Research on the Decoupling Effect of China's Regional Digital Economy Development and Carbon Emissions

Zhang Mengke[1,a], Huang Yan[1,b*], Bao Yuan[1,c], Jin Yifan[1,d]

[1]School of Management, Beijing Union University, North Fourth Ring Road East 97, Beijing 100101, China

Abstract: The development of digital economy is conducive to empowering technological innovation and optimizing industrial structure, thus reducing the environmental pollution caused by industrial development. However, the development of digital economy also implies an increase in energy demand. Whether its impact on CO2 emissions is the same as or opposite to the Kuznets hypothesis in a "U-shaped" or "N-shaped" relationship, and whether there is a decoupling effect between the two, deserves further study. In this paper, we analyze the non-linear impact of digital economy on carbon emissions through literature research, and the possible decoupling relationship between the two. The decoupling is examined by two measures: velocity decoupling and quantity decoupling. In addition, the inter- and intra-regional variability of digital economy development and carbon emissions is analyzed through the Thiel index. The results of this study add to the empirical techniques and findings on the link between digital economy and carbon emissions, as well as provide theoretical references to support high-quality growth of digital economy and inter-regional cooperation in each region.

1. Introduction

China's economy has changed from rapid to high-quality development, and constructing a modern economic system has become an essential demand and strategic aim in order to accomplish rapid growth. At this point, China's digital economy industry is in an important period of scale expansion and value creation, based on the "Digital China" development strategy, based on the integration of artificial intelligence and big data, and other economic technologies to promote the construction of a multi-dimensional digital economy has become the trend of China's economy's high-quality development. In fact, China's digital economy is developing rapidly, and according to the scale of China's digital economy and the "14th Five-Year Plan" research report [1], the added value of China's digital economy industry reached 1,702,934 billion yuan in 2019, with an actual growth rate of 11.3%, and accounted for 17.2% of the national economy in the same period, which has become an important part of the current economic development. The China Digital Economy Development Report 2020 [2] points out that, in terms of regional development, the scale of the national digital economy development shows a trend of gradually decreasing from the southeast coast to the western inland. With the rise of the "cluster economy" in urban clusters, the economic agglomeration model of "going from point to surface, from line to piece" has emerged as the fundamental pattern of regional growth. How to achieve an effective match between the digital economy and the global aim of high-quality development is a practical issue that must be addressed quickly in China.

The growth of the digital economy opens up new possibilities for changing the geographical structure of economic output. Based on the rich connotation of the information revolution and factor reconfiguration, digital economy development breaks the traditional constraints of geographic conditions, information transmission, and time costs, and strengthens the free flow of technological-based production factors in the spatial scope, becoming one of the decisive locational factors for spatial economic layout. Simultaneously, sustaining stable growth in the digital economy entails an increase in energy demand, and China's carbon emission reduction objectives are unquestionably under significant strain and difficulty. China is a big contributor to climate change, making any effort to lessen its economy's reliance on fossil-fueled energy carriers all the more important [3,4]. As a great and responsible country, the Chinese government has also proposed a dual carbon target of "carbon peaking" by 2030 and "carbon neutral" by 2060 to control carbon emissions. The digital economy plays an important leading role in promoting economic and social development, and studies have shown that as an emerging economy, the digital economy has further enhanced the digitalization, networking, and intelligence of the economy and society through the new development of digital industrialization and digitalization of industry, and has shown good ecological enhancement while strongly promoting the economic development and innovation capacity of enterprises. role. Castro et al. [5] reviewed previous studies and concluded that combining digitalization with sustainable development will provide tremendous opportunities for creating a green economy and society

* Corresponding author: [b]glthuangyan@buu.edu.cn
[a]alwaysseet1001@163.com
[c]by13303459780@163.com
[d]1023003038@qq.com

and pave the way for achieving the SDGs.

