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Impact of Energy-Biased Technological Progress on Inclusive Green Growth

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Abstract: Inclusive green growth is a sustainable development approach that pursues the coordination of economic growth, the ecological environment, and social equity, which is conducive to solving the problems of environmental pollution and unbalanced economic growth in the industrialization process. Based on provincial data from 2005 to 2020 in China, this study examines the impact of energy-biased technological progress on inclusive green growth and explores the mechanism of its effects from the perspective of industrial structure upgrading using a panel regression model and mediating effect model. The results show the following: (1) China's technological progress is characterized by energy-biased technological progress and the level of inclusive green growth is gradually increasing. (2) Energy-biased technological progress can positively contribute to inclusive green growth and is heterogeneous over time and space. (3) Energy-biased technological progress can promote inclusive green growth through industrial structure advancement and industrial structure cleanliness, and the two mechanisms are complementary. This article considers the biased characteristics of technological progress and the impact of industrial structure cleanliness on inclusive green growth and provides a reference for developing countries to achieve inclusive green growth.

Keywords: energy-biased technological progress; industrial structure advancement; industrial structure cleanliness; inclusive green growth; China

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1. Introduction

With the acceleration of the industrial development process, social inequity, environmental overdraft, ecological deficit, and other problems are becoming increasingly prominent, which seriously affects the world's sustainable development [1,2]. Over the past two decades, economic growth has lifted 660 million people out of poverty and increased the incomes of millions more. Nevertheless, economic expansion has frequently occurred at the expense of the environment and societal well-being [3]. As can be seen in Figure 1, carbon emissions have increased every year since the Paris targets were reached, except in 2020 when the COVID-19 pandemic was at its worst. In 2021, the global demand for primary energy climbed by 31 EJ (an increase of 5.8%), the greatest growth in history. In 2020, not only was the trend of the dropping energy demand reversed, but it also grew by 1.3% over 2019 [4]. The number of people living in extreme poverty in the world climbed by 12 percent in 2020, and the world still faces pressing issues such as environmental degradation and social inequality [5]. The loss of traditional growth methods' "inclusivity" and "greening" is the primary cause of these problems. Inclusive green growth (IGG) was proposed at the 2012 United Nations Conference on Sustainable Development (Rio + 20), emphasizing the balance between economic growth, social equity, and green production [6]. Following the 2016 introduction of the new Sustainable Development Goals by the United Nations, many nations have begun to implement "inclusive green growth"-centered development policies [7,8].

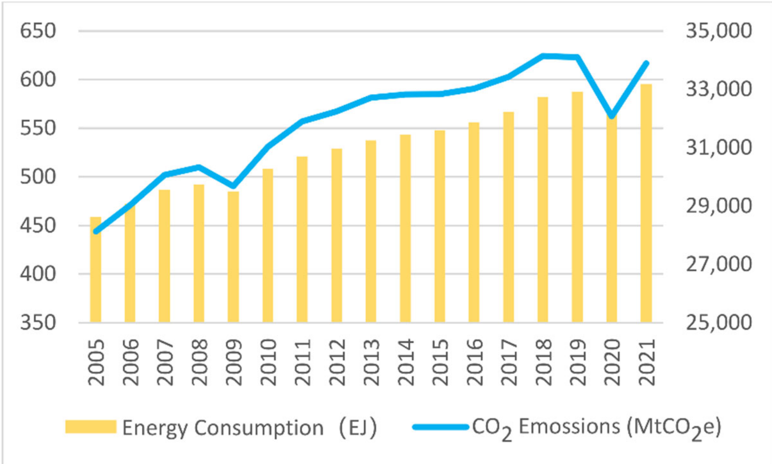

Figure 1. Global energy consumption and carbon emission trends.

Biased technological progress reflects changes in the marginal rate of substitution, which was first proposed by Hicks [9]. Energy-biased technological progress can change the marginal productivity and marginal rate of substitution of energy and promote industrial structure upgrading to influence inclusive green growth [10,11]. Existing studies have mainly explored biased technological progress from labor and capital factors [12]. Most scholars believe that technological progress can affect inclusive green growth not only directly [13,14], but also indirectly through mechanisms of action such as energy demand [15], financial development [16], and economic growth [17]. Although the existing literature is rich in research on the impact of technological progress on inclusive green growth, there are still the following gaps. First, the energy factor is not discussed in the context of biased technological progress. Second, the biased characteristics of technological progress are not considered when studying its impact on inclusive green growth. Third, there is a lack of studies that explore the impact of energy-biased technological progress on inclusive green growth from the perspective of industrial structure advancement and industrial structure cleanliness. Consequently, this paper seeks to investigate the following issues: (1) Is energy-biased technological progress driving the economy in a green and inclusive direction? (2) Can energy-biased technological progress (EBT) influence inclusive green growth through industrial structure advancement and industrial structure cleanliness?

In response to the questions raised above, this study investigates the impact of EBT on inclusive green growth, and explores the mechanism of its effects from the perspective of industrial structure upgrading. Developing countries are facing enormous environmental and economic pressures. China, as the largest developing country, is facing serious economic, social, and ecological problems as its energy consumption and carbon emissions rank first in the world and its national Gini coefficient far exceeds the international alert line. Therefore, addressing the issue of inclusive green growth in China is of great importance to promoting sustainable development around the world.

The main contributions are as follows: First, at the research perspective level, this paper explores the impact of energy-biased technological progress on inclusive green growth by considering the biased characteristics of technological progress. Second, at the level of the measurement method, the energy factor is added to the stochastic frontier model to measure the energy-biased technological progress. Third, the mechanism of energy-biased technological progress on inclusive green growth is analyzed from the perspective of industrial structure advancement and industrial structure cleanliness.

The remaining sections of this study are structured as follows: Section 2 presents the relevant literature; Section 3 puts forward the theoretical analysis and research hypotheses; Section 4 provides the model construction and variable descriptions; Section 5 explains the characteristics of energy-biased technological progress and inclusive green growth;

Section 6 presents the empirical results; Section 7 discusses the results; Section 8 elaborates on the conclusions and policy recommendations.

