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# *The Impact of Digitalization on Green Product Exports*

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***Abstract:*** This study examines the effects of digitalization on exports of green products and addresses the mechanisms of action and regional heterogeneity using provincial panel data from China from 2012 to 2016. The findings of the study indicate that the growth of the digital economy significantly boosts exports of green products. At the same time, this promoting effect exhibits regional heterogeneity, specifically significant in the eastern regions but not significant in the central and western regions. On this basis, this paper continues to use a mediation effect model for analysis. Further research has found that digitalization can expand green product exports by promoting green technological progress and reducing trade costs. The research in this paper has certain practical significance for deeply understanding the economic and environmental effects brought by digitalization and exploring new forms of synergistic development between digitalization and greening. It also provides a possible basis and inspiration for further promoting the construction of the digital economy and optimizing China's foreign trade structure.

***Keywords:*** Digital Economy, Trade Barriers, Trade Costs, Green Technology, Green Exports.

## 1. Introduction

Since the beginning of the 21st century, digitalization and green transformation have increasingly become important trends in the global economic and social development. On one hand, due to issues such as environmental pollution and climate change, green transformation has become a key focus for countries worldwide as a critical safeguard for sustainable human development. In academia, research related to green technology, green markets, renewable energy, and other areas has also been growing and is closely linked to the economic field [1]. Meanwhile, digitalization has emerged as a major driver of economic growth over the past several decades, making it a significant topic within the field of economics. As the world's second-largest economy and the largest developing economy, China has adopted digitalization and green transformation as central tenets of its overall development strategy. The Guidelines for Coordinated Digital and Green Transformation, jointly issued by the National Development and Reform Commission and nine other departments, outlines the fundamental principles for promoting coordinated digital and green transformation and highlights two major areas of focus to drive this dual transformation. This paper further explores the impact of digital economic development from the perspective of green product exports and analyzes its mechanisms and heterogeneity, providing empirical evidence for the coordinated development of green and digital transformations through the lens of green product exports.

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The effect of the digitalization on green exports is covered in a body of literature that is directly related to the study's theme. According to current research, green exports may be significantly impacted by digitization. Digitalization has a positive effect on reducing trade-related carbon emissions and can increase the competitiveness of low-carbon trade, according to Guo Feng et al. [2]. The impact of digital empowerment on green exports exhibited a dynamic evolution from weak to strong, according to Zhang Yifang et al. [3], who found a nonlinear relationship between digitalization and green exports. Zhang Feng and Liu Jiayue [4], using the World Input-Output Database, assessed the level of digitalization in China's manufacturing sector and examined its impact and mechanisms on green exports, finding that digitalization can facilitate green upgrading in exports by promoting green technological innovation and enhancing the complexity of green technologies in exports. Another body of literature relevant to this study discusses the relationship between the digital economy and the level of green technology. Existing research indicates that the digital economy can promote green technological innovation. Guo Bingnan et al. [5] discovered that the digital economy can stimulate local green technological innovation based on panel data from 30 Chinese provincial administrative units between 2004 and 2019. Cheng Qiongwen and Lu Siyu [6], using data from Chinese listed manufacturing companies from 2009 to 2019, found that the application of digital technology can promote green innovation by reducing financing constraints and increasing the number of research reports. This study is also closely related to the literature on international trade in the context of digitalization. Existing research suggests that digitalization can promote international trade in various ways, including reducing trade costs. Yao Zhanqi [7], through establishing a mediation effect regression model, found that the digital economy can enhance China's international trade competitiveness by promoting innovation output and improving innovation efficiency. Pan Jiadong and Xiao Wen [8] found that the mechanisms by which digitalization affects export trade lie in the cost pathway, including reductions in information search costs, communication costs, and production costs.

