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Effects of Higher Education on Green Eco-Efficiency and Its Optimization Path: Case Study of China

Yue Xu [1], Zihao Xu [1], Dayu Zhai [2,*] and Yanyu Li [2]

[1] School of Management, China University of Mining and Technology-Beijing, Beijing 100083, China; xuyue@cumtb.edu.cn (Y.X.)
[2] School of International Development and Cooperation, University of International Business and Economics, Beijing 100029, China
* Correspondence: zhaidy@uibe.edu.cn

Abstract: Based on the annual panel data of 30 provinces in China, this paper evaluates the green eco-efficiency of each province via factor decomposition and analyzes the impact of higher education on green eco-efficiency using the two-way fixed effect model, considering economic development, urban scale, industrial structure, foreign investment and government regulation as control factors. The results show that the penetration of higher education has a significant positive impact on green eco-efficiency. Heterogeneity analysis suggests that the positive impact of undergraduate and postgraduate education is significant, and this impact increases with the increasing levels of education; however, the influence of junior college education is not significant. Higher education in eastern China significantly affects green eco-efficiency in a positive manner, while the relationship between the two is not significant in the central and western regions. The test of mediating effects further shows that technological innovation has a partial mediating effect, while environmental attention does not show a mediating effect in the influencing path of higher education on green eco-efficiency. Accordingly, this paper proposes certain implications regarding green-related courses, transformation from consciousness to practice, and incorporation of green education in higher education systems.

Keywords: higher education; green eco-efficiency; technological innovation; environmental attention; green education

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1. Introduction

In recent years, climate change has become a serious global challenge, and promoting green and low-carbon development has become a common goal of many countries. China has put forward a specific timetable of "carbon peaking" and "carbon neutralization" in September 2020. Adhering to green and high-quality development has become the new trend in development. In the current energy consumption structure of China, traditional fossil fuels, mainly coal, still account for a large proportion, which poses a challenge to China's green development and the achievement of these goals. Some literature shows that the factors affecting high-quality economic development include innovation-driven infrastructure construction, development and application of green technology, power supply, efficient utilization of electrical equipment, increased financial investment in pollution prevention and control, and manufacturing of agglomeration [1–4]; the level of education is also an important driving force for high-quality development.

To achieve green development, on one hand, it is necessary to improve the understanding and knowledge level of the broad masses of people, especially college students, on the importance of green development. On the other hand, it is also necessary to cultivate high-quality specialized personnel with green and low-carbon awareness and relevant knowledge and skills. In November 2022, the Ministry of Education of China issued The Implementation Plan for the Construction of the National Education System for Green and

Low-carbon Development, which requires that green and low-carbon development should be integrated into all levels of the national education system, to cultivate a new generation of young people who would practice green and low-carbon concepts, adapt to a green and low-carbon society, and lead the pathway for green and low-carbon development. As an important pillar of social progress and sustainable development, higher education plays a key role in shaping the future green and low-carbon development path. Therefore, in China, a country with a large higher education system, it is necessary to study the impact of higher education on green and low-carbon development and its promotion path, which has important theoretical and practical values.

This paper aims to analyze the effect of higher education, including junior college, undergraduate and postgraduate education, on green and low-carbon development of society using the panel data of various provinces (in this paper, the word "provinces" refers to provinces, autonomous regions and municipalities directly under the central government) in China. First, this paper builds an index to evaluate green eco-efficiency and investigates the relationship between the penetration rate of higher education and green eco-efficiency at different levels and in different regions. In addition, the mechanisms of higher education influencing green eco-efficiency is explored via analyzing the mediating effects of technological innovation and environmental attention. Based on empirical research pertaining to China's education strategy and policy, the path of strengthening green education in higher education institutions is further analyzed. This paper discusses efficient ways to incorporate the knowledge and concepts of green and low-carbon development into different specialties and aspects of higher education, and means to improve green eco-efficiency more effectively through higher education.

The contributions of this paper are as follows: First, there is a lack of research on the relationship between higher education and green and low-carbon development. This paper can provide empirical evidence on this topic and further innovations in the research perspective, which may provide inspiration for similar exploration in other countries. Second, this paper finds that a higher level of higher education has a greater impact on green eco-efficiency and that the effect is also greater in regions with a higher penetration rate of higher education, which is of great reference value for improving green education at different levels and regions more pertinently. Third, this paper suggests that in the impact mechanism of higher education on green eco-efficiency, technological innovation has a mediating effect, while environmental attention does not, which indicates that practical education is more effective than ideological education; this has significant reference value for strengthening the combination of thought and practice in green education. In short, this paper provides new perspectives and ideas for promoting green development through the analysis of the effect of China's higher education on eco-efficiency. At the same time, this paper also offers a scientific basis for reforming higher education and formulating green education strategies in China and other countries.

The remainder of the paper is organized as follows. Section 2 provides a literature review and theoretical hypotheses. Section 3 illustrates the research methodology. Section 4 discusses the results. Section 5 further analyzes the influencing path of higher education on green eco-efficiency. Section 6 presents the conclusions and implications.

2. Literature Review and Theoretical Hypotheses

2.1. Literature Review

In modern society, higher education is regarded as an important driving force of economic and social development. Many studies show that there is a close relationship between higher education and economic growth through data from different regions and countries and various methods. Bertoletti et al. [5] found that the size of higher education institutions, the degree of internationalization of students and research efficiency play an important role in regional economic development based on 649 regional data from 29 European countries. Based on the data of the World Bank, Ziberi et al. [6] defended that an increase in public education expenditure has a positive impact on the economic growth

of Northern Macedonia. Hao and Min [7] used China's provincial panel data and proved that education has the dual attributes of long-term investment and expanding consumption, which can boost economic growth. Min et al. [8] also used the panel data of China's regions and obtained similar results. Lenkei et al. [9] found that the number of students in higher education has a significant positive impact on economic growth based on their research on Romania. It can be seen that the improvement in higher education investment and quality contributes a lot to economic growth. There are differences in the relationship between higher education and economic development between different regions and countries, and corresponding policies and measures need to be taken according to the specific situation.