As a result, it is both theoretical and practical to investigate the influence of regional digital economy development on carbon emissions in China. Decoupling theory has been used to different domains such as industrial development, tourism economy, agriculture, energy, and so on. Most earlier research on the digital economy and carbon emissions used model regression for empirical testing [6]. Incorporating decoupling theory into the research of digital economy development and carbon emission may investigate the dynamic link between the two and determine if digital economy development can contribute to environmental improvement, energy savings, and emission reduction. Meanwhile, diversified regional development methods (originating in the east, rising in the center, growing in the west, and rejuvenating in the northeast) demonstrate that China has considerable regional variances in economic level, industrial structure, and natural resource endowment. Therefore, in implementing the low-carbon economic transition, it is important to focus not only on the universality of development but also to consider the local heterogeneity of carbon emissions [7]. In order to broaden the scope of research on the decoupling effect of digital economy and CO2 emissions, and to fill the gap of this research topic by combining the disciplinary characteristics of regional economic and environmental sustainable development. This paper will focus on exploring the decoupling effect and regional heterogeneity of digital economy development and carbon emissions. Complementary empirical test research is conducted to provide a scientific basis and theoretical reference for promoting regional coordination, synergy, and joint development of the digital economy, reducing carbon emissions in each region, and promoting high-quality urban development. To sum up, the main contributions of this paper are as follows: first, as a relatively new concept, this paper constructs a digital economy development index system from four dimensions: digital infrastructure, digital financial development, digital industry development, and digital technology innovation, and selects the entropy method using time decay function processing to measure the level of digital economy development. Second, this paper analyzes the impact of digital economy development on carbon emissions from a regional perspective. On the one hand, the reasons for the differences in regional carbon emissions in China are explained. On the other hand, the black box of the decoupling relationship between digital economy development and carbon emissions is opened. This paper enriches the empirical research on the decoupling effect; it provides a new perspective and a feasible path to achieve the dual carbon target. Future carbon emission reduction policies can consider the integration of digital technology to achieve sustainable social development through digital emission reduction.

2. Literature review

2.1. Introduction to the decoupling method

People's demand for economic development has not only been limited to the speed of development but also to raise the quality of development to a higher level. The relationship between the development of the digital economy and the ecological environment has become a hot issue for academic research. The relationship between energy use or related CO2 emissionand economic growth can be explored by many methods, such as simple regressions, correlation analysis, bivariate causality, panel cointegration, multivariate cointegration, unit root testing, variance decomposition and vector error correction modeling [8]. Among all available methods, decoupling is the best way to characterize the de-dependence of economic growth (GDP) on energy consumption, using the theory of "decoupling" to analyze the relationship between the development of each region or industry and its environmental impact (environmental pressure). The notion of decoupling was firstly introduced by Von [9]. Initially decoupling was defined as a state of rupture in the relationship between economic growth and the response to environmental shocks, and it was considered that a decoupling relationship exists between the two when the regional economy brings about the same or faster economic growth with lower resource consumption and environmental stress in a certain period of time. However, Zhang [10] firstly utilized the decoupling concept to explore the relationship between China's energy-related CO2 emission and economic growth. This was the first application of decoupling theory in the environmental field. In 2002, the OECD [11] developed that concept into an indicator. Common measures of decoupling analysis can be divided into velocity decoupling and quantity decoupling. Velocity decoupling means that the rate of growth of environmental pollutants diverges from the rate of economic growth. If the rate of increase of environmental pollutants in a certain period is smaller than the rate of economic growth, the link between environmental pressure and economic performance has been broken and the two are decoupled. The most commonly used model is the Tapio decoupling model, which is the "Tapio decoupling index" and the corresponding decoupling status classification criteria proposed by Tapio [12] in his study of GDP growth and carbon emission changes in 15 EU countries. Quantitative decoupling refers to the tendency of the total increase of environmental pollutants to decrease with the process of economic growth, and the more commonly used is the environmental Kuznets curve [13], which analyzes the fluctuation of carbon emissions with economic growth by determining the existence of the inflection point [14,15]. The decoupling theory and the EKC hypothesis, both of which describe the dynamic relationship between economic development and environmental pollution, among which the decoupling theory reveals the correlation between economic development and whether environmental pressure changes synchronously, while the EKC hypothesis precedes the decoupling theory and illustrates the non-linear relationship between environmental pollution and the level of economic development. Gradually, scholars have also combined the two measures and introduced them into the data analysis simultaneously [16], increasing the robustness of the decoupling effect.

Combining the above two theoretical understandings, the EKC hypothesis describes the non-linear relationship between economic development and resource and environmental loads, while the decoupling theory explains the synchronization (or lag) between the two in the process of sustainable development. If the EKC hypothesis and the decoupling theory can be effectively combined, the absolute and relative changes of digital economic development and environmental pollution can be explored to determine whether the decoupling status of cities lags behind economic growth, and finally provide directions for improving the green development of cities.