Based on existing literature, this paper explores the impact of provincial-level digital economic development on green product exports and examines its mechanisms and heterogeneity. The innovations of this study are as follows: 1. This paper investigates the relationship between digitalization and green exports from a provincial perspective. Existing research on green exports primarily uses national [9] or micro-enterprise [10] units of analysis, with few studies examining the impact of digital economic development on green product exports at the provincial level. Compared with existing literature, this paper explores the impacts and mechanisms of the development of the digitalization on the export of green products, both theoretically and empirically, to form a marginal contribution to this area. 2. By employing a mediation effect model, this study enables a more detailed examination of causality and the mechanisms at work. Heterogeneity tests conducted across different regions further deepen the literature's understanding of the impact of digitalization on international trade. The findings of this paper suggest that accelerating digitalization and promoting digital economic development can reduce the cost of foreign trade, foster advancements in green technology, and facilitate coordinated digital-green development, which has significant practical implications. Promoting the digital-green transformation of export industries is a crucial path for China to achieve long-term, high-quality economic development.

This paper's remaining sections are arranged as follows: The theoretical hypotheses are introduced in Section 2, the research design and data sources are presented in Section 3, the empirical results and analysis are discussed in Section 4, the heterogeneity testing and mechanism analysis are carried out in Section 5, and the conclusions and policy implications are presented in Section 6.

DOI: 10.54254/2754-1169/159/2025.19694

## 2. Theoretical Hypotheses

According to certain research, there is regional variation in the effects of digitalization on trade. For instance, Lang Lihua and Chu Tingting [11] discovered that the growth of the digital economy has varying effects on exports in China's eastern, central, and western regions, strengthening exports in the latter two while having the biggest effect on exports in the western region. Additionally, Tao Aiping and Zhang Zhen [12] pointed out that while the impact on service imports is much greater in low-income countries or regions than in high-income ones, the promotion of service exports by digital economic development is more noticeable in high-income countries or regions than in low-income ones. Other studies point out that regional differences exist in the effects of digitalization on green technological innovation. According to Guo Bingnan et al. [5], the impact of China's digitalization on green technological innovation varies greatly by region, with the central and western regions experiencing a greater influence than the eastern regions. According to Chen Jinyi et al. [13], digital economic development does show regional heterogeneity in promoting green technological advancement, even though this promoting effect is more pronounced in the eastern region than in the central and western regions. The following hypothesis is put forth in this paper based on the literature mentioned above:

Hypothesis 1: Digitalization has a significant promoting effect on green product exports in the eastern region, while its effect in the central and western regions is insignificant.

Extensive literature points out that the digital economy can promote international trade by reducing trade costs. For instance, Liu Hongkui [14] argued that digitalization can reduce trade barriers and alleviate information asymmetry. Fan Xin [15], utilizing a heterogeneity stochastic frontier model and provincial export panel data from China (2008-2017), conducted a mechanism analysis and empirical test on the impact of digital economic development on export efficiency in different regions of China. The study also indicated that digital economic development can improve export efficiency by lowering export costs and optimizing regional resource allocation, with regional variations in its effects. Similarly, He Shuqian et al. [16] built an evaluation system for digital economic development indicators, measuring digital economic growth across 42 countries, and found that comprehensive digital economic development can enhance the domestic value-added of exports by reducing bilateral trade costs. Wang Mengying and Zhang Cheng [17], based on HS6-digit green product export trade data from 42 developing countries from 2008 to 2019, explored the impact of digital infrastructure construction on green product exports in developing countries, finding that digital infrastructure significantly reduces information costs and facilitates the green transformation of industries. Based on this analysis, this paper proposes the following hypothesis:

Hypothesis 2: Digitalization can influence green product exports by reducing trade costs.

Some literature suggests that digitalization can affect green exports by promoting advancements in green technology. For instance, Guo Bingnan et al. [5] built a spatial Durbin model to test the local and spatial spillover effects of the digital economy on green technological innovation in China and using panel data from 30 Chinese provincial administrative units between 2004 and 2019 and the entropy method to thoroughly evaluate the levels of digital economic development. They found that the digital economy can enhance the level of local green technological innovation. Zhang Feng and Liu Jiayue [4], in their study of China’s manufacturing sector, pointed out that digitalization can promote the green upgrading of exports by enhancing the complexity of green technologies in exports and improving the green technological level throughout the product lifecycle. Guo Feng et al. [2], by constructing a low-carbon trade competitiveness index and measuring digital economic development, found that digital economic growth can enhance low-carbon trade competitiveness by advancing green technological progress. Furthermore, Cheng Qiongwen and Lu Siyu [6], using data from listed Chinese manufacturing companies from 2009 to 2019, conducted an empirical test on the impact of

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digital technology applications on green innovation under economic uncertainty. They also found that by lowering financial barriers and boosting research output, digital technology applications can support green innovation. The following hypothesis is put forth in this paper based on the analysis above:

Hypothesis 3: Digitalization can influence green product exports by promoting advancements in green technology.