Some studies focus on how higher education promotes economic development by improving innovation ability. Xu et al. [10] pointed out that higher education, economic growth and innovation ability can promote each other. Improving the quality of higher education to meet the needs of innovative economy can effectively promote regional sustainable development. Geng et al. [11] argued that the funding for scientific research activities in higher education and the number of patents are significant factors affecting the development of digital economy. The above research shows that higher education, economic growth and innovation ability facilitate each other, and they play an important role in social and economic development. The improvement in the quality of higher education is essential to support the development of innovative economy.

Some research analyzes how higher education in different countries and regions contributes to economic growth by enhancing social human capital. Bilan et al. [12] believed that the coverage rate of higher education can have an impact on labor productivity, has obvious personal and social interests on personal development and improves human capital of the labor market. Neamtu [13] asserted that education and human capital investment have an important impact on national economic growth, and the success of the education system has laid the foundation for the economic system. McMahon [14] argued that the externality of higher education has a positive and substantial influence on economic growth, which requires more public support. Ji et al. [15] pointed out that higher education promotes human capital training and economic construction. The above research indicates that the development of human capital brought about by higher education is the key factor to boost economic development. The government and society should increase support for higher education in order to improve the level of human capital and promote sustainable economic growth.

Some research discusses ways to enhance and improve higher education to better serve economic development. Kruss et al. [16] believed that universities should strengthen their understanding of students' technical ability and enterprise skill needs, and establish clear strategies, structures and mechanisms to communicate with enterprises, departmental intermediary structures, governments and other knowledge producers. Pana and Mosora [17] defended that if the choice to receive a certain type of education is determined by the labor market mechanism, the institutional arrangement must allow the market mechanism to play a full role. Zhang et al. [18] pointed out that we should pay attention to the relationship between the supply of human capital types and the demand of industrial structure, and improve the allocation efficiency of human capital. Rachman [19] concluded that education donation projects have the potential to promote normal national economy. Janzen et al. [20] argued that by obtaining core funds for high-quality teaching and research, universities can enhance regional attraction and realize positive interaction between higher education and regional economy. These studies provide important references for higher education institutions and policymakers to better realize the potential of higher education to promote regional economic development.

Some studies also focus on the important role of higher education institutions in promoting sustainable development. Using the provincial data of China, Huang et al. [21] found that higher education has a positive contribution to high-quality economic development, and its impact path includes human capital accumulation, technological innovation and the complementary effect of industrial structure. Valls-Val et al. [22] pointed out that

a special circular economy (CE) tool should be developed for higher education institutions. Mendoza et al. [23] proposed a methodology framework for applying the idea of circular economy to sustainable campus management to help universities develop circular economy strategies. Pereira Ribeiro et al. [24] believed that the green campus initiative is an effective strategy, which can improve students' awareness and enthusiasm for sustainable development. Dong et al. [25] stated that promoting international cooperation, using E-education capabilities, can improve students' green awareness through media and social networks. Serrano-Bedia and Perez-Perez [26] opined that higher education institutions can effectively cope with the challenges in the transformation of circular economy by cooperating with stakeholders such as the government, industrial practitioners and consumers. Ofei-Manu and Didham [27] proposed the learning performance framework of sustainable development education and the methods of implementing and evaluating sustainable development education.

From previous literature, it can be concluded that colleges and universities are not only the educators of sustainable development but also important practitioners. The initiatives and practices of higher education institutions in this field are essential to cultivate students' awareness and abilities of sustainable development.

In general, current research on higher education and economic development is considerably abundant. Improving the ability of technological innovation and the quality of human capital is considered to be the main mechanism for higher education to promote economic development. At the same time, some studies pay attention to the role of higher education in promoting sustainable development and believe that it is necessary to cultivate students' relevant awareness and abilities. However, this kind of research is mainly based on qualitative views. In the context of the global challenge of climate change, there is still a lack of specific research on the impact of higher education on green and low-carbon development. There is also a lack of empirical evidence on whether higher education can promote regional green and low-carbon development and its impact mechanism. This paper aims to fill this gap through the study of different provinces in China and put forward the path of strengthening green and low-carbon education in higher education. This research is pertinent as well as has important theoretical and practical values.

2.2. Theoretical Mechanism and Research Hypotheses

2.2.1. Relationship between Higher Education and Green Eco-Efficiency

The concept of eco-efficiency was first proposed by Schaltegger and Sturm [28] and measured by the value of products and services per unit of eco-environmental load. The World Business Council for Sustainable Development [29] defines eco-efficiency as the ability to provide goods and services that meet human needs, while reducing ecological impact and resource intensity to a level at least consistent with the estimated carrying capacity of the earth. The Organization for Economic Co-operation and Development [30] suggests that eco-efficiency refers to the efficiency of environmental resources to meet human needs. It is likely that the key point of improving eco-efficiency is to reduce resource consumption and environmental pollution, while improving social output. On one hand, higher education can directly promote the improvement in green eco-efficiency. On the other hand, it can improve green eco-efficiency through technological innovation and improving public environmental attention. Its mechanism is shown in Figure 1.

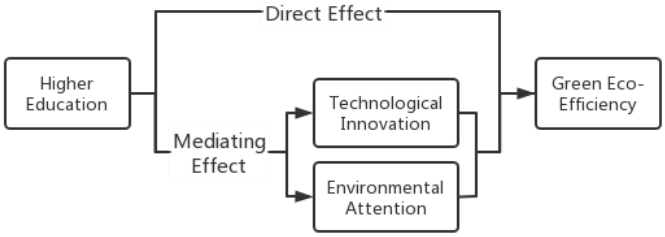

Figure 1. Mechanism of higher education affecting green eco-efficiency.

2.2.2. Overall Impact of Higher Education on Green Eco-Efficiency

Higher education can promote the all-round development and progress of society. Many studies have shown that higher education has the functions of expanding consumption and long-term investment [7,8], and can improve the quality of the population, enhance the accumulation of social human capital [13–15], and increase labor productivity. The improvement in human resources investment and its training quality has played an important role in accelerating economic growth and high-quality economic development [5,6,21]. Therefore, it can be inferred that the popularization of higher education can promote the improvement in green eco-efficiency.