2.2. Study on the decoupling relationship between economic development and carbon emissions

Due to the rational decoupling positions with eight possible combinations, the Taipo decoupling method has being widely used by many researchers [17]. For example, Climent and Pardo [8] used the Taipo decoupling indicator to investigate the causal relationship between energy use and Spanish economic growth. The Taipo decoupling indicator was utilized by Freitas and Kaneko [18] to study the occurrence of a decoupling between Brazil's economic growth and energy-related CO2 emission over the period 2004-2009. That indicator was also used by Zhang and Wang [19] to study the decoupling status between GDP and energy-related CO2 emission in Jiangsu province during the period 1995-2009. Over time, scholars have enriched the research perspectives on decoupling effects. From a global perspective, some studies reveal the decoupling process between the global economy and carbon emissions as a key breakthrough point in the search for a global low-carbon economic development path [20]. Narrowing the scope further, the absolute decoupling and relative decoupling effects of economic development and CO2 emissions were observed in all GCC countries except Saudi Arabia [13]. Decoupling relationships between agricultural carbon emissions [21], industrial carbon emissions [7,22], and transportation [23] and regional economic growth are also found in different industry perspectives, and there are significant differences between regions. Jiang et al. [24]studied the relationship between CO2 emissions and the economy from a sectoral perspective by applying the Tapio decoupling method. In addition to this, decoupling theory is no longer limited to the study of carbon emissions, as Wang et al. [25] used the Tapio decoupling method to study the dependence of the economy on water use in Beijing, Shanghai, and Guangzhou. This shows that the definition of economic development is being subdivided in the scope of the decoupling effect study, and is not limited to the level of economic development expressed in terms of GDP. The method has been applied more widely, including in studies of transportation, agriculture and industry, and management, enriching the application scenarios of quantitative decoupling and velocity decoupling.

2.3. Study on the decoupling relationship between the digital economy and carbon emissions

Green growth theory states that continued economic expansion is compatible with the ecology of our planet. This is because technological change and substitution will allow us to absolutely decouple GDP growth from resource use and carbon emissions. However, the theory is still assumed. The findings of empirical studies on resource use and carbon emissions do not support this assertion. [26] This leads us to ponder whether the growth of the digital economy can explain technological enhancements and thus environmental improvements. In academia, there are divergent opinions on the definition of the “digital economy”. From a qualitative point of view, the digital economy is also called the “new economy”. It is a special economic form that emphasizes the trading of goods and services in the digital form of new activities and new products [27,28].

The development of the digital economy is underpinned by technological upgrading, where the environmental improvement effects of the digital economy are one of the major ongoing concerns of both academic and practical communities. The digital economy is gradually becoming an important driver of regional low-carbon development [29], which not only significantly improves the efficiency level of the green economy in regional cities, but also has a positive spatial spillover effect on the efficiency of the green economy in neighboring regions [30]. At the same time, different boosting effects were generated in regions with different regional and industrial structures [31,32]. Some scholars have already started to explore the nonlinear influence effect of digital economy development on carbon emissions [33]. To create the economic agglomeration, Xiaoyang Li et al. [34] combined digital economy and carbon emission components into the standard production function and EKC curve analysis. To explain the non-linear relationship between digital economy development and spatial emission reduction and its mechanism of action in a normative way, a theoretical model of spatial emission reduction effect of digital economy development under the influence of economic agglomeration was developed. The results show an inverted U-shaped curve relationship between digital economy development and local carbon intensity and carbon emissions, and when the level of digital economy development is below a certain threshold, it shows a negative emission reduction effect of raising carbon intensity and increasing total carbon emissions, whereas when it exceeds this threshold, it shows a positive emission reduction effect of lowering carbon intensity and decreasing total carbon emissions. In addition, other scholars have empirically tested the effect of the digital economy on carbon emission decoupling by constructing a panel smooth transition regression (PSTR) model [31]; as well as narrowing down the industry, there is a u-shaped correlation between carbon emissions in China's logistics industry, and it is in the first half of the u-shaped correlation [35]. And, through an in-depth study, ZHI QIANG LI and YING LIU [36] have explored the spatial distribution pattern of China's digital economy, specifically characterized by a huge gap in the level of digital economy development between regions. The overall level and high-quality development of the digital economy is not high and is mainly concentrated in the coastal areas and the middle reaches of the Yangtze River and the Yellow River. The level of digital economy development in different regions is not randomly distributed, but significantly spatially positively correlated agglomeration distribution. The existence of high and low agglomeration with significant spatial path dependence and spatial locking [37], this result indicates that there are significant differences in the effect of the development of the digital economy on carbon emissions among Chinese regions.