2. Literature Review

Most studies of biased technological progress have focused on labor and capital factors. For example, Grossman and Oberfield [18] and Bergholt et al. [19] found that technological progress in the U.S. manifested itself as capital-biased technological progress due to greater automation of production processes. For the measurement of biased technological progress, the following methods are available. The first method is the constant elasticity of the substitution production function [20,21]. Klump [22] used the CES technique to gauge technological progress in the United States and discovered a labor bias. Li and Stewart [23] used this method to measure the direction of technological progress in Canada and reached the same conclusion. This method, however, presupposes constant substitution elasticity, which is inconsistent with reality. The second method is the non-parametric method (DEA) [24,25]. Hampf and Krüger [12] utilized this method to evaluate the technological progress of 81 nations and discovered that the majority supported the use of capital. Dasgupta and Roy [26] suggested that India's technological progress has been gradually characterized by energy efficiency using the DEA approach. Nonetheless, the DEA approach is susceptible to sampling variance and random influences, and the evaluation results may be skewed [27]. The third method is the stochastic frontier method (SFA) [28]. Bravo et al. employed the SFA method to identify a bias favoring technological progress in Nicaragua [29]. Karanfil and Yeddir [30] employed this method to measure technological progress in France and discovered that capital-saving technological progress is present in the majority of industries. The SFA technique incorporates an inefficiency element that quantifies the degree of deviation and makes the model more realistic.

There are a number of factors currently affecting inclusive green growth, including economic policy [31], institutional quality [32], technological progress [13], land resource allocation [33], FDI [34], industrial structure [35], and government governance [36]. Among these elements, technological progress is a key element in achieving inclusive green growth [37]. Most studies have concluded that technological progress can reduce pollution emissions. For example, Mensah et al. [38] used the FMOLS model to find that innovation facilitates pollution reduction in OECD countries. Khan et al. [16] and Fernández et al. [39] utilized OLS models to determine that technological advancement can cut carbon emissions in EU nations. Ahmed et al. [40] arrived at an identical conclusion. Using quantile regression methods, Kartal et al. [1] conducted a study and discovered that technology can lessen environmental degradation in newly industrialized nations. Using DOLS and CCR methodologies, Raihan et al. [41] determined that both the utilization of renewable energy and technological innovation are advantageous to green development. However, in real life, technological progress is biased [42]. Technological progress can be driven by factors of production through price effects, which affect rare factors primarily, and market effects, which affect plentiful factors primarily [43]. When biassed technological progress utilizes more clean energy or emits a more desirable output, this has substantial effects on green growth [44]. Furthermore, EBT can achieve energy savings and pollution decrease by changing the marginal rate of substitution [45]. A few academics believe that biased technological progress will raise energy consumption and impede green development [46]. The majority of research agrees that energy-biased technological progress can effectively promote green economic growth [44,47]. Using data for OECD economies from 2000 to 2017, Yang and Zha [45] found that biased technological progress reduces pollution in high-income economies while increasing it in low-income economies. Er et al. [48] discovered that technological advancement helps the development of an advanced industrial structure, hence reducing environmental pollution.

Concerning the study on the mechanism of the role of technological progress in inclusive green growth, scholars believe that technological progress can influence inclusive green growth through energy demand [49], economic growth [17], labor employment [50], financial development [51], and environmental regulation [52]. Pradhan [53] and Dasgupta [26] studied India through a CGE model and found that technological progress can promote a low-carbon economy by reducing the price of non-fossil energy sources. Santhakumar et al. [54] found that technological progress can influence economic development patterns through learning mechanisms. Ahmad and Wu [55] found that financial deepening moderated the influence of technological progress on the ecological efficiency of 28 selected G-20 countries from 1985 to 2017. However, the improvement of technological progress will also have a greater impact on the industrial structure [56]. Ngai and Pissarides identified that technological progress plays an important role in the formation of industrial structure imbalances [57]. Some scholars found that biased technological change would affect the production efficiency of factors, which would cause the flow of factors between different departments, and then affect the industrial structure [58]. Industrial structure upgrading can further influence inclusive green growth. Tanaka and Managi demonstrated that an advanced industrial structure improves energy efficiency and reduces environmental pollution [59]. Despite this, industrial structure cleanliness does have a substantial influence on inclusive green growth. Evidence shows that industrial structure ecologicalization promotes fossil fuel efficiency and environmental efficiency for sustainable development [60]. Industrial structure green adjustment can significantly contribute to ecological well-being performance growth [61]. Therefore, it is necessary to study the impact of EBT on IGG from the perspectives of industrial structure advancement and industrial structure cleanliness.

Given the current research, three gaps should be noted: First, there are more influences on inclusive green growth, and technological progress is a key factor in achieving inclusive green growth. Most studies have concluded that the impact of technological progress on inclusive green growth is significantly facilitated, yet research on the impact of energy-biased technological progress is worth exploring in depth. Second, the main methods for measuring biased technological progress are the constant elasticity of substitution production function (CES) method, the non-parametric method (DEA), and the stochastic frontier approach (SFA). Among them, the SFA method adds an inefficiency term to the model to measure the degree of bias, which is more in line with reality. The measurement of biased technical progress is usually based on two factors, capital and labor, and less consideration is given to the energy factor. Third, scholars currently believe that technological progress can influence inclusive green growth through mechanisms of action such as energy demand, economic growth, and environmental regulation, but there is a lack of systematic analysis from the perspective of industrial structure advancement and industrial structure cleanliness.