From the perspective of the level of higher education (junior college, undergraduate, and postgraduate), it can be inferred that if a province has a higher penetration rate of high level of education, its population and human capital would have better quality. Accordingly, there would be a greater promotion effect on social economic development and green eco-efficiency. Therefore, this paper puts forward the following hypotheses:

Hypothesis 1. *The improvement in higher education penetration has a positive impact on green eco-efficiency.*

Hypothesis 2. *The increase in the penetration rate of a high level of higher education has a greater positive impact on green eco-efficiency.*

In addition, there is strong heterogeneity in the level of economic development and the penetration rate of higher education in various regions of China. In the region with a high penetration rate of higher education, higher education tends to have a greater influence on green eco-efficiency due to the talent agglomeration effect and economies of scale. Therefore, the paper proposes the following hypothesis:

Hypothesis 3. *In the region with a high penetration rate of higher education, higher education has a greater positive impact on green eco-efficiency.*

2.2.3. Indirect Influence Path of Higher Education on Green Eco-Efficiency

In addition to having a direct impact, higher education may also indirectly affect green eco-efficiency through technological innovation and improving public environmental attention. Higher education can facilitate the improvement in innovation ability and promote regional labor productivity as well as economic growth, which has been confirmed by some studies [10,11]. Higher education promotes technological innovation by providing knowledge and scientific skills, which can not only help to improve output, but may also reduce resource consumption and environmental pollution. Therefore, this paper puts forward the following assumption:

Hypothesis 4. *Higher education can improve green eco-efficiency by promoting technological innovation. That is, technological innovation has a mediating effect in the path of higher education promoting green eco-efficiency.*

In addition, some studies believe that higher education can play a certain role in the dissemination of green development ideas, circular economy ideas and sustainable development awareness [22–27]. Green education in higher education may lead the public to pay more attention to the field of ecology and environmental protection, improve environmental attention and thus promote green eco-efficiency. Hence, this paper puts forward the following assumption:

Hypothesis 5. *Higher education can improve green eco-efficiency by improving environmental attention. That is, environmental attention has a mediating effect in the path of higher education promoting green eco-efficiency.*

3. Methodology

3.1. Variable Selection

3.1.1. Explained Variable: Green Eco-Efficiency (*GEE*)

Referring to the method of He et al. [31], this paper uses the factor decomposition method to divide the annual green eco-efficiency (*GEE*) of provinces in China into green energy efficiency and green environmental efficiency, and constructs the green eco-efficiency index as follows:

$$GEE = (GENE \times GEVE)^{(1/2)} \tag{1}$$

where *GEE* represents the annual green eco-efficiency of provinces, *GENE* represents green energy efficiency, and *GEVE* represents green environmental efficiency. *GENE* is computed as follows:

$$GENE = (EN_{CON} \times EN_{CAR})^{(1/2)} \tag{2}$$

where EN_{CON} denotes the economic efficiency of energy consumption and EN_{CAR} represents the economic efficiency of carbon emissions, which are calculated using Equations (3) and (4), respectively:

$$EN_{CON} = \frac{GDP_i}{CON_i} \tag{3}$$

$$EN_{CAR} = \frac{GDP_i}{CAR_i} \tag{4}$$

where GDP_i represents regional GDP, CON_i and CAR_i represent the energy consumption and carbon emission of each province, respectively. *GEVE* is calculated as follows:

$$GEVE = (EV_W \times EV_G \times EV_S)^{(1/3)} \tag{5}$$

where EV_W, EV_G and EV_S represent the environmental efficiency of wastewater discharge, exhaust emissions and solid waste emissions of each province, respectively, and are calculated using Equations (6)–(8), respectively:

$$EV_W = \left(\frac{GDP_i}{COD_i} \times \frac{GDP_i}{ANE_i}\right)^{(1/2)} \tag{6}$$

where GDP_i represents regional GDP, COD_i and ANE_i represent the chemical oxygen demand and ammonia nitrogen emissions in wastewater of each province, respectively, which are major pollutants in wastewater and have more available data.

$$EV_G = \frac{GDP_i}{SO_{2i}} \tag{7}$$

where GDP_i denotes regional GDP, and SO_{2i} denotes the sulfur dioxide emissions in the exhaust gas of each province, which are major pollutants in the exhaust gas and have more available data.

$$EV_S = \frac{GDP_i}{SW_i} \tag{8}$$

where GDP_i represents regional GDP. Due to the lack of data on solid waste from the living sector, only solid waste from the industrial sector is considered here, and SW_i represents the amount of industrial solid waste produced in each province.

3.1.2. Core Explanatory Variable: Penetration Rate of Higher Education

Referring to Huang et al. [21], this paper takes the sum of the proportion of employees with junior college, undergraduate, and postgraduate education in provinces of China as the overall penetration rate of higher education (*HEDU*) and takes it as the core explanatory variable.

In addition, to separately explore the impact of each level of higher education on green eco-efficiency, the explanatory variable is also replaced with the proportion of employees with junior college education (*JEDU*), undergraduate education (*UEDU*) and postgraduate education (*PEDU*), respectively, for a more detailed analysis.

3.1.3. Control Variables

The control variables in the study are set as follows:

1. The level of economic development, measured with the logarithm of per capita GDP (ln*PGDP*). With the development of ecological civilization in China, regions with high levels of economic development are more likely to engage in technological innovation and industrial upgrading, thereby reducing high pollution and energy consumption, and promoting eco-efficiency [31–33];
2. The scale effect, measured with the logarithm of the built-up area (ln*BUA*). With the expansion of urban scale, the scale effect may exacerbate environmental pollution and resources consumption, while the structural and technological effects may also improve environmental quality [31,34]. Therefore, urban scale expansion tends to have an impact on eco-efficiency;
3. The structural effect, measured with the ratio of tertiary industry output to regional GDP (*INDUS*). If the industrial structure is dominated by heavy industry, it may cause overexploitation of resources and excessive pressure on the environment [33]. If the proportion of the tertiary industry increases and the industrial structure is optimized, eco-efficiency is likely to increase [31];
4. The spillover effect of foreign investment, measured with the ratio of foreign direct investment to regional GDP (*FDI*). The inflow of foreign investment promotes the rapid development of an export-oriented economy, expands the host country's economic scale, and has technology spillover effects, which can improve industrial quality, promote technological innovation, and may also affect its eco-efficiency [31,35];
5. The regulation of government, measured with the ratio of the completed investment of pollution control projects to the regional GDP (*IPC*). The government can play a supportive role in environmental governance for enterprises and markets, which may have an influence on green eco-efficiency [31].