## 3. Methodology and Data

### 3.1. Methodology

This paper primarily investigates the impact of provincial digitalization levels on green product exports and further explores the mechanisms behind this effect. Based on theoretical models and drawing from existing studies, this paper constructs a baseline regression model as shown in Equation (1):

$$lnGexpi,t= \beta0+\beta1DEDI+\beta2Control1+\mu r+\mu s+\varepsilon1 \quad (1)$$

where lnGexpi,t represents the logarithmic value of green product exports in province i in year t; DEDI denotes the Digital Economy Development Index, the core explanatory variable of this study. μr represents province fixed effects, μs denotes time fixed effects, and ϵ is the error term. Control represents a set of additional relevant control variables. Referring to Fan Xin's [15] study, this paper includes the following control variables:

Table 1: Control Variables and Metrics.

| Variable Name | Measurement Method |
|---|---|
| Level of Transportation Infrastructure (lnR) | Logarithm of highway mileage in each province |
| Degree of Government Intervention (Gov) | Fiscal expenditure / Gross Domestic Product (GDP) |
| Research and Development Intensity (Res) | Internal R&D expenditure / GDP |
| Degree of Openness (Open) | Total import and export volume / GDP |
| Human Capital Level (Human) | Number of enrolled college students / total population |
| Urbanization Level (Urban) | Urban population / total population |
| Level of Technological Market Development (Tech) | Technological market transaction volume / GDP |

Building on the baseline regression model, to investigate the mechanisms by which digitalization influences green product exports, this paper applies the mediation effect model proposed by Wen Zhonglin and Ye Baojuan [18]. The specific regression models are set as follows:

$$M=\alpha0+\alpha1DEDI+\alpha2Control2+\varepsilon3 \quad (2)$$

……

$$lnGexpi,t=\sigma0+\sigma1DEDI+\sigma2M+\sigma3Control3+\mu r+\mu s+\varepsilon2 \quad (3)$$

Equation (2) represents the regression of the core explanatory variable on the mediating variable, and Equation (3) is the final total effect regression model. This paper considers two mediating variables: the first, based on the research of Guo Feng et al. [2], measures green technology levels as the number of green patents in each province, logged in the regression as lnGTPi,t, representing the

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logarithmic value of green technological progress in province i in year t. The second mediating variable is trade costs for each province. Given that trade costs are relatively abstract and challenging to capture directly through regional characteristic variables, this paper uses the measure of international trade barriers for provinces as calculated in the study by Li Ziruo et al. [19]

### 3.2. Data Sources

The sample data for the provinces used in this study spans from 2012 to 2016. Since there is no consensus in academia on the definition of green products, this paper adopts the definition of green products as outlined in the classification of clean products proposed by Wang Jun et al. [20]. The green product export data for each province from 2012 to 2016 is sourced from Chinese customs data. The Digital Economy Development Index is calculated by the approach in Wang Jun et al. [21], which assesses various dimensions, including digital infrastructure, digital industries, and digital integration applications, to derive a composite digital economy development indicator for each province through weighted processing. The relevant data primarily come from the National Bureau of Statistics website, the China Academy of Information and Communications Technology, industry and information technology research reports and public data, annual statistical yearbooks for each province, annual China Digital Economy Development Reports, China Statistical Yearbook, China Information Yearbook, and China Information Industry Yearbook. The data for control variables is sourced from the China Statistical Yearbook, the National Bureau of Statistics, and provincial statistical yearbooks. For mechanism testing and heterogeneity analysis, the study further uses the following data: the number of green patents in 30 provinces from 2012 to 2016, with relevant data from the China Research Data Services Platform (CNRDS), and the international trade barrier index for 28 provinces from 2012 to 2016, sourced from the study by Li Ziruo et al. [19].