3. Theoretical Analysis and Research Hypotheses

3.1. Technological Progress and Inclusive Green Growth

On the one hand, energy-biased technological progress (EBT) can enhance inclusive green growth through the effect of marginal production improvement [62]. In the framework of endogenous technological progress, energy-biased technological progress can improve energy efficiency in the process of energy use through the "learning by doing" effect [63]. Improvements in energy efficiency can promote social justice and enhance the environment [64,65]. Studies have indicated that biased technological progress has a spillover effect on regional energy consumption [66]. As the technology spreads to other industries, regional energy consumption reduces, and overall regional output rises as marginal energy production increases, contributing to inclusive green growth [67]. However, on the other hand, EBT can enhance inclusive green growth through the effect of marginal substitution rate change [68]. Acemoglu's pioneering work combines biased technological progress with endogenous growth theory to form the "endogenous growth theory of the direction of technological progress" [69]. The endogenous growth theory proposes that price effects will match technological progress with higher-priced factors, resulting in biased technological progress. When there is energy-biased technological progress, energy will substitute with other factors due to changes in the marginal rate of substitution between energy and other factors, thus changing the relative production of energy factors [70,71]. The effect of a marginal substitution rate change makes factors flow to industries with high production, prompting elements to create new industries. Further, these new industries can absorb industrial workers in traditional or declining industries to provide more jobs for society, reduce unemployment rates, and promote inclusive economic growth. Both the effects of marginal production improvement and marginal substitution rate change can contribute to inclusive green growth (Figure 2).

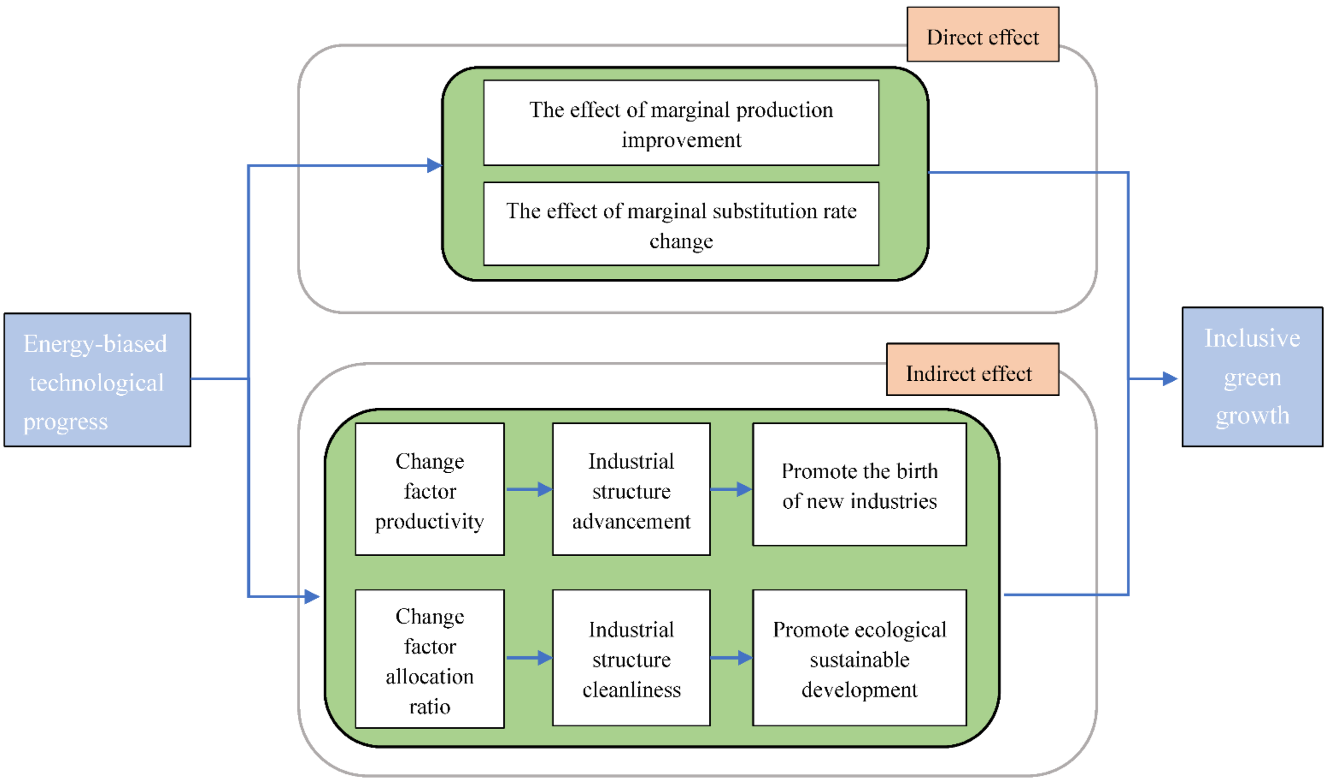

Figure 2. Mechanism analysis diagram.

This paper proposes the first hypothesis based on the above analysis:

H1. *Energy-saving technological progress has a positive impact on inclusive green growth.*

3.2. Energy-Biased Technological Progress, Industrial Structure Upgrading, and Inclusive Green Growth

Historical practice shows that industrial structure upgrading is strongly associated with technological progress. Hence, it is crucial to investigate the effects of EBT on inclusive green growth from the perspective of industrial structure upgrading. Technological progress can indirectly encourage inclusive green growth through industrial structure advancement [72]. On the one hand, EBT affects factor productivity. The cost of capital increases when it is more technically efficient than energy, and the cost of energy increases when the two factors are complementary. Substitutability between factors results in an increase in labor and output variables. This is also true in the opposite direction. Industrial structure theory suggests that when production factors are relocated from low- to high-productivity sectors, such intersectoral factor mobility can heighten the industrial structure. On the other hand, EBT increases total factor productivity regardless of the type of biased factors [73]. Antonelli proposes the theory of technological consistency, which identifies neutral and biased technological progress from the displacement and bias effects of technological progress leading to changes in the equal output curve, and emphasizes the key impact of the degree of consistency between biased technological progress and factor endowments on total factor productivity growth [74]. The essence of technological consistency is the meta-substitution progress triggered by biased technological progress, i.e., biased technological progress leads to the substitution of expensive factors of production for cheaper ones, which in turn leads to the intensive use of relatively abundant factors of production and brings about an increase in overall production efficiency [75]. An increase in total factor productivity leads to an increase in output and a decrease in the relative price of products [76]. A technologically advanced industry can upgrade or restructure products and promote the restructuring of supply and demand, resulting in a more advanced industrial structure. Environmental friendliness is determined by the quality and sophistication of the industrial structure [77,78]. It is possible to establish high-tech industries, boost employment possibilities, improve people's lives, and promote inclusive green growth with the development of industrial structure advancement.