Variables used in this paper are described in Table 1.

Table 1. Introduction to relevant variables.

	Variable	Symbol	Interpretation	Remark
Explained variable	Green eco-efficiency	*GEE*	Value of green eco-efficiency	
Explanatory variables	Penetration rate of higher education	*HEDU*	Proportion of employees with higher education	Overall penetration rate of higher education
		JEDU	Proportion of employees with junior college education	Penetration rate of junior college education
		UEDU	Proportion of employees with undergraduate education	Penetration rate of undergraduate education
		PEDU	Proportion of employees with postgraduate education	Penetration rate of postgraduate education
Control variables	Economic development	ln*PGDP*	Logarithm of per capita GDP	Economic development level
	Urban scale	ln*BUA*	Logarithm of built-up area	Scale effect
	Industrial structure	*INDUS*	Output of tertiary industry/regional GDP	Structural effect
	Foreign investment	*FDI*	Foreign investment/regional GDP	Spillover effect of foreign investment
	Government regulation	*IPC*	Completed investment of pollution control projects/regional GDP	Government regulation

3.2. Data Source and Description of Core Variables

3.2.1. Data Source

This paper uses the annual panel data of 30 provinces (including autonomous regions and municipalities directly under the central government) in China from 2003 to 2021. Due to data availability issues, it does not include the data of Tibet, Hong Kong, Macao and Taiwan. Data are obtained from the National Bureau of Statistics of China, China Statistical Yearbook on Environment, China Environment Yearbook, Ministry of Human Resources and Social Security of China, provincial statistical yearbooks and MEIC (http://meicmodel.org.cn (accessed on 27 May 2023), see Li et al. [36] and Zheng et al. [37] for more details.). The energy consumption of Hunan in 2020 and 2021, and Inner Mongolia, Xinjiang and Jiangsu in 2021 lack original data, and hence are estimated based on the energy consumption growth rate in the regional statistical bulletin or statistical yearbook or the linear interpolation method. The descriptive statistics of variables are shown in Table 2.

Table 2. Descriptive statistics of variables.

Variable	Observations	Mean	Std. Dev.	Min	Max
GEE	570	7.342	11.464	0.693	148.560
HEDU	562	15.442	10.301	3.006	63.000
JEDU	570	8.256	3.872	1.380	21.500
UEDU	570	6.342	5.508	0.580	33.500
PEDU	562	0.710	1.334	0.005	11.974
ln*PGDP*	570	10.413	0.760	8.190	12.123
ln*BUA*	565	7.062	0.783	4.623	8.792
INDUS	570	0.464	0.093	0.298	0.837
FDI	565	0.003	0.003	0.000	0.021
IPC	570	15.035	14.193	0.086	110.339

3.2.2. Descriptive Analysis of Core Variables

Figure 2 shows the trend of *GEE* in the sample period of the nationwide, eastern, central and western regions of China. Provinces in the eastern, central and western regions are classified according to the national data of the National Bureau of Statistics of China, which is based on the criteria of the Seventh Five-Year Plan and the "Western Development" strategy of China. One of the main criteria for dividing the three regions is the level and

speed of economic development. Due to different geographical locations and natural resources, each region has its own development characteristics. The eastern region is along the coast, benefiting from the opening-up policy, and has the highest level of economic development. The economic development level of the central region is worse than that of the eastern region, and the western region is the least economically developed part among the three [38,39]. (In the paper, the eastern region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan; the central region includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan; the western region includes inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang.) It can be seen that *GEE* is on the rise as a whole, and the overall *GEE* level in the eastern, central and western regions is decreasing in turn. It indicates that green eco-efficiency is basically positively correlated with the economic development level of each region.

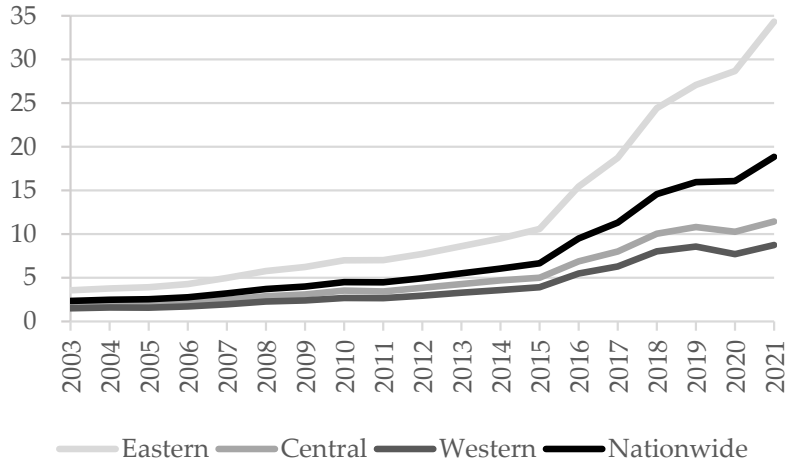

Figure 2. Green eco-efficiency by regions of China.

Figure 3 demonstrates the overall penetration rate of higher education in the nationwide, eastern, central and western regions of China. It suggests that the overall level is on the rise and the overall rate in the eastern region is the highest, while the central and western regions are relatively close. Figure 4 illustrates the penetration rate of higher education by academic qualifications, which shows that the proportion of employees with junior college education is the highest, followed by undergraduate, and the lowest is postgraduate.

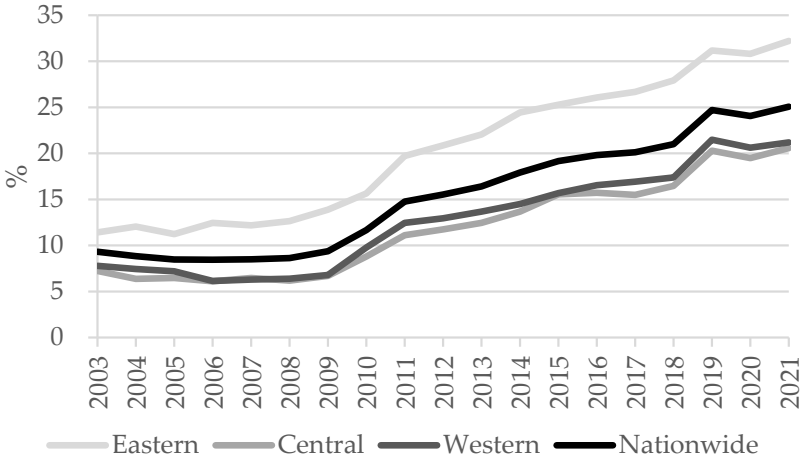

Figure 3. Penetration rate of higher education by regions of China.