Although scholars at home and abroad have conducted comprehensive and in-depth studies on the impact factors and environmental improvement effects of the digital economy, and theoretically explained the impact of the digital economy on CO2 emissions, the above literature analysis shows that they still cannot provide sufficient empirical support for the impact of the digital economy on CO2 emissions. On the one hand, in the study of the relationship between economy and environment, the decoupling effect analysis is the best way to explain the phenomenon of "damage before repair" of resources and the environment over time. Therefore, introducing the decoupling model into the study of the relationship between digital economy development and carbon emissions is a complement to the empirical test method. On the other hand, the development of digital economy varies spatially, so it is necessary to study the spatial and temporal differences among regions in more detail and grasp the heterogeneity of decoupling between digital economy development and the environment in different regions. Through the above analysis, this paper analyzes the decoupling effect between regional digital economy development and carbon emissions in China based on decoupling theory, using two measures of the Tapio elastic decoupling model and the EKC model.

3. Data analysis and result

3.1. Speed decoupling analysis

Based on the Tapio decoupling model, the decoupling elasticity indices of digital economy development and carbon emissions in Chinese regions are calculated (Table 1). The results show that the decoupling relationship between digital economy development and carbon emissions includes six types: weak decoupling, strong decoupling, weak negative decoupling, strong negative decoupling, expansionary connection, and expansionary negative decoupling. Among them, the national digital economy development and carbon emissions have been weakly decoupled in the statistical year, but the state is different among regions. Three regions, Central, South, and Southwest China, have been in decoupling, with different years of strong decoupling, indicating that the conflict between the development of the digital economy and the environment tends to be moderated. North China, Northeast China, and Northwest China are in negative decoupling for 1-2 years, and the development of the digital economy and carbon emissions are decreasing in the same direction and the rate of decrease of the digital economy is greater than the rate of decrease of carbon emissions, but these regions are in weak decoupling for most of the time in the statistical year. East China also experiences the "decoupled-un-decoupled-decoupled" state, but its un-decoupled state is an expansionary connection, indicating that digital economic development and regional carbon emissions are growing at the same rate. It can be seen that even though a few regions are in the non-decoupled state in 1-2 years, the overall performance is still in a more desirable decoupled state. This is because, from 2013-2019, China is in the "12th Five-Year Plan" and "13th Five-Year Plan" period, the country will take energy conservation and emission reduction as an important grasp to adjust the industrial structure and transform the development mode of enterprises, and optimize the industrial structure and eliminate backward production capacity as the primary task of energy conservation and emission reduction. The implementation of the national big data strategy and the promotion of open sharing of digital resources has kept the decoupling index mostly below 0.8, and carbon emissions and the digital economy in all regions of the country remain decoupled.

Table 1. Decoupling Elasticity Index of Regional Digital Economy Development and Carbon Emissions in China, 2013-2019.

Region	Year	e	Status
National	2013		
	2014	0.126	Weak decoupling
	2015	0.053	Weak decoupling
	2016	0.066	Weak decoupling
	2017	0.213	Weak decoupling
	2018	0.170	Weak decoupling
	2019	0.259	Weak decoupling
North China	2013		
	2014	-0.064	Strong decoupling
	2015	0.614	Weak decoupling
	2016	0.383	Weak negative decoupling
	2017	0.248	Weak decoupling
	2018	0.559	Weak decoupling
	2019	0.676	Weak decoupling
Northeast	2013		
	2014	0.020	Weak decoupling
	2015	0.286	Weak negative decoupling
	2016	0.251	Weak decoupling
	2017	0.652	Weak decoupling
	2018	-0.607	Strong negative decoupling
	2019	0.710	Weak decoupling
East China	2013		
	2014	0.384	Weak decoupling
	2015	0.911	Expansion of the connection
	2016	0.129	Weak decoupling
	2017	0.221	Weak decoupling
	2018	0.040	Weak decoupling
	2019	0.300	Weak decoupling