This paper proposes the second hypothesis based on the above analysis:

H2. *Energy-biased technological progress can indirectly affect inclusive green growth through industrial structure advancement*.

In addition, biased technological progress can indirectly encourage inclusive green growth through industrial structure cleanliness. The renewal of machines and devices can contribute to the advancement of environmentally friendly technology, thereby promoting industrial structure cleanliness and driving inclusive green growth [79]. According to the new economic growth theory, economic development occurs when the price of a factor is relatively high. Economic development will, in turn, lead to technological innovation in the production unit for that factor, which will lead to bias in favor of that factor [43]. In addition to altering the ratio of input factors such as energy and labor, EBT also decreases the share of heavily polluting industries, and promotes the cleanliness of the industrial environment [80]. Industrial structure cleanliness is the most important and sustainable strategic path in economic growth approaches [81]. On the one hand, it may minimize pollution levels, support sustainable environmental development, and improve economic output capacity. On the other hand, it can improve factor utilization efficiency and use recyclable resources to promote green economic development [82].

This paper proposes the third hypothesis based on the above analysis:

H3. *Energy-biased technological progress can indirectly affect inclusive green growth through industrial structure cleanliness*.

4. Model Construction and Variable Selection

4.1. Model Construction

Panel models simultaneously control the individual effect and the time effect and are effective for samples with significant individual differences. For these reasons, we first applied a panel model to explore the effect of input energy-biased technological progress on inclusive green growth, in the following way:

$$IGG_{\mathrm{it}} = a_0 + a_1 EBT_{it} + a_2 X_{it} + \varepsilon_{it} \quad (1)$$

where *IGG* stands for inclusive green growth, and *EBT* represents energy-biased technological progress. We are most interested in the coefficient a_1 which reflects the effects of *EBT* on *IGG*. The variable *X* indicates control variables, including population density, coal consumption per capita, and level of external opening.

Second, in order to explore the mechanism of the effect of *EBT* on *IGG* from the perspective of industrial structure advancement and industrial structure cleanliness, the following model is established:

$$ISA_{\mathrm{it}} = b_0 + b_1 EBT_{it} + b_2 X_{it} + \varepsilon_{it} \quad (2)$$

$$ISC_{\text{it}} = c_0 + c_1 EBT_{it} + c_2 X_{it} + \varepsilon_{it} \quad (3)$$

where *ISA* denotes industrial structure advancement, *ISC* means industrial structure cleanliness, b_1 is the coefficient of the effect of *EBT* on *ISA*, representing the mediating effect of industrial structure advancement, and c_1 is the coefficient of the effect of *EBT* on *ISC*, representing the mediating effect of industrial structure cleanliness.

4.2. Variable Selection

4.2.1. Core Explanatory Variable

The core explanatory variable is energy-biased technological progress (EBT). Neoclassical economic growth theory posits that external technical advancement boosts input growth [83]. The single-output, three-input SFA model is used in this paper to measure EBT. Due to the fact that SFA relaxes the assumption of technology neutrality by introducing a time factor, it can reveal more characteristics of the economic system in greater detail [84]. This paper draws on the study of Niroui et al. [28] with the following equation:

$$\begin{aligned} \ln y = \alpha_0 + \alpha_1 t + 1/2\alpha_2 t^2 + \alpha_3 \ln L + \alpha_4 \ln K + \alpha_5 \ln E + \alpha_6 t \ln L + \alpha_7 t \ln K \\ + \alpha_8 t \ln E + 1/2\alpha_9 \ln L \ln K + 1/2\alpha_{10} \ln L \ln E + 1/2\alpha_{11} \ln K \ln E \\ + 1/2\alpha_{12} (\ln L)^2 + 1/2\alpha_{13} (\ln K)^2 + 1/2\alpha_{14} (\ln E)^2 + v_{it} - \mu_{it} \end{aligned} \quad (4)$$

where y is the output, measured by GDP in constant 2000 prices; L denotes labor, measured by total employment; K represents capital stock, measured by the perpetual inventory method; E denotes energy, expressed as energy consumption; v is a random disturbance term, and μ stands for technical inefficiency.

The energy output elasticity can be obtained using Equation (5) as:

$$\varepsilon_E = \alpha_5 + \alpha_8 t + 1/2\alpha_{10} \ln L + 1/2\alpha_{11} \ln K + \alpha_{14} \ln E \quad (5)$$

where ε_E is the energy output elasticity, and drawing on Baron and Kenny [85], bringing Equation (4) into Equation (6) yields *EBT*.

$$EBT = \frac{\alpha_8}{\varepsilon_E} \quad (6)$$

where *EBT* represents energy-biased technological progress, and ε_E denotes the output elasticity of energy.

$EBT > 0$ indicates energy-use-biased technological progress, and $EBT < 0$ means energy-saving-biased technological progress. The energy-biased technological progress in this paper represents energy-saving-biased technological progress. A smaller *EBT* value indicates greater progress in energy-saving-biased technological progress.

4.2.2. Explained Variable

The explained variable is inclusive green growth (IGG). This paper integrates the World Bank and OECD principles of inclusive green growth [86,87] and in-depth assessments by other experts [87] to construct the IGG indicator system from four perspectives: economic development, social opportunity and equity, green production and consumption, and ecological sustainability. Economic development reflects economic development and structural transformation and is the essence of IGG. Social equity and fairness emphasize the equal participation of all people in the growth process and are the logical starting points of IGG. Green production and consumption promote the coordinated development of environmental economics and are an important guarantee of IGG. Ecological sustainability strengthens ecological repair and pollution control and is an inherent requirement of IGG. Appendix A Table A1 shows the variables used to construct IGG.

4.2.3. Intermediate Variables

The intermediate variable is industrial structure upgrading, which is assessed out mainly from two perspectives: industrial structure advancement (ISA) and industrial structure cleanliness (ISC).