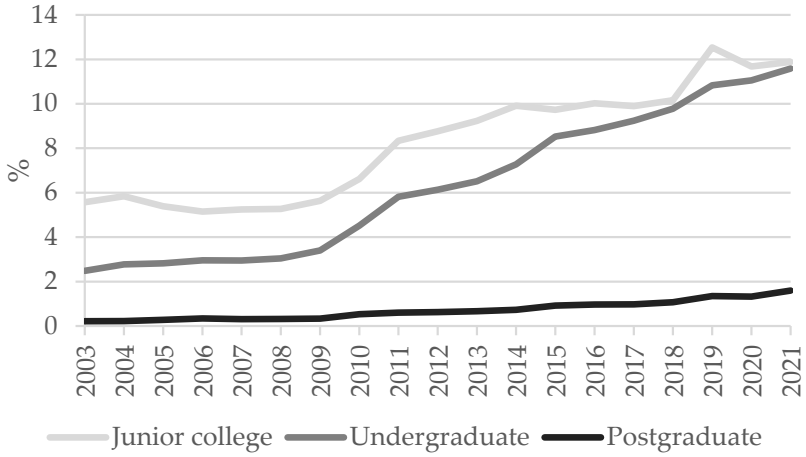

Figure 4. Penetration rate of higher education by academic qualifications in China.

3.3. Model Specification

This paper aims to use the panel data of China's provinces to investigate the impact of higher education on green eco-efficiency. First, *GEE* is set as the explained variable, and *HEDU*, ln*PGDP*, ln*BUA*, *INDUS*, *FDI* and *IPC* are set as explanatory variables to construct the regression model. Chow, LR and Hausman tests are used to test the model specification, respectively. The results are shown in Table 3, which reject all the null hypotheses at the level of 5%. Thus, this paper utilizes a two-way fixed effect model for analysis and adopts robust standard error to eliminate the influence of heteroscedasticity.

Table 3. Model specification test results.

Hypothesis	Test Statistics	Statistics Value	5% Critical Value of Statistics	Whether to Reject the Null Hypothesis
H_0: Pooled model	Chow test F statistic	6.91	1.39	Y
H_1: Two-way fixed effect model	LR test statistics	274.51	63.30	Y
H_0: Pooled model	Chow test F statistic	6.47	1.49	Y
H_1: Individual fixed effect model	LR test statistics	171.09	42.56	Y
H_0: Pooled model	Chow test F statistic	2.28	1.63	Y
H_1: Time fixed effect model	LR test statistics	40.11	28.10	Y
H_0: Random effect model	Hausman test	48.58	0.00	Y
H_1: Fixed effect model	Chi-square statistics			

Notes: column 4 in the last row is the *p* value.

The baseline two-way fixed effect model is constructed as follows:

$$GEE_{i,t} = \alpha_0 + \alpha_1 HEDU_{i,t} + \alpha_2 X_{i,t} + \lambda_i + \mu_t + \varepsilon_{i,t} \quad (9)$$

where $GEE_{i,t}$ stands for green eco-efficiency, and $HEDU_{i,t}$ represents the overall penetration rate of higher education. $HEDU_{i,t}$ is also replaced with $JEDU_{i,t}$, $UEDU_{i,t}$ and $PEDU_{i,t}$, which denotes the penetration rate of junior college, undergraduate and postgraduate education for further analysis. $X_{i,t}$ represents a series of control variables, including economic development level (ln*PGDPi,t*), urban scale (ln$BUA_{i,t}$), industrial structure ($INDUS_{i,t}$), foreign direct investment ($FDI_{i,t}$), and government regulation ($IPC_{i,t}$). α_1 and α_2 are regression coefficients. α_0 is the constant term. λ_i is the individual fixed effect of each province and μ_t is the time fixed effect. $\varepsilon_{i,t}$ is the error term.

4. Results and Discussions

4.1. Results of Baseline Regression

Table 4 shows the results of baseline regression. It is likely that the overall penetration rate of higher education has a significant positive impact on green eco-efficiency at the 5% level, indicating that higher education can significantly promote the level of green eco-efficiency. Hypothesis 1 is verified.

Table 4. Regression results of the baseline model.

Variable	(1) *GEE*	(2) *GEE*	(3) *GEE*	(4) *GEE*
HEDU	1.156 ***			
	(0.282)			
JEDU		0.218		
		(0.418)		
UEDU			2.107 ***	
			(0.514)	
PEDU				8.232 ***
				(0.535)
ln*PGDP*	6.028 *	1.166	8.872 **	6.250 **
	(2.979)	(3.287)	(3.568)	(2.992)
ln*BUA*	−7.029	−13.036	−7.684	−1.309
	(8.469)	(13.867)	(7.751)	(4.171)
INDUS	13.304	17.159	15.427	0.129
	(25.358)	(26.962)	(24.112)	(16.998)
FDI	226.902	84.838	292.769 *	236.446 *
	(161.183)	(189.447)	(154.631)	(125.133)
IPC	0.076 **	0.063 *	0.069 **	0.056 ***
	(0.028)	(0.034)	(0.026)	(0.019)
Constant	−23.942	67.842	−42.381	−49.656 *
	(47.471)	(94.498)	(41.850)	(27.341)
Observations	552	560	560	552
Individual fixed effect	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y
Adj. R-squared	0.578	0.456	0.601	0.742

Notes: *, **, *** indicate that t statistic is significant at 10%, 5% and 1% levels, respectively. Standard errors are in brackets.