Central China	2013		
	2014	0.013	Weak decoupling
	2015	-0.257	Strong decoupling
	2016	-0.016	Strong decoupling
	2017	-0.009	Strong decoupling
	2018	0.152	Weak decoupling
	2019	-0.105	Strong decoupling
South China	2013		
	2014	0.074	Weak decoupling
	2015	-0.009	Strong decoupling
	2016	0.117	Weak decoupling
	2017	0.295	Weak decoupling
	2018	0.132	Weak decoupling
	2019	0.052	Weak decoupling
Southwest	2013		
	2014	-0.103	Strong decoupling
	2015	-0.769	Strong decoupling
	2016	0.053	Weak decoupling
	2017	0.059	Weak decoupling
	2018	-0.037	Strong decoupling
	2019	0.781	Weak decoupling
Northwest	2013		
	2014	0.158	Weak decoupling
	2015	-0.091	Strong negative decoupling
	2016	0.403	Weak decoupling
	2017	1.474	Expansion negative decoupling
	2018	0.370	Weak decoupling
	2019	0.265	Weak decoupling

3.2. Volume decoupling analysis

The EKC model was developed based on the traditional EKC hypothesis to capture the relationship between environmental pollution and economic growth, which is described in linear and nonlinear terms in terms of GDP per capita.

$$\ln Y_C = \beta_0 + \beta_1 \ln r_D + \beta_2 (\ln r_D)^2 + \varepsilon_C \quad (1)$$

$$\ln Y_C = \beta_0 + \beta_1 \ln r_D + \beta_2 (\ln r_D)^2 + \beta_3 (\ln r_D)^3 + \varepsilon_C \quad (2)$$

Where Y_C is the regional carbon emissions, r_D indicates the regional digital economy development level; β_0 is the intercept β_1, β_2 and β_3 are the parameters to be estimated, ε_C is the random error, the purpose of taking the logarithm of the variables is to eliminate the fluctuation trend and heteroskedasticity

Regression analysis was performed on the data from 2013-2019 using Stata statistical software (the results are shown in Table 2), with p-statistics in parentheses; ***, **, and * indicate passing significance tests at the 1%, 5%, and 10% levels, respectively, and R2 indicates the goodness of fit. As can be seen from Table 2, the EKC curve model achieved a good fit, and different optimal models were fitted nationally as well as for each region individually. The fit of the model (1) from the national perspective is higher and all coefficients are significant (β0>0, β1<0, β2>0, β3=0), and the fitted curve is a decreasing interval "U-shaped" curve with no inflection point. From the perspective of each region, the coefficients of the fitted equations in East China and Northwest China are not significant, indicating that the curves do not conform to the EKC model and there may be multiple inflection points. North China (β0<0, β1>0, β2<0, β3=0) and Southwest China (β0>0, β1<0, β2>0, β3=0) regions fit the model (1) better and the coefficients are significant, and the fitted graph of North China is "inverted U-shaped" with the inflection point in the year of In 2016, the fitted graph for Southwest China is a decreasing interval "U-shaped" curve with no inflection point. Northeast (β0>0, β1<0, β2>0, β3<0), Central China (β0<0, β1>0, β2<0, β3>0), and South China (β0<0, β1>0, β2<0, β3>0) regions are more suitable for model (2), and the fitted graphs are first The fitted graphs are "inverted N" with the year of the inflection point in 2017, "N" with the year of the inflection point in 2014, and "N" with the year of the inflection point in 2014. ", the year where the inflection point is located is 2015. It can be seen that the state presented by most regions in the latter years of the statistical interval is that the regional carbon emissions decrease as the development of the digital economy rises.

Table 2. Estimation results of fitting the Kuznets curve model of China's regional digital economy and carbon emission environment.

Region	β0	β1	β2	β3	R2
China	50.086*** (0.002)	-4.7102*** (0.007)	0.154*** (0.006)	0	0.9937
	-483.988 (0.441)	96.690 (0.431)	-6.262 (0.421)	0.135 (0.462)	0.9951
North China	-12.217* (0.064)	4.891*** (0.000)	-0.253*** (0.000)	0	0.7785
	-97.781 (0.164)	28.833 (0.143)	-2.467 (0.173)	0.068 (0.220)	0.7891
Northeast	49.990*** (0.001)	-8.020*** (0.004)	0.404*** (0.002)	0	0.8829
	853.589*** (0.000)	-234.256*** (0.000)	21.591*** (0.000)	-0.660*** (0.000)	0.9689
East China	14.321 (0.329)	-1.096 (0.638)	0.064 (0.492)	0	0.4084
	223.720 (0.328)	-51.396 (0.349)	4.078 (0.351)	-0.106 (0.359)	0.4195
Central China	47.897** (0.038)	-5.891 (0.123)	0.231 (0.151)	0	0.6098
	-1167.002** (00.017)	303.724** (0.015)	-26.034** (00.014)	0.742** (0.013)	0.7303
South China	-13.902* (0.084)	3.848*** (0.009)	-0.146** (0.015)	0	0.8285
	-87.030** (0.014)	22.547** (0.012)	-1.711** (0.020)	0.043** (0.031)	0.8705