Industrial structure advancement (ISA): industrial structure advancement is the dynamic progression of the industry from the primary industry to the secondary industry and, subsequently, to the tertiary industry, measured by the ratio of the output value of the tertiary industry to that of the secondary industry [88].

Industrial structure cleanliness (ISC): China is currently in the middle and late stages of industrialization, so the details of structural adjustment within the industry are more worthy of attention. In this paper, we define industrial structure cleanliness as the dynamic process of transforming industrial pollution emissions from high to low to meet the requirements of energy conservation and environmental protection, and the increasing proportion of clean industrial sectors representing industrial low-carbon technologies, which gradually drive the transformation of the industrial structure from a path dominated by high energy consumption and carbon emissions. This is an extension and supplement of industrial structure advancement, which illustrates the dynamic details of the change in industrial structure upgrading.

Using the classification approach of [89,90] to categorize industrial categories by pollutant emission intensity per unit of production, the following phases comprise the industrial structure cleanliness measurement process:

First, the intensity of each pollutant's emissions for each industry is determined.

$$PI_{\mathrm{ir}} = E_{\mathrm{ir}}/Y_{\mathrm{i}} \tag{7}$$

where i reprents industry, r reprents to a pollutant, and PI_{ir} denotes the emission intensity of pollutant r of industry i, which is equal to the ratio of the total emission of pollutant r of that industry E_{ir} to the total output value Y_i of that industry.

Second, the min-max normalization of PI_{ir} is performed to make the data dimentionless.

$$PI^{*}_{\mathrm{ir}} = [PI_{ir} - \min(PI_{ir})]/[\max(PI_{ir}) - \min(PI_{ir})] \tag{8}$$

where PI^{*}_{ir} denotes the standardized value of each industry's pollutant emission intensity index.

Then, PI^{*}_{ir} is weighted equally and averaged to obtain the pollution emission intensity index of each industry.

$$TPI_i = \frac{1}{r}\sum_{r=1}^{n} PI^{*}_{ir} \tag{9}$$

Finally, the change in the inter-industry output ratio and inter-industry cleanliness level is used to measure the industrial structure cleanliness.

$$ISC_j = \sum_{i=1}^{n} \frac{Y_i}{Y}\frac{1}{TPI_i} \tag{10}$$

where TPI_i is the complete index of industry i's pollution emission intensity, and ISC_j signifies the degree of industrial structure cleanliness; hence, the greater the value of ISC_j, the greater the degree of industrial structure cleanliness. In light of the data availability, this article focuses on the industrial and service sectors. Industrial and service sector pollutants include wastewater and waste gas.

4.2.4. Control Variables

Population density (PD): It was found that population density can influence social equity and green development [91]. Therefore, we used population density as a control variable, based on the percentage of the resident population in the city's jurisdictional area. Coal consumption per capita (PC): An increase in PC increases pollution emissions [92]. Therefore, we used PC as a control variable, expressed as the ratio of coal use to population.

Level of external opening (OP): A study showed that opening up to the outside world helps to reduce energy consumption [93], therefore, we used OP as a control variable, calculated by dividing imports and exports by the gross domestic product.

4.3. Data Sources

This study studied 30 Chinese provinces to verify the association between energy-biased technological progress, industrial structure upgrading, and inclusive green growth (excluding Tibet, Hong Kong, Macao, and Taiwan due to missing data). Due to China's progressive growth in environmental management beginning in 2005, the data period for this report is 2005 to 2020. Data were obtained from the China Statistical Yearbook, China Environmental Statistical Yearbook, and Wind database. The descriptive statistics of the variables are shown in Table 1.

Table 1. Descriptive statistics of variables.

Variable	Obs	Mean	Std. Dev	Min	Max
IGG	480	0.3251	0.0891	0.2069	0.6656
EBT	480	−0.1254	0.1985	−0.6146	0.4164
ISA	480	1.1085	0.6390	0.4971	5.2969
ISC	480	0.0612	0.1370	0	1
PD	480	0.0276	0.0126	0.0019	0.0631
PC	480	0.9863	0.6211	0.0195	3.8922
OP	480	0.2993	0.3600	0.0076	1.7215

5. Characterization of Energy-Biased Technological Progress and Inclusive Green Growth

5.1. Characterization of Typical Features of Energy-Biased Technological Progress

5.1.1. Model Testing and Identification

According to Table 2, the test results of the estimation of Equation (1) show that the value of γ is 0.993, indicating that the model is valid. Most of the parameters in the estimation results are significant, and the value of the total variance is 0.179, which indicates that the technical inefficiency and error term fluctuations are low, resulting in a good estimation.

Table 2. Logarithmic SFA function estimation results.

Parameters	Coefficient	T-Value	Parameters	Coefficient	T-Value
α_0	5.956 ***	5.832	α_9	−0.185 ***	−2.718
α_1	0.160 ***	5.348	α_{10}	−0.041	−0.372
α_2	−0.002 ***	−2.613	α_{11}	0.037	0.319
α_3	1.713 ***	5.548	α_{12}	−0.103 **	−1.960
α_4	−0.006	−0.022	α_{13}	0.086	1.399
α_5	−1.057 ***	−3.245	α_{14}	0.140 *	1.794
α_6	0.021 ***	4.932	σ^2	0.179 ***	24.390
α_7	−0.009	−1.412	γ	0.993 ***	1595.620
α_8	−0.017 ***	−2.886	μ	0.844 ***	13.646
Log-likelihood function				774.714	
LR test value				1216.550	

Notes: * represents $p < 0.1$; ** represents $p < 0.05$; *** represents $p < 0.01$.