## 4. Empirical Analysis

### 4.1. Baseline Regression

This study first uses the baseline regression model (1) for analysis to test the effect of digital economy on the export volume of green products. Table 2 displays the specific regression results. Levels of urbanization, digitalization, provincial openness, and technological market development are included in Column (1), while time and province fixed effects are controlled for. According to the regression results, the explanatory variable's regression coefficient is 3.913, which is significant at the 10% level. This indicates that the development of the digitalization significantly promotes green product exports. In this column, the coefficient for provincial openness is 1.042 and is significant at the 5% level, suggesting that provinces with higher levels of openness have greater green product export volumes. This result aligns with economic principles and existing research. In Column (2), human capital levels of the provinces are further controlled, and the coefficient of the explanatory variable is 3.856, remaining significant at the 5% level. In Column (3), the degree of government intervention is added as a control variable, with the coefficient of the explanatory variable still showing a positive and significant effect. In this column, the urbanization level is positively significant at the 5% level, indicating that provinces with higher urbanization levels have higher green product export volumes. Column (4) adds research intensity as a new control variable based on Column (3). In Column (5), infrastructure level is included in addition to all other control variables, yielding the most robust results. In these two columns, the coefficient of the explanatory variable becomes even more significant, positively significant at the 5% level, further verifying that digitalization has a significant positive impact on green product exports.

DOI: 10.54254/2754-1169/159/2025.19694

Table 2: Baseline Regression Results.

| VARIABLES | ln_Gexp | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| DEDI | 3.913* | 3.856* | 3.831* | 5.056** | 4.848** |
| | (2.103) | (2.231) | (2.192) | (2.160) | (2.157) |
| Open | 1.042** | 1.079* | 1.025 | 1.240** | 1.255** |
| | (0.518) | (0.582) | (0.632) | (0.615) | (0.636) |
| Urban | 13.27** | 13.31** | 13.40** | 13.29** | 13.84** |
| | (5.552) | (5.464) | (5.581) | (5.551) | (5.582) |
| Tech | 19.43** | 19.00** | 21.08** | 22.89** | 23.60** |
| | (7.679) | (8.116) | (9.926) | (9.957) | (10.11) |
| human | | -10.36 | -13.33 | -15.77 | -20.81 |
| | | (74.67) | (69.42) | (71.03) | (70.93) |
| gov | | | -1.136 | -0.865 | -0.999 |
| | | | (2.467) | (2.567) | (2.570) |
| res | | | | -33.95 | -35.08 |
| | | | | (22.20) | (22.44) |
| lnR | | | | | -0.709 |
| | | | | | (1.146) |
| Constant | 11.19** | 11.34** | 11.57** | 12.22** | 18.59 |
| | (4.589) | (5.251) | (4.868) | (4.973) | (12.19) |
| Year Fixed | Yes | Yes | Yes | Yes | Yes |
| Province fixed | Yes | Yes | Yes | Yes | Yes |
| Observations | 150 | 150 | 150 | 150 | 150 |
| Number of provinces | 30 | 30 | 30 | 30 | 30 |

Robust standard errors in parentheses

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

## 4.2. Robustness Check

To test whether the promoting effect of digitalization on green product exports is reliable, this study conducts the following robustness checks, with results shown in Table 3. First, to avoid the potential impact of outliers in the dependent variable on the regression results, Column (1) performs a 5% two-sided winsorization on the dependent variable without controlling for province fixed effects. Column (2) adds province fixed effects based on Column (1). The findings demonstrate the robustness of the regression results by showing that the estimated coefficients and signs for the digital economy in both columns do not change significantly and continue to be significant at the 10% level. Second, we look at the influence of industrial structure, specifically whether regional industrial structure may have an impact on how the digitalization promotes the export of green products. To this end, Columns (3) and (4) incorporate the ratio of tertiary industry output to secondary industry output as an additional variable, with Column (3) not controlling for year-fixed effects. The findings demonstrate that the regression results are robust since the estimated coefficients and signs of the explanatory variables stay constant across both columns and are still significant at the 10% level.

The above results demonstrate that digitalization has a certain promoting effect on green product exports, and the regression results are robust.

