Thailand, and Vietnam." At the same time, "spanning the period 2005–2018 with a total sample size of 210, some missing values are supplemented by linear interpolation and proximate year means"; descriptive statistics for all variables are shown in Table 5.

Table 5:Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
lnTCO2	210	18.476	2.118	14.047	23.075
lnPDIG	210	5.591	2.145	-0.274	10.569
$(\ln PDIG)^2$	210	35.838	24.557	0.061	111.71

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IFOR	210	-1.49e-09	0.773	-0.712	4.131
lnPGDP	210	8.868	1.56	5.377	11.13
Urban	210	59.694	25.219	19.17	100

4.Empirical Analysisof The Model

4.1 Model regression analysis

Table 6 shows the analysis of the overall sample of RCEP countries. In this paper, the primary term of the digital economy is included in the regression model before controlling for other variables that may affect the level of carbon emissions, and the regression results are shown in column (1) of Table 6. The regression coefficient of the digital economy on carbon emissions is -0.276, which does not pass the significance test.The quadratic term of the digital economy was then added to the model to examine whether the digital economy affects carbon emissions in a non-linear relationship. The regression results are shown in column (2), where the coefficient of the primary term of the digital economy (lnPDIG) is positive and passes the 1% significance test, while the coefficient of the quadratic term of the digital economy is negative and passes the 1% significance test, indicating a significant inverse U-shaped relationship between the digital economy and carbon emissions.This is because the digital economy is not mature in the early stages of development. In the process of digital industrialization and digitalization of industry, the high input and high cost caused by the digital economy have raised the carbon emissions in production and life, further leading to the level of carbon emissions in the previous period only rising but not decreasing.As the digital economy continues to mature, the initial investment in capital, manpower, and technology gradually produces a positive net effect. Energy use efficiency is improved, the industrial structure is optimized and upgraded, and the production costs of enterprises are reduced, thus significantly reducing the level of carbon emissions.In column (2), every 1% increase in lnPGDP is associated with a 0.662% decrease in $lnTCO_2$, showing a negative inhibitory effect and passing the 1% significance test,indicating that the higher the country's GDP per capita, the more attention people pay to carbon emissions, which in turn reduces them, while every 1 increase in urban areas increases $lnTCO_2$ by 0.085%, passing the 1%

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significance test, indicating that higher levels of urbanization increase people's carbon emissions.

The paper also uses a mediation model to test whether there is a mediation effect between infrastructure development and carbon emissions in the digital economy,the test results are shown in columns (3) and (4) of Table 6.Column (3) shows that the impact of the digital economy on the level of information infrastructure is significant at the 1% significance level, where the coefficient of the primary term of the digital economy is significantly positive and the coefficient of the second term is significantly negative, indicating that the digital economy has an inverted U-shaped relationship of first promoting and then inhibiting the level of information infrastructure.In the early stages of the digital economy, the level of information infrastructure was raised, but the latter reached a peak and then turned to a downward trend.Integrating information infrastructure and the digital economy into the model to examine the impact on carbon emissions,the regression results are shown in column (4) of Table 6, which shows that the impact of the digital economy on carbon emissions is still a significant inverted U-shaped relationship. The coefficient of the regression of the digital economy on carbon emissions decreases in both the primary and secondary terms after the inclusion of the information infrastructure variable, indicating that the information infrastructure plays a partial mediating role, i.e. the digital economy indirectly suppresses carbon emissions by affecting the information infrastructure. In addition, the regression coefficient of information infrastructure is significantly positive at the 1% significance level, indicating that information infrastructure has a significant contribution to carbon emissions, and that the level of carbon emissions will gradually increase as the information infrastructure increases, but when the impact of digitalisation level on information infrastructure reaches a certain peak and starts to gradually decrease, this is when the carbon emissions start to decrease.

Further, in terms of the inflection point at which the development of the digital economy has a dampening effect on carbon emissions, the inflection point was 4.975 before the inclusion of IFOR, i.e. when the level of the digital economy is greater than 4.975, it has a dampening effect on carbon emissions. The current average level of the digital economy is 5.591, which is greater than its inflection point of 4.975. 124 out of 210 samples have crossed the inflection point and exerted the

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carbon reduction effect of the digital economy, indicating that the digital economy in RECP countries is mainly distributed on the right side of the inverted U-shape and has a suppressive effect on carbon emissions. After adding the variable "information infrastructure", the inflection point value is 5.818, and 108 out of the total 210 samples have crossed the inflection point and exerted the carbon emission reduction effect of the digital economy. The inflection point of the variable "information infrastructure" is 2.370, which is smaller than the current average level of the digital economy of 5.591. 198 out of 210 samples crossed the inflection point and exerted the inhibiting effect of the digital economy on the level of information infrastructure, indicating that the digital economy in RECP countries is mainly distributed on the right side of the inverted U-shape. As they are still in the early stages of digital economy development, the development of their information infrastructure is at an early stage and, therefore, the development of the digital economy has a catalytic effect on the level of information infrastructure.