5.1.2. Overall Characterization of Energy-Biased Technological Progress in China

Energy-biased technological progress (EBT) can be measured based on the results in Table 2 and Equations (5) and (6). Figure 3 shows the kernel density distribution of EBT. The results indicate that the distribution of EBT tends to shift to the left during the examination period, indicating that the EBT index decreases and the degree of energy-saving technological progress increases. This is mostly attributable to China beginning to evaluate energy conservation and pollution reduction as mandatory benchmarks in 2006 and enacting a series of energy conservation regulations, therefore, technological progress is gradually moving towards energy conservation. However, multiple peaks appear in the density function of EBT, reflecting the polarization of energy-biased technological progress in the development process. The peak of the EBT density function in 2020 decreases gradually and the main peak pattern has a flattening trend, indicating that the imbalance of overall EBT in China has been increasing over time, demonstrating an inevitable divergence. Following the findings of Yang and Zha [45], technological progress in APEC countries is manifested in energy-biased technological progress. Shyamasree [26] determined that India demonstrates a notable aptitude for technical innovation and energy conservation. The conclusions of this study imply that China, India, and APEC countries have comparable technological progress tendencies.

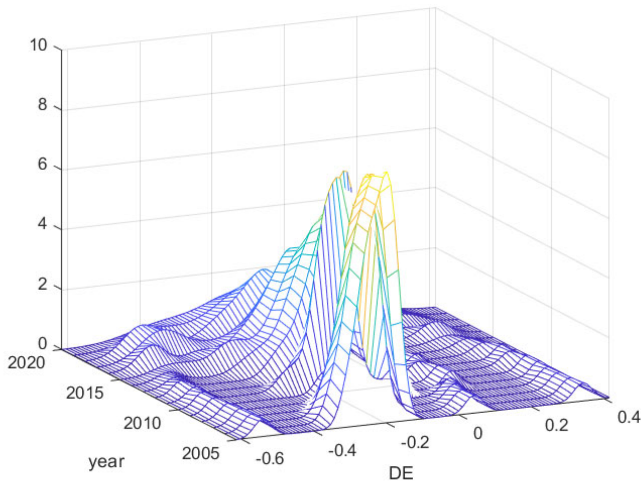

Figure 3. Kernel density distribution of EBT.

5.1.3. Provincial Characteristics of Energy-Biased Technological Progress

The mean (M) of EBT from 2005 to 2020 in China is −0.1254, and the standard deviation (SD) is 0.1298. Based on the relationship between M and SD, this paper classifies the 30 provinces into three types: frontrunners (M − 0.5SD), followers (between M − 0.5SD and M + 0.5SD), and pursuers (M + 0.5SD). The spatial distribution of EBT is drawn based on the three types (Figure 4). First, the EBT index belongs to the frontrunners with seven provinces, mainly concentrated in the central region, indicating that the technological progress in the central region has strong energy-saving, low-carbon, and friendly. Second, followers include ten eastern provinces, two central provinces, and eight western provinces, which reveals that the energy-biased technological progress in most eastern and western provinces is at a moderate level. The main reason lies in the spatially dispersed distribution of energy resources in China, as well as the concentration of energy consumption in eastern regions. Third, three provinces are pursuers, and all are located in the western region. Due to the fact that the western region's economic development is relatively sloppy and the industry presents the phenomenon of "high energy consumption, high emissions, low efficiency," technological progress in western provinces is relatively slow. According to Figure 4, the distribution of energy-biased technological progress has apparent characteristics of the "Hu Huanyong Line" distribution. The "Hu Huanyong Line" represents an imbalance in China's economic and social development as well as an inversion and mismatch of its natural and social resources [94]. It divides the energy-biased technological progress into southeast and northwest regions, with the southeast region having the best distribution and the northwest region having the second-best distribution.

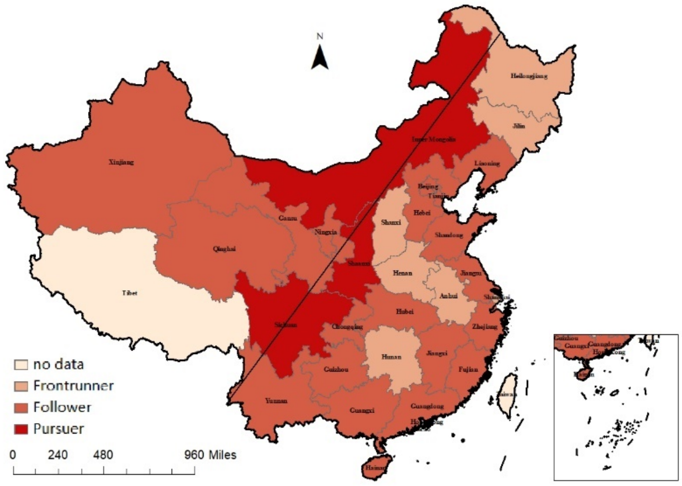

Figure 4. Energy-biased technological progress in 2020.

In summary, the overall energy-biased technological progress in China appears to be energy-saving-biased, and its degree has risen steadily over time. However, the degree of imbalance continues to increase, exhibiting an inevitable dispersion trend. From the perspective of provincial features, China's energy-biased technological progress is most advanced in the central area, followed by the eastern region, lagging behind in the western region. It also possesses the "Hu Huanyong Line" distribution pattern, with the best EBT in the southeast and the second best in the northwest.

5.2. Characterization of Typical Features of Inclusive Green Growth

5.2.1. Overall Characterization of Inclusive Green Growth in China

Using the entropy method, inclusive green growth can be measured using the indicators in Appendix A Table A1. Figure 5 shows the kernel density distribution of inclusive green growth (IGG). It indicates that China's IGG level increased from 0.29 to 0.34 from 2005 to 2020. The center position of the IGG distribution curve shifts gradually to the right, indicating that the IGG index gradually increases and shows a stable, rising trend. Based on the distribution pattern, the main peak of IGG rises in height and narrows in width, and the distribution of the curve evolves from a "multi-peak" distribution in 2005 to a "single-peak" distribution in 2020. Moreover, the change in the kernel density distribution of IGG after 2015 is more apparent, which is related to the introduction and practice of the five development concepts in 2016. Overall, China's inclusive green growth shows a stable growth trend, consistent with the study by Herrero et al. [95] who studied the IGG index of 157 countries and found that more than 87% of the countries in their sample experienced growth. Agradi et al. [65] discovered that only nine of twenty-three African countries experienced growth and that China's IGG development trend may be relatively superior to that of African countries.