Southwest	23.874 *** (0.005)	-2.579 * (0.078)	0.120 * (0.067)	0	0.2191
	-38.027 (0.718)	14.169 (0.619)	-1.384 (0.588)	0.045 (0.557)	0.2306
Northwest	7.384 ** (0.036)	0.333 (0.639)	-0.044 (0.904)	0	0.2606
	-5.886 (0.705)	5.137 (0.357)	-0.562 (0.381)	0.021 (0.384)	0.2787

Note: p-statistics in parentheses; ***, **, and * indicate passing significance tests at the 1%, 5%, and 10% levels. For each locale, the first row is model (1) and the second row is model (2).

4. Conclusion

The decoupling impact of regional digital economy development on carbon emissions is investigated in this research using two metrics of Tapio elastic decoupling and the EKC curve. The findings confirm the decoupling link between the digital economy and carbon emissions, and they infer that the effect varies greatly among locations. Unlike classic model regression, this article discovers that the link between digital economy development and carbon emission is not only "inverted U-shaped" as previously examined, but also "U", "N-shaped", and "inverted N-shaped". The intervals contain decreasing intervals, indicating that the conflict between digital economy expansion and carbon emissions has been alleviated. The results of this study are complementary to those obtained from traditional regression models. However, as the rise of digital economy is not long, it is also reflected from the data in this paper. Therefore, the study of the decoupling effect of digital economy and carbon emissions needs to be continuously promoted in the future to extend the observation years.

In each area of China, there is a decoupling effect between digital economy development and carbon emissions, although it is unstable. Half of the areas have a "decoupled-non-decoupled" transition, and the inflection point of the digital economy's influence on carbon emissions in East China, Southwest China, and Northwest China is unknown. This suggests that these regions may only focus on the digital economy's strong carbon reduction benefits in enabling the traditional industrial development model, while ignoring the reality that the digital economy has high negative carbon externalities, i.e., the development of the digital economy generates carbon emissions. If the construction of a digital economy is pursued unilaterally without linking it to carbon emission reduction and high quality rather than high-speed development, the two will always be in a contradictory relationship.

The gap in China's digital economy development level is gradually decreasing regionally, but the development gap between cities within each region is gradually widening. In carbon emissions, there are significant differential effects in both inter- and intra-regional cities. This also explains to some extent that the decoupling relationship verified in the previous section is not a strong decoupling, and most of the regions are in a weak decoupling state. It means that the development of prefecture-level cities in China is uneven, and the mismatch between the development of decoupling and economic development within cities is prominent, and these cities will face the double task of "maintaining growth" and "promoting decoupling" in the future process of digital economy development and green decoupling construction. The findings give some inspiration for future research, such as the causes of the decoupling effect. This will require scholars to analyze the impact of groups in regions with a micro perspective in subsequent studies.

This paper incorporates decoupling impact analysis into the investigation of the link between digital economy development and carbon emissions using two measures: speed and quantity decoupling. Unlike earlier studies, present empirical research on the link between the digital economy and carbon emissions is insufficient, and most research techniques are classic regression models; nevertheless, the incorporation of decoupling models enhances the empirical research methods of this study. Furthermore, the results of empirical studies in this field are supplemented by a more in-depth analysis of the decoupling effect between digital economy development and carbon emissions in each region of China, as well as the dynamic evolution differences between regions, providing theoretical references to promote high-quality digital economy development in each region.