Further, the regression results based on academic qualifications show that the penetration rates of undergraduate and postgraduate education significantly affect green eco-efficiency. The coefficient of *PEDU* is greater than that of *UEDU*, and both are greater than that of *HEDU*. The coefficient of *JEDU* is positive but not significant. It suggests that postgraduate and undergraduate education play a significant role in improving green eco-efficiency, and the impact increases with the increasing levels of education. However, junior college education does not significantly affect green eco-efficiency. Hypothesis 2 is verified. Combined with the previous descriptive analysis, the proportion of junior college graduates is the highest; hence, it is more urgent to boost the level of green education in junior college education.

4.2. Discussion on Endogeneity

Causes of endogenous problems include missing variables, reverse causality and data measurement errors. The fixed effect model used in the paper can solve the problem of missing variables to a certain extent. To avoid the endogenous problem caused by other factors, the one lag period of variables *HEDU*, *JEDU*, *UEDU* and *PEDU* are selected as instrumental variables, and the two-stage least squares method is used to test each baseline regression. Since the instrumental variable is the lag period of the explanatory variable, it is highly correlated with the explanatory variable and meets the constraints of correlation. And the current disturbance term is not related to the lag period of the explanatory variable,

which meets the exogenous constraints. The estimation results of the two-stage least squares method are shown in Table 5.

Table 5. Estimation results of the two-stage least squares method.

Variable	(1) *GEE*	(2) *GEE*	(3) *GEE*	(4) *GEE*
HEDU	1.609 ***			
	(0.376)			
JEDU		0.385		
		(0.720)		
UEDU			2.985 ***	
			(0.690)	
PEDU				8.965 ***
				(0.379)
ln*PGDP*	9.421 **	3.693	13.137 ***	7.549 **
	(3.815)	(3.920)	(4.654)	(3.317)
ln*BUA*	−7.202	−16.201	−7.391	−2.161
	(8.262)	(15.572)	(7.061)	(5.208)
INDUS	10.215	12.045	13.634	−2.176
	(26.614)	(30.559)	(24.641)	(16.711)
FDI	304.158 *	80.792	426.977 **	284.503 **
	(167.527)	(202.871)	(165.914)	(121.165)
IPC	0.085 ***	0.072 **	0.079 ***	0.059 ***
	(0.029)	(0.033)	(0.025)	(0.019)
Constant	−58.987	66.526	−88.676 **	−57.293 *
	(44.794)	(98.598)	(39.578)	(31.287)
Observations	522	530	530	522
Individual fixed effect	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y
R-squared	0.578	0.479	0.598	0.748

Notes: *, **, *** indicate that t statistic is significant at 10%, 5% and 1% levels, respectively. Standard errors are in brackets.

After controlling the endogenous issue, the sign, significance and ranking of coefficients of *HEDU*, *JEDU*, *UEDU* and *PEDU* are in full accord with the baseline regression results. It suggests that the baseline regression results are robust, and the improvement in the overall penetration rate of higher education and the penetration rate of undergraduate and postgraduate education can significantly improve green eco-efficiency.

4.3. Analysis of Regional Heterogeneity

From the above descriptive analysis, great differences are observed in the level of green eco-efficiency and higher education penetration rate in the eastern, central and western regions of China. Both levels in the eastern region are apparently higher than that of the central and western regions. To further explore the regional heterogeneity in the relationship between higher education and green eco-efficiency, the data of the eastern, central and western regions are regressed, respectively, according to the baseline regression model (9). The results are shown in Table 6.

In the three regions, only higher education in the eastern region has a significant positive impact on green eco-efficiency at the 5% level, while coefficients of central and western regions are not significant. It indicates that, higher the penetration rate of higher education, the greater the role it plays in promoting green eco-efficiency. Higher education in eastern China has formed an obvious talent agglomeration and scale effect, which plays a significant role in promoting green development. Hypothesis 3 is verified. Combined with the previous results that higher education significantly improves green eco-efficiency nationwide, it is likely that the eastern region has a greater impact on the whole country statistically.

Table 6. Regression results by regions.

Variable	Eastern *GEE*	Central *GEE*	Western *GEE*
HEDU	1.356 ***	−0.142	0.339
	(0.291)	(0.159)	(0.300)
ln*PGDP*	12.596	9.618 **	6.366 *
	(7.832)	(3.205)	(2.890)
ln*BUA*	−23.713	−2.309	4.383
	(14.009)	(3.809)	(2.784)
INDUS	−58.432	3.946	25.988 *
	(56.496)	(13.053)	(14.015)
FDI	93.412	100.008	−24.639
	(279.564)	(255.476)	(139.848)
IPC	0.159 *	0.004	0.013
	(0.083)	(0.026)	(0.010)
Constant	51.468	−69.335 **	−94.727 **
	(119.702)	(24.614)	(36.617)
Observations	203	144	205
Individual fixed effect	Y	Y	Y
Time fixed effect	Y	Y	Y
Adj. R-squared	0.688	0.872	0.742

Notes: *, **, *** indicate that t statistic is significant at 10%, 5% and 1% levels, respectively. Standard errors are in brackets.

In today's world, the issue of imbalance and inequality in higher education has received widespread attention [40–42], and some research also suggested that the quality and system of higher education show obvious differences among countries [43,44], which may further cause imbalances in economic and social development. Based on the results of this study on China, it can be inferred that the imbalance and inequality in higher education globally may also lead to differences in levels of green eco-efficiency among countries or regions. In countries with high penetration rates of higher education, higher education tends to promote green development more effectively. However, in countries with lower penetration rates, green education may require more urgent optimization.

5. The Influencing Path of Higher Education on Green Eco-Efficiency

5.1. Test Method of Mediating Effect

Previous results show that higher education can significantly improve green eco-efficiency nationwide. This paper further analyzes the influencing path for all provinces as a whole, aiming to provide a reference for improving green eco-efficiency on a national scale. On one hand, the education level of knowledge and technology can improve local scientific and technological innovation, thus promoting the production efficiency of enterprises, reducing energy consumption and environmental pollution, and increasing green eco-efficiency. On the other hand, receiving higher education, especially green education, may enable people to pay more attention to the field of ecology and environmental protection, thus enhancing their awareness of green development and promoting green eco-efficiency. Therefore, technological innovation and environmental attention are taken as the mediating mechanisms to explore the impact path of higher education on green eco-efficiency, so as to verify Hypothesis 4 and Hypothesis 5.