5.2.2. Provincial Characteristics of Inclusive Green Growth

The mean (M) of IGG from 2005 to 2020 in China is 0.3251, and the standard deviation (SD) is 0.0877. This paper categorizes the 30 provinces into three types: frontrunners (M + 0.5SD), followers (between M + 0.5SD and M − 0.5SD), and pursuers (M − 0.5SD). The spatial distribution of IGG is drawn based on the three types (Figure 6). First, most frontrunners of the IGG index are located in the developed coastal areas in the east, indicating that eastern provinces have a higher level of inclusive green growth performance. Second, followers are represented by fourteen provinces, including five eastern provinces, three central provinces, and six' western provinces. The development of IGG is not affected by the low economic development level of some western provinces because there are a number of factors that have an impact on IGG. Third, ten provinces are pursuers, including one eastern province (Hebei Province), five central provinces and four western provinces, indicating that most central provinces have a lower level of IGG. This study is congruent with the findings of Nguyen et al. [96], who utilized a dynamic kernel density function approach to evaluate inclusive development in Vietnam and found that provinces located in major national economic zones experience greater inclusive growth levels.

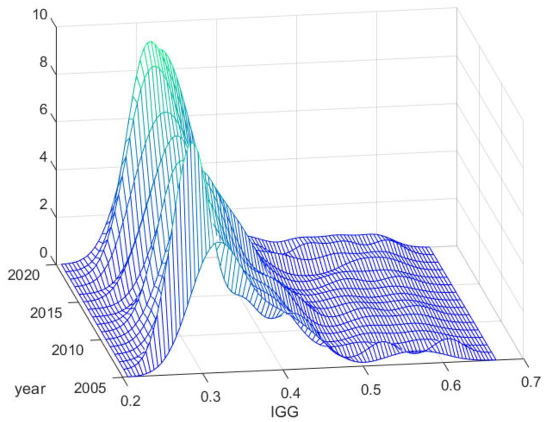

Figure 5. Kernel density distribution of IGG.

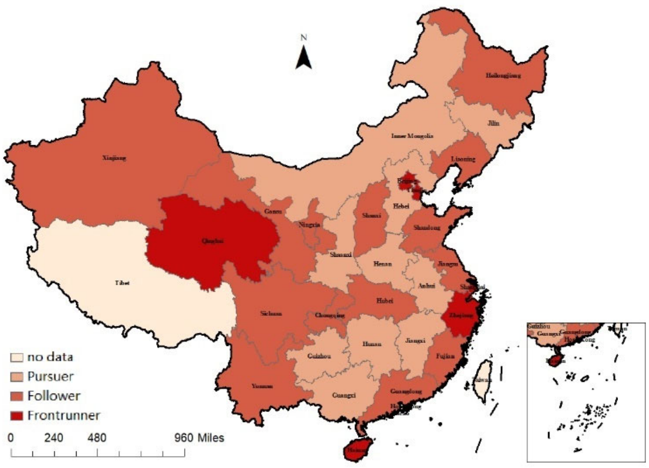

Figure 6. Inclusive green growth in 2020.

In summary, IGG in China from 2005 to 2020 showed a stable upward trend and the overall distribution showed a convergence trend with gradually decreasing differences. This changing trend was evident in the five development strategies proposed in 2016. From the perspective of provincial characteristics, each half of the eastern region belongs to the frontrunners and followers. Conversely, the majority of provinces in the central and western regions belong to the pursuers and followers, respectively. In China, inclusive green growth shows a distribution characteristic according to which the eastern region is the best, the western region is the second best, and the central region is the most backward.

6. Results

6.1. The Impact of Energy-Biased Technological Progress on Inclusive Green Growth

6.1.1. Benchmark Regression

In the benchmark model, we focused on testing the impacts of EBT on IGG by testing Equation (6). Table 3 presents the specific regression results. Column (1) shows the results without any control variables and fixed effects. Columns (2) and (3) show the results with fixed effect models and random effect models, respectively. Hausman's p value was

0.0000, so a fixed effect model was chosen. The estimated coefficient of the EBT variable is negative, indicating that the smaller the EBT index, the higher the level of energy-biased technological progress, and the greater the level of inclusive green growth. This result confirms Hypothesis H1.

Table 3. Benchmark regression analysis of EBT on IGG.

Variable	IGG		
	(1)	**(2)**	**(3)**
EBT	−0.0125 *	−0.0167 **	−0.0158 **
	(−1.86)	(−2.46)	(−2.22)
PD		0.0337	0.0768
		(0.21)	(0.46)
PC		0.0176 ***	0.0126 ***
		(4.15)	(2.92)
OP		0.0038	0.0223 ***
		(0.45)	(2.60)
Constant	0.3235 ***	0.3036 ***	0.3019 ***
	(20.15)	(48.21)	(25.49)
Model	OLS	FE	RE
Observations	480	480	480
R-squared	0.0334	0.0772	0.1297

Notes: * represents $p < 0.1$; ** represents $p < 0.05$; *** represents $p < 0.01$.

6.1.2. Heterogeneity Analysis

Given the complexity and development heterogeneity in China, we investigated the impact of EBT on IGG from the heterogeneity of time, geographic regions, and the development level of IGG. Firstly, we selected the period around 2012, when the 18th National Congress proposed the construction of ecological civilization, as the time node. Further, the "Hu Huanyong line" is chosen as the dividing line of geographic regions. The area north of the Hu Huanyong Line is referred to as the northwest region, and the area south of the Hu Huanyong Line IS referred to as the southeast region. Finally, 30 provinces were divided into frontrunners, followers, and pursuers, according to the preceding section. Table 4 displays the specific regression results. In terms of temporal heterogeneity, the impact of EBT on IGG was insignificant from 2005 to 2011 and significant from 2012 to 2020. This shows that, since the 18th National Congress, provinces have been actively developing green technological progress to promote IGG. Based on the point of regional geographic heterogeneity, EBT may contribute to IGG in the southeast, but not in the northwest. In contrast to existing studies [97], this study divided the regions into frontrunners, followers, and catchers based on the characteristics of IGG. EBT is significantly negatively correlated with the IGG of the frontrunners, indicating that energy-saving technological progress significantly contributes to regions with higher levels of IGG.