Acknowledgments

This research was funded by National Social Science Foundation of China: A study on the mechanism of digital transformation paradox in SMEs from the perspective of organizational change and the path of breaking it (grant number 21BGL237) and Beijing Social Science Foundation Project: Study on the Model and Path of Digital Transformation of SMEs in Beijing (grant number 22GLB029)

References

1. China's Digital Economy and the 14th Five-Year Plan. Available online: http://ex.cssn.cn/zx/zx_gjzh/zhnew/202009/t20200904_5178924.shtml
2. China Digital Economy Development Report 2020. Foresight Industry Research Institute. Available online: https://bg.qianzhan.com/report/detail/2008191709558723.html
3. Sepehri, A., Sarrafzadeh, M.-H. (2018) Effect of nitrifiers community on fouling mitigation and nitrification efficiency in a membrane bioreactor. Chem. Eng., 128: 10-18. https://doi.org/10.1016/j.cep.2018.04.006
4. Wang, J., Hu, M., Rodrigues, J. F. D., (2018) The evolution and driving forces of industrial aggregate energy intensity in China: an extended decomposition analysis. Appl., 228:2195-2206. https://doi.org/10.1016/j.apenergy.2018.07.039
5. Del Río Castro, G.; Fernández, M.C.G.; Colsa, U.

(2021) Unleashing the convergence amid digitalization and sustainability towards pursuing the Sustainable Development Goals (SDGs): A holistic review. J. Clean. Prod., 280: 122204. https://doi.org/10.1016/j.jclepro.2020.122204

6. Yu, Z.; Liu, S.; Zhu, Z. (2022) Has the Digital Economy Reduced Carbon Emissions?: Analysis Based on Panel Data of 278 Cities in China. Int. J. Environ. Res. Public Health., 19: 11814. https://doi.org/10.3390/ijerph191811814
7. Zhou, X., Zhang, M., Zhou, M., & Zhou, M. (2017) A comparative study on decoupling relationship and influence factors between China's regional economic development and industrial energy–related carbon emissions. Journal of Cleaner Production., 142: 783-800. https://doi.org/10.1016/j.jclepro.2016.09.115
8. Climent, F., Pardo, A. (2007) Decoupling factors on the energy-output linkage: The Spanish case. Energy Policy., 35: 522–528. https://doi.org/10.1016/j.enpol.2005.12.022
9. Von, W.E.U. (1989) Erdpolitik: Ökologische Realpolitik an der Schwelle zum Jahrhundert der Umwelt., 397-398. https://doi.org/10.1093/yiel/1.1.397
10. Zhang, Z.X. (2000) Decoupling China's carbon emissions increase from economic growth: an economic analysis and policy implications. World Dev., 28: 739–752. https://doi.org/10.1016/S0305-750X(99)00154-0
11. OECD (Organization for Economic Cooperation and Development). Indicators to Measure D-ecoupling of Environmental Pressure from Economic Growth. Sustainable Development. https://search.oecd.org/officialdocuments/?hf=10&b=0&sl=official_documents&s=desc(document_lastmodifieddate)
12. Tapio, P. (2005) Towards a theory of decoupling: degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. Transport Policy., 12: 137-151. https://doi.org/10.1016/j.tranpol.2005.01.001
13. Salahuddin, M., & Gow, J. (2014) Economic growth, energy consumption and CO2 emissions in Gulf Cooperation Council countries. Energy., 73: 44-58. https://doi.org/10.1016/j.energy.2014.05.054
14. Azlina, A.A., Law, S.H., Mustapha, N.H.N. (2014) Dynamic linkages among transport energy consumption, income, and CO2 emission in Malaysia. Energy Policy., 73: 598–606. https://doi.org/10.1016/j.enpol.2014.05.046
15. Kharbach, M., Chfadi, T. (2017) CO2 emissions in Moroccan road transport sector: Divisia, Cointegration, and EKC analyses. Sustain. Cit. Soc., 35: 396–401. https://doi.org/10.1016/j.scs.2017.08.016
16. Jiang J J, Ye B, Zhou N, et al. (2019) Decoupling analysis and environmental Kuznets curve modeling of provincial-level CO2 emissions and economic growth in China: A case study. Journal of Cleaner Production., 212(MAR.1): 1242-1255. https://doi.org/10.1016/j.jclepro.2018.12.116
17. Ren, S.G., Hu, Z. (2012) Effects of decoupling of carbon dioxide emission by Chinese nonferrous metals industry. Energy Policy., 43: 407–414. https://doi.org/10.1016/j.enpol.2012.01.021
18. Freitas, L.C., Kaneko, S. (2011) Decomposing the decoupling of CO2 emissions and economic growth in Brazil. Ecol. Econ., 70: 1459–1469. https://doi.org/10.1016/j.ecolecon.2011.02.011
19. Zhang, M., Wang, W.W. (2013) Decouple indicators on the CO2 emission-economic growth linkage: the Jiangsu Province case. Ecol. Indic., 32: 239–244. https://doi.org/10.1016/j.ecolind.2013.03.033
20. Yang, J., Hao, Y., & Feng, C. (2021) A race between economic growth and carbon emissions: What play important roles towards global low-carbon development? Energy Economics., 100. https://doi.org/10.1016/j.eneco.2021.105327
21. Su, M., Jiang, R., Li, R. (2017) Investigating low-carbon agriculture: a case study of China's Henan province. Sustainability., 9(12): 2295. https://doi.org/10.3390/su9122295
22. Wang, Q., & Jiang, R. (2019) Is China's economic growth decoupled from carbon emissions? Journal of Cleaner Production., 225: 1194-1208. https://doi.org/10.1016/j.jclepro.2019.03.301
23. Liu, Y., & Feng, C. (2020) Decouple transport CO2 emissions from China's economic expansion: A temporal-spatial analysis. Transportation Research Part D: Transport and Environment., 79. https://doi.org/10.1016/j.trd.2020.102225
24. Jiang, R., Zhou, Y., Li, R. (2018) Moving to a low-carbon economy in China: decoupling and decomposition analysis of emission and economy from a sector perspective. Sustainability., 10(4): 978. https://doi.org/10.3390/su10040978
25. Wang, Q., Jiang, R., Li, R. (2018) Decoupling analysis of economic growth from water use in City: a case study of Beijing, Shanghai, and Guangzhou of China. Sustain. Cities. Soc., 41: 86e94. https://doi.org/10.1016/j.scs.2018.05.010
26. Hickel, J., & Kallis, G. (2019) Is Green Growth Possible? New Political Economy., 25(4): 469-486. https://doi.org/10.1080/13563467.2019.1598964
27. B. Kim, A. Barua, and A. B. (2002) Whinston. Virtual field experiments for a digital economy: A new research methodology for exploring an information economy. Decis. Support Syst., 32: 215–231. https://doi.org/10.1016/S0167-9236(01)00094-X
28. B. Carlsson. (2004) The Digital Economy: What is new and what is not? Struct. Change Econ. Dyn., 15: 245–264. https://doi.org/10.1016/j.strueco.2004.02.001
29. Zhang, J., Lyu, Y., Li, Y., & Geng, Y. (2022) Digital economy: An innovation driving factor for low-carbon development. Environmental Impact Assessment Review., 96.