Stepwise regressions, Sobel–Goodman test and bootstrap test are used to verify the effect, so as to enhance the robustness. In the bootstrap test, sampling is repeated 1000 times. Models of stepwise regression are constructed using Equations (10)–(12):

$$GEE_{i,t} = \alpha_0 + \alpha_1 HEDU_{i,t} + \alpha_2 X_{i,t} + \lambda_i + \mu_t + \varepsilon_{i,t} \quad (10)$$

$$M_{i,t} = \beta_0 + \beta_1 HEDU_{i,t} + \beta_2 X_{i,t} + \lambda_i + \mu_t + \varepsilon_{i,t} \quad (11)$$

$$GEE_{i,t} = \gamma_0 + \gamma_1 HEDU_{i,t} + \gamma_2 M_{i,t} + \gamma_3 X_{i,t} + \lambda_i + \mu_t + \varepsilon_{i,t} \quad (12)$$

where $GEE_{i,t}$ represents green eco-efficiency. $X_{i,t}$ represents a series of control variables, as stated previously. A_1, α_2, β_1, β_2, γ_1, γ_2, and γ_3 are regression coefficients. A_0, β_0, and γ_0 are constant terms, λ_i is the individual fixed effect of each province and μ_t is the time fixed effect. $E_{i,t}$ is the error term. $M_{i,t}$ are mediating variables, which are technological innovation ($PATENT_{i,t}$) and environmental attention ($ATTENTION_{i,t}$).

5.2. Description of Mediating Variables

Technological innovation (*PATENT*) is measured with the ratio of three kinds of patent (invention, utility model and appearance design) authorizations in each province to the number of permanent residents. Data are obtained from the State Intellectual Property Office and the National Bureau of Statistics of China. The time interval and provinces involved are consistent with the previous illustration.

For the measurement of environmental attention (*ATTENTION*), referring to the method of Li and Wei [45] and combining the development of "internet plus" and "big data", this paper measures it by using the ratio of Baidu Search Index of keywords "environment+ecology+sustainable development" to the number of permanent residents. Baidu Search Index is computed based on the search volume in Baidu and it takes keywords as the statistical object. It analyzes and calculates the weighted sum of search frequency of keywords in Baidu web search, and can illustrate the sum of data of multiple keywords. The index reflects public's attention to the keywords searched (For more details, see https://index.baidu.com (accessed on 3 July 2023)). In this paper, the specific operation is to search the keywords "environment+ecology+sustainable development" (all in Chinese) in Baidu Index, select the sum of PC and mobile data as the statistical scope, and use the daily average of Baidu Search Index of each province each year to obtain the index. Due to data availability, the time interval of the variable *ATTENTION* is 2014–2021, and the provinces involved are the same as the previous statement. The descriptive statistics of mediating variables are shown in Table 7.

Table 7. Descriptive statistics of mediating variables.

Variable	Observations	Mean	Std. Dev.	Min	Max
PATENT	570	8.526	13.070	0.130	90.808
ATTENTION	240	0.981	0.551	0.377	2.727

5.3. Results and Discussions

5.3.1. Results of Stepwise Regression

In Table 8, column (1) presents the baseline regression results, and columns (2)–(5) show the results of model (11) and model (12) in the stepwise regression with *PATENT* and *ATTENTION* as the mediating variables, respectively. The coefficients of *HEDU* in columns (1) and (2), and the coefficients of *PATENT* and *HEDU* in column (3) are all significant at the level of 5%, so the variable *PATENT* has a significant partial mediating effect. Hypothesis 4 is verified. According to the regression coefficients, the mediating effect of technological innovation is 0.752, the direct effect of higher education on green eco-efficiency is 0.404, and the total effect is 1.156. The mediating effect of technological innovation accounts for 65.0%.

At the 5% level, the coefficient of *HEDU* in column (4) is significant, which indicates that higher education helps to improve public environmental attention. However, the coefficient of *ATTENTION* in column (5) is not significant, suggesting that the improvement in environmental attention cannot significantly promote green eco-efficiency. In general, environmental attention does not play a significant mediating role in the path of higher education's impact on green eco-efficiency. Hypothesis 5 cannot be verified.

Table 8. Stepwise regression results of mediating effect.

Variable	(1) *GEE*	(2) *PATENT*	(3) *GEE*	(4) *ATTENTION*	(5) *GEE*
PATENT			0.493 ***		
			(0.162)		
ATTENTION					−1.49
					(2.430)
HEDU	1.156 ***	1.526 ***	0.404 **	0.022 ***	0.839 **
	(0.282)	(0.175)	(0.167)	(0.008)	(0.379)
ln*PGDP*	6.028 *	−7.053	9.502 **	−0.258	13.07
	(2.979)	(6.156)	(4.001)	(0.219)	(8.859)
ln*BUA*	−7.029	9.276	−11.598	0.37	−7.901
	(8.469)	(7.335)	(8.067)	(0.457)	(18.032)
INDUS	13.304	13.191	6.806	−3.201	−10.922
	(25.358)	(28.304)	(18.620)	(2.015)	(39.581)
FDI	226.902	248.084	104.699	0.208	−148.673
	(161.183)	(442.493)	(200.881)	(7.867)	(179.046)
IPC	0.076 **	0.069 *	0.042 *	−0.006 ***	0.11 *
	(0.028)	(0.039)	(0.023)	(0.001)	(0.064)
Constant	−23.942	−15.649	−16.234	2.109	−88.618
	(47.471)	(54.610)	(36.918)	(2.470)	(102.648)
Observations	552	552	552	233	233
Individual fixed effect	Y	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y	Y
Adj. R-squared	0.578	0.704	0.709	0.618	0.417

Notes: *, **, *** indicate that t statistic is significant at 10%, 5% and 1% levels, respectively. Standard errors are in brackets.

5.3.2. Results of Sobel–Goodman Test and Bootstrap Test

Due to the low test power of stepwise regression, the Sobel–Goodman test and bootstrap test are further used to test the mediating effect, and the results are shown in Table 9. It can be seen that in the path of higher education influencing green eco-efficiency through technological innovation, both tests reject the null hypothesis that technological innovation does not have an intermediary effect, and also reject the null hypothesis that higher education has no direct effect on green eco-efficiency at the 5% level. Both prove that technological innovation has a partial mediating effect, which accounts for 65.0%, This is completely consistent with the results of the stepwise regression test.