DOI: 10.54254/2754-1169/159/2025.19694

Table 3: Robustness Test Results.

| VARIABLES | (1)<br>ln_GEXP | (2)<br>ln_GEXP | (3)<br>ln_Gexp | (4)<br>ln_Gexp |
|---|---|---|---|---|
| DEDI | 7.286*** | 4.141* | 4.273* | 4.227* |
| | (1.989) | (2.178) | (2.365) | (2.545) |
| structure | | | -0.587 | -0.244 |
| | | | (0.380) | (0.424) |
| Constant | 6.582 | 19.26 | 28.00*** | 22.98* |
| | (6.697) | (12.33) | (8.603) | (13.53) |
| Control Variables | Yes | Yes | Yes | Yes |
| Year fixed | No | Yes | Yes | Yes |
| Province fixed | Yes | Yes | No | Yes |
| Observations | 150 | 150 | 150 | 150 |
| Number of provinces | 30 | 30 | 30 | 30 |

Robust standard errors in parentheses

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

## 5. Mechanism Analysis

### 5.1. Heterogeneity Analysis

The degree of economic development varies greatly among China's regions due to a variety of factors, including historical legacies, geographic location, and resource endowment. The eastern region is noticeably more developed than the central and western regions. A significant digital divide between various provinces and regions is also indicated by the study's measurement of the digital economy development levels across the 30 provinces. To discuss the regional heterogeneity in the impact of digital economic development on green product exports, this paper splits the sample into eastern and central-western regions for group regression analysis. Columns (1) to (3) of Table 4 report the regression results for the eastern region, while Columns (4) to (6) report the results for the central and western regions. The regional regression results show that digitalization development has a significant positive impact on green product exports in the eastern region at the 1% level, while the effect in the central-western regions is not significant. In terms of the mediating effect of green technological progress, the effect is significantly positive in the western region; although positive in the eastern region, it is not significant, which aligns with the findings of Guo Bingnan et al. (2022). Moreover, the total effect results for both the eastern and central-western regions are positive, but only significant in the eastern region, while not significant in the western region. This suggests that while the promotion of green technological progress by digital economy is more significant in the central-western regions, the other advantages held by the eastern region (such as infrastructure and human capital levels) compensate for this shortfall, indirectly indicating that the impact of green technological progress on green product exports may not be as strong as other factors. Thus, Hypothesis 1 is confirmed.

Table 4: Heterogeneity Test Results.

| | Eastern Region | | | Central and Western Region | | |
|---|---|---|---|---|---|---|
| VARIABLES | (1)<br>ln_Gexp | (2)<br>ln_GTP | (3)<br>ln_Gexp | (4)<br>ln_Gexp | (5)<br>ln_GTP | (6)<br>ln_Gexp |
| | | | | | | |

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Table 4: (continued).

| | | | | | | |
|---|---|---|---|---|---|---|
| DEDI | 4.625*** | 2.027 | 4.678*** | 6.613 | 13.28*** | 5.821 |
| | (1.029) | (1.553) | (1.006) | (8.588) | (5.058) | (8.347) |
| ln_GTP | | | 0.120 | | | 0.279 |
| | | | (0.101) | | | (0.186) |
| Control Variables | Yes | Yes | Yes | Yes | Yes | Yes |
| Year fixed | Yes | Yes | Yes | Yes | Yes | Yes |
| Province fixed | Yes | No | Yes | Yes | No | Yes |
| Observations | 55 | 55 | 55 | 95 | 95 | 95 |
| Number of provinces | 11 | 11 | 11 | 19 | 19 | 19 |

Robust standard errors in parentheses

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

## 5.2. Mediation Effect Analysis

From the standpoints of green technological advancement and trade costs, we examine the possible explanations for how digital economic development encourages the export of green products in this section.

Table 5's mediation effect regression results for green technological advancement are shown in Columns (1) and (2), while the results for trade costs are shown in Columns (3) and (4). The result in Column (1) of Table 5 for the mediation effect of green technological progress indicates that digital economic development can significantly promote green technological progress, with the explanatory variable's coefficient of 4.179 being significant at the 5% level. In Column (2), the coefficient of the mediating variable is 0.303, significant at the 5% level, and the coefficient of the explanatory variable is 4.758, slightly lower than the coefficient in the baseline regression, yet still significant at the 5% level. This indicates that the mediation effect of digital economic development on green technology is a partial mediation effect, meaning that digitalization can expand green product exports by promoting green technological progress. Therefore, Hypothesis 2 is supported.