Table 4. Heterogeneity analysis of EBT on IGG.

	Time Heterogeneity		**Geographical Heterogeneity**		**IGG Heterogeneity**		
Variable	**2005–2011 (1)**	**2012–2020 (2)**	**Southeast (3)**	**Northwest (4)**	**Frontrunners (5)**	**Followers (6)**	**Pursuers (7)**
EBT	0.0119	−0.0278 ***	−0.0201 **	−0.0115	−0.0424 **	−0.0159 *	0.0039
	(1.02)	(−3.24)	(−2.42)	(−0.90)	(−2.26)	(−1.77)	(0.32)
Constant	0.3221 ***	0.2865 ***	0.3084 ***	0.3054 ***	0.4559 ***	0.2891 ***	0.2084 ***
	(33.62)	(33.66)	(39.28)	(20.48)	(23.26)	(33.92)	(14.59)
Control	YES	YES	YES	YES	YES	YES	YES
Observations	210	270	400	80	96	224	160
R-squared	0.062	0.070	0.030	0.208	0.070	0.070	0.098

Notes: * represents $p < 0.1$; ** represents $p < 0.05$; *** represents $p < 0.01$.

In conclusion, energy-biased technological progress can contribute significantly to inclusive green growth. Regarding temporal heterogeneity, energy-biased technological progress had the most significant influence on inclusive green growth between 2012 and 2020. In light of the regional geographic heterogeneity, EBT in the southeast region has a more substantial impact on inclusive green growth. In terms of the heterogeneity of IGG, EBT in the pursuer region has a non-significant effect on inclusive green growth. In contrast, EBT in the frontrunner and follower regions can substantially promote IGG, with the impact of the frontrunner region being more significant than that of the follower region.

6.2. Energy-Biased Technological Progress, Industrial Structure Upgrading, and Inclusive Green Growth

6.2.1. Analysis of the Impact Mechanism

The conclusion from the above sections shows that EBT has a negative linear relationship with IGG. To further explore the mechanism of EBT affecting IGG, this paper focused on two aspects: industrial structure advancement and cleanliness. From the results of the mediating effect test (Table 5), columns (1) and (2) show that energy-biased technological progress affects inclusive green growth through industrial structure advancement (ISA). EBT has an adverse effect on ISA, and ISA has a substantial beneficial effect on IGG. Due to the fact that EBT is a reverse indicator, the above regression results show that EBT eases industrial structure advancement and improves inclusiveness. Hypothesis H2 is proved. From columns (3) and (4), we can see that the regression coefficient of EBT to ISC is −0.1658, and the regression coefficient of ISC to IGG is 0.0236. Therefore, the regression results show that EBT affects inclusive green growth through industrial structure cleanliness. Hypothesis H3 is confirmed.

Table 5. Intermediary inspection results.

Variable	(1)	(2)	(3)	(4)
	ISA	**IGG**	**ISC**	**IGG**
EBT	−0.1735 **	−0.0124 *	−0.1658 ***	−0.0127 *
	(−2.05)	(−1.91)	(−5.83)	(−1.82)
ISA		0.0248 ***		
		(6.87)		
ISC				0.0236 **
				(2.10)
PD	5.2081 ***	−0.0954	1.6601 **	−0.0055
	(2.60)	(−0.62)	(2.47)	(−0.03)
PC	−0.0918 *	0.0199 ***	−0.0679 ***	0.0192 ***
	(−1.73)	(4.90)	(−3.80)	(4.47)
OP	−1.3066 ***	0.0362 ***	−0.5192 ***	0.0161
	(−12.28)	(3.86)	(−14.51)	(1.56)
Constant	1.4248 ***	0.2683 ***	0.2170 ***	0.2985 ***
	(18.11)	(33.97)	(8.20)	(44.35)
Observations	480	480	480	480
R-squared	0.307	0.140	0.427	0.058

Notes: * represents $p < 0.1$; ** represents $p < 0.05$; *** represents $p < 0.01$.

6.2.2. Heterogeneity Analysis

Heterogeneity analysis was performed according to the previous division criteria. It can be seen from Table 6 that, in terms of temporal heterogeneity, EBT had a stronger negative impact on IGG from 2012 to 2020. In terms of regional geographic heterogeneity, energy-biased technological progress can contribute to inclusive green growth through industrial structure advancement in the southeast. Meanwhile, non-significant effects can be observed in the northwest. In terms of inclusive green growth heterogeneity, energy-saving technological progress in the follower region can contribute significantly to industrial structure advancement. The influence shows the characteristic of "follower region > pursuer region > frontrunner region". In other words, when inclusive green growth reaches intermediate levels, industrial structure advancement exerts the best mediating effect.

Table 6. Heterogeneous results of EBT on ISA.

Variable	Time Heterogeneity		Geographical Heterogeneity		IGG Heterogeneity		
	2005–2011 (1)	**2012–2020 (2)**	**Southeast (3)**	**Northwest (4)**	**Frontrunners (5)**	**Followers (6)**	**Pursuers (7)**
EBT	0.1653	−0.2449 **	−0.3649 ***	0.0739	−0.0702	−0.2009 *	−0.1350
	(1.10)	(−2.47)	(−3.55)	(0.69)	(−0.28)	(−1.80)	(−1.10)
Constant	1.6675 ***	1.1333 ***	1.7175 ***	1.1511 ***	3.1578 ***	0.9209 ***	0.5465 ***
	(13.51)	(11.55)	(17.63)	(9.26)	(12.21)	(8.68)	(3.83)
Control	YES	YES	YES	YES	YES	YES	YES
Observations	210	270	400	80	96	224	160
R-squared	0.529	0.073	0.413	0.401	0.631	0.170	0.096

Notes: * represents $p < 0.1$; ** represents $p < 0.05$; *** represents $p