Table 9. Results of the Sobel–Goodman test and bootstrap test for mediating effect.

Path		***HEDU*→*PATENT*→*GEE***				***HEDU*→*ATTENTION*→*GEE***
Test Effect		**Mediating Effect**	**Direct Effect**	**Total Effect**	**Proportion of Mediating Effect**	**Mediating Effect**
Estimates		0.752	0.404	1.156	65.0%	−0.033
Sobel–Goodman test	Std. err.	0.073	0.094	0.095		0.067
	Z value	10.288	4.320	12.134		−0.492
	p value	0.000	0.000	0.000		0.623
	To reject the null hypothesis	Y	Y	Y		N
Bootstrap test	Std. err.	0.147	0.130			0.062
	95% confidence interval	0.451	0.122			−0.202
		1.018	0.605			0.062
	To reject the null hypothesis	Y	Y			N

In the path of higher education influencing green eco-efficiency through environmental attention, at the 5% level, neither method can reject the null hypothesis that environmental attention does not have a mediating effect. It is likely that environmental attention does not

play a significant mediating role, which is also consistent with the results of the stepwise regression test.

The mediating effect is summarized and shown in Figure 5. In the influencing path of higher education on green eco-efficiency, technological innovation has a significant mediating effect, while environmental attention has no mediating effect. Although higher education can significantly improve environmental attention, environmental attention cannot significantly improve green eco-efficiency. For other countries, technological innovation is also likely to play a more effective intermediary role in promoting green development.

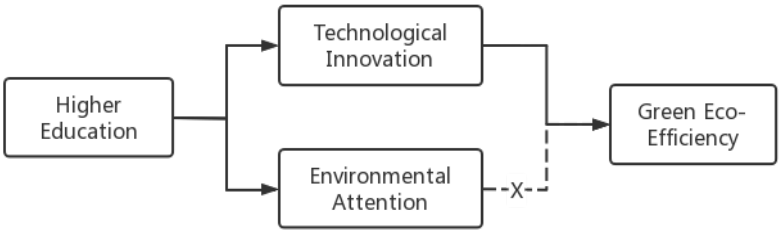

Figure 5. Mediating path of higher education affecting green eco-efficiency.

6. Conclusions and Implications

6.1. Conclusions

Based on the annual panel data of 30 provinces in China from 2003 to 2021, this paper constructs the green eco-efficiency index of each province and uses the two-way fixed effect model to analyze the impact of the overall penetration rate of higher education and the penetration rate of different levels of higher education on green eco-efficiency. It further analyzes the heterogeneity of the impact of higher education in eastern, central and western China on green eco-efficiency. In addition, this paper uses stepwise regression, Sobel–Goodman test and bootstrap test to study the mediating effect of technological innovation and environmental attention in the influence path of higher education on green eco-efficiency. The results show the following:

1. For all provinces as a whole, the improvement in the penetration of higher education has a significant positive impact on green eco-efficiency. The positive impact of undergraduate and postgraduate education on green eco-efficiency is significant, and the impact increases with the increasing levels of education. However, the impact of junior college education is not significant;
2. The impact of higher education on green eco-efficiency has regional heterogeneity. Higher education in eastern China has a significant positive impact on green eco-efficiency, while the relationship between the two is not significant in the central and western regions;
3. In the influencing path of higher education on green eco-efficiency nationwide, technological innovation has a significant partial mediating effect, while environmental attention has no mediating effect. Although higher education can significantly improve environmental attention, environmental attention cannot significantly improve green eco-efficiency.

6.2. Policy Implications

Based on the previous results, the following suggestions to strengthen the development of green education in China's higher education system are put forward:

First, higher education plays a significant role in improving green eco-efficiency; hence, higher education institutions should strengthen green development-related majors and courses and further promote green education. This can also be extended to other countries. For general education curriculum, colleges and universities should offer courses such as Introduction to Green and Low-Carbon Development, popularize the basic theory and knowledge for students of different majors, and enhance social awareness of environmental protection and green development. In terms of professional education, colleges and

universities should promote the construction of green development curriculum system. Qualified institutions are supposed to strengthen relevant majors and disciplines such as environmental engineering, clean energy, low-carbon economy and green finance. Scientific and technological innovation contributes significantly to green development. Higher education institutions should strengthen the integration of green education and science and technology education, develop more double degrees and minor programs related to green development, and cultivate "Green Development Plus" talents who not only have professional knowledge and skills in a certain field, but can also better serve green development [46]. Especially, developing countries should focus more on science and technology education, which may facilitate green development more effectively.

Second, although higher education can improve public environmental attention, the effect of environmental attention in promoting green eco-efficiency needs to be strengthened. Higher education institutions should enhance the practice of green development education and encourage students to transform knowledge and awareness into action. More practical opportunities for students should be created to help them better understand the theoretical knowledge related to green development and apply it to the solution of practical problems. Through social practice, volunteer services and internships, students can participate in environmental protection projects and sustainable development practice. Higher education institutions are also supposed to cooperate closely with industries, governments and communities to promote the implementation and application of green and low-carbon development education.

Finally, the influence of higher education on green eco-efficiency shows an obvious imbalance. Therefore it is essential to strengthen the development of green education in the higher education system. The development of green education at the junior college level, which accounts for the largest proportion of the public receiving higher education, ought to be greatly strengthened. Relevant educational institutions should set up more majors and courses related to green development. Part of the green education development for undergraduate and postgraduate students should be moved to the junior college level, to improve the relevant knowledge, skills and awareness of junior college graduates. From the perspective of geographical distribution, the green education development of higher education institutions in central and western China should be reinforced. The government is supposed to expand the financial input to universities in central and western regions and encourage higher education exchanges and support among different regions, to enhance scientific and technological innovation and environmental awareness in those regions through better higher education, and further promote the country's green development. Other countries can learn from China's experience, recognize the distinctions in the effect of higher education among different regions, and thus formulate specific educational and sustainable development policies. It is necessary to reinforce educational exchanges at a global level and strengthen the assistance of developed countries to developing countries, which may help to better optimize green education and green development in developing countries.

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