For the mediation effect of trade costs, the result in Table 5's Column (3) indicates that, at the 10% level, digital economic development has significantly negative impact on trade costs, indicating that trade costs can be considerably decreased across provinces through digitalization. The coefficient of digital economic development in Column (4) is 3.614, which is less than the baseline regression coefficient and significant at the 10% level, while the coefficient of trade costs is -0.250, which is significant at the 5% level. This suggests that digitalization has a partial mediation effect on trade costs, which means that by lowering trade costs, digitalization can encourage the export of green products. Consequently, Hypothesis 3 is likewise validated.

Table 5: Mediation Effect Test Results.

| | Green Technology | | Trade Costs | |
|---|---|---|---|---|
| VARIABLES | (1) ln_GTP | (2) ln_Gexp | (3) COST | (4) ln_GEXP |
| DEDI | 4.179** | 4.785** | -5.520* | 3.614* |
| | (2.007) | (1.933) | (3.009) | (2.066) |
| ln_GTP | | 0.303** | | |
| | | (0.135) | | |

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Table 5: (continued).

| | | | | |
|---|---|---|---|---|
| COST | | | | -0.250** |
| | | | | (0.100) |
| Constant | -18.57*** | 24.31* | 5.355 | 26.90** |
| | (6.557) | (13.26) | (17.06) | (12.65) |
| Control Variables | Yes | Yes | Yes | Yes |
| Year fixed | No | Yes | Yes | Yes |
| Province fixed | Yes | Yes | Yes | Yes |
| Observations | 150 | 150 | 140 | 140 |
| Number of provinces | 30 | 30 | 28 | 28 |

Robust standard errors in parentheses

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

## 6. Conclusion

Digitalization and green transformation are crucial trends in the global economic and social transition. Promoting digital development is beneficial for stimulating technological innovation, advancing industrial green transformation, reducing trade costs, and expanding green product exports. This holds significant importance for fostering coordinated digital-green development, promoting high-quality economic growth, and further unlocking economic growth potential. This paper first establishes a theoretical framework to examine the impact and mechanisms of digitalization on green product exports. According to the theoretical model, the growth of the digitalization lowers trade costs for provinces, encourages the advancement of green technologies, and increases the export of green products. In regions with more advanced infrastructure, higher economic development levels, and greater openness, such as the eastern region, the positive impact of digitalization on green product exports is even more pronounced. Subsequently, the impact of digitalization on provincial green product exports is investigated using a mediation effect model and provincial panel data from 30 Chinese provinces between 2012 and 2016 as well as the computed Digital Economy Development Index. The findings show that digital economic development can significantly increase green product exports in foreign trade. Under general conditions, the digital economy weakens international trade barriers across provinces, reduces trade costs, and promotes green technological advancements related to green products, thereby expanding provincial green product exports. Furthermore, compared to the central and western regions, the promoting effect of digitalization on green product exports is more pronounced in areas with greater openness and more developed infrastructure, especially in the eastern region.

This study shows that the growth of the digital economy can significantly boost the expansion of green exports by driving innovation in green technology and successfully lowering the costs of international trade. This is crucial to China's long-term, high-quality economic development and the advancement of the coordinated digital-green transformation. The following policy recommendations are provided by this study in light of these findings to foster high-quality economic growth, accelerate digital economic development, and continuously advance coordinated digital-green transformation: 1. Enhance Awareness of the Role of the Digital Economy in Promoting Green Product Exports: The research indicates that digitalization can significantly increase green product exports. Therefore, the government should accelerate digital transformation across regions, fully utilizing “Internet Plus” methods in the green export process to expand green product exports. 2. Foster Coordinated Digital-Green Development Across Regions: Governments at different regional levels should work together to promote coordinated digital and green development. The eastern region should maintain its advantages in the digital economy and green exports by increasing investments in talent and resources

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and encouraging capital investment in digital-green initiatives. To achieve high-quality economic growth and close the development gap between the eastern, central, and western regions, the central and western regions should take advantage of government support to maximize the digitalization as a new economic driver and encourage coordinated digital-green development. 3. Strengthen Cross-Border Cooperation in Green Technology Innovation and Green Product Development: Actively introduce advanced technology and talent, develop new green products, and drive coordinated digital-green transformation through joint efforts in digitalization and greening.

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