When analysing the variable lnPGDP in column (3), it is found that for every 1% increase in lnPGDP, the IFOR increases by 0.287%. This indicates that the higher the country's GDP per capita, the greater the level of information infrastructure required. IFOR in column (4) is significant at the 1% level for lnTCO2 and shows a positive contribution, indicating that the development of information infrastructure is still in its early stages and therefore increases carbon emissions; meanwhile, every 1% increase in lnPGD is associated with a 1.162% decrease in lnTCO2 and passes the 1% significance test; every 1% increase in Urban is associated with an increase in lnTCO2 of 1.162%; the explanation is similar to that of lnPGDP and Urban in column (2).

Column (5) contains more variables IFOR and lnPDIG*IFOR than column (1). According to the analysis, “we found that the increase in lnPDIG has a suppressive effect on $lnTCO_2$ and passes the 1% significance test, indicating that the development of the digital economy will reduce carbon emissions; each 1 increase in IFOR will increase $lnTCO_2$ by 5.973% and it passes the 1% significance test, indicating that the development of information infrastructure increases carbon emissions.For the cross-sectional term lnPDIG*IFOR, the study shows that carbon emissions are significantly suppressed by both the digital economy and the level of information infrastructure and passes the 1%

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significance test". Therefore, carbon emissions cannot be reduced by the development of information infrastructure alone, but can only be effectively suppressed by both the digital economy and the level of information infrastructure.

Table 6 Results of The Model Regression

	(1)	(2)	(3)	(4)	(5)
VARIABLES	$\ln TCO_2$	$\ln TCO_2$	IFOR	$\ln TCO_2$	$\ln TCO_2$
lnPDIG	-0.276	1.980***	0.128***	1.757***	-0.336**
	(0.187)	(0.198)	(0.0484)	(0.168)	(0.134)
$(\ln PDIG)^2$		-0.199***	-0.0272***	-0.151***	
		(0.0189)	(0.00592)	(0.0127)	
IFOR				1.739***	5.973***
				(0.167)	(0.732)
lnPDIG*IFOR					-0.847***
					(0.164)
lnPGDP	0.343	-0.662**	0.287***	-1.162***	-0.612**
	(0.314)	(0.263)	(0.0966)	(0.206)	(0.243)
Urban	0.027	0.085***	0.006	0.074***	0.063***
	(0.020)	(0.016)	(0.004)	(0.013)	(0.015)
Constant	15.39***	15.36***	-2.639***	19.95***	22.32***
	(1.671)	(1.345)	(0.502)	(1.121)	(1.290)
Observations	210	210	210	210	210
R-squared	0.103	0.357	0.188	0.685	0.598

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

5.Conclusions and Policy Analysis

By analyzing the 15 sample countries of the RECP from 2005–2018, a total sample size of 210 was found. When only the primary term of the digital economy was studied, it was found that the development of the digital economy did not affect carbon emissions; when the second term of the digital economy was added, it was found that the digital economy showed an inverted U-shape on carbon emissions. When "information infrastructure" is used as a mediating variable, it is found that the level of information infrastructure development partially mediates between the digital economy and carbon emissions and allows the digital economy to have a certain reduction effect on carbon emissions; at the same time, the dual effect of the digital economy and information infrastructure development has a significant effect on carbon emissions. The following policy recommendations are therefore made based on the conclusions drawn above.

5.1Enhance Digital Infrastructure for Energy Efficiency in The Digital Economy

By promoting the construction of a new generation of information infrastructure, accelerating the realization of higher quality interconnection, and providing solid information infrastructure support for the development of the digital economy, thereby promoting the application of the digital economy more widely, exploring environmentally-friendly models for public participation, and promoting the digital economy to further reduce carbon emissions, We should accelerate the construction of new infrastructure that carries digital technologies and platforms, such as 5G network base stations, big data centers, blockchain services, and artificial intelligence, to promote the digital transformation of the economy comprehensively.

5.2Strengthen Research and Development of Digital Innovations and Improve The Capacity for Technical Support

On the one hand, it will increase the intensity of investment in innovation and research and development, promote the research and development of technologies such as cloud computing, industrial internet, and big data, improve the application and transformation of basic and publicly applicable technologies, and increase production efficiency; on the other hand, it will focus on the digital economy education field, cultivate digital awareness of the public, and increase production efficiency.

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5.3Focus on The Development of Innovative Efficiency

Research has found that innovation efficiency not only curbs carbon emissions, but that the digital economy will have a pre-existing curbing effect on carbon emissions when innovation efficiency is available, but that this effect is currently more limited. Scientific planning and rational and efficient allocation are needed to ensure that innovation inputs are active and moderate, green and environmentally friendly, and that input and output losses are reduced, thus ensuring high efficiency and quality of innovation outputs. At the same time, the government should exercise good management, supervision, and control functions， build and improve the innovation efficiency transformation mechanism; improve the communication and collaboration mechanism with enterprises, and form an efficient operation system of macro governance and micro implementation.

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