https://doi.org/10.1016/j.eiar.2022.106821

30. Zhu, Z., Liu, B., Yu, Z., & Cao, J. (2022) Effects of the Digital Economy on Carbon Emissions: Evidence from China. Int J Environ Res Public Health., 19(15). https://doi.org/10.3390/ijerph19159450
31. Zhong, K., Fu, H., & Li, T. (2022) Can the Digital Economy Facilitate Carbon Emissions Decoupling? An Empirical Study Based on Provincial Data in China. Int J Environ Res Public Health., 19(11). https://doi.org/10.3390/ijerph19116800
32. Li, J., Chen, L., Chen, Y., & He, J. (2021) Digital economy, technological innovation, and green economic efficiency—Empirical evidence from 277 cities in China. Managerial and Decision Economics., 43(3): 616-629. https://doi.org/10.1002/mde.3406
33. Ma, D., & Zhu, Q. (2022) Innovation in emerging economies: Research on the digital economy driving high-quality green development. Journal of Business Research., 145: 801-813. https://doi.org/10.1016/j.jbusres.2022.03.041
34. Li, X., Liu, J., & Ni, P. (2021) The Impact of the Digital Economy on CO2 Emissions: A Theoretical and Empirical Analysis. Sustainability., 13(13). https://doi.org/10.3390/su13137267
35. Li, J., & Wang, Q. (2022) Impact of the Digital Economy on the Carbon Emissions of China's Logistics Industry. Sustainability., 14(14). https://doi.org/10.3390/su14148641
36. Li, Z., & Liu, Y. (2021) Research on the Spatial Distribution Pattern and Influencing Factors of Digital Economy Development in China. IEEE Access. 2021, 9, 63094-63106. https://ieeexplore.ieee.org/document/9411866
37. Ding, C., Liu, C., Zheng, C., & Li, F. (2021) Digital Economy, Technological Innovation and High-Quality Economic Development: Based on Spatial Effect and Mediation Effect. Sustainability., 14(1). https://doi.org/10.3390/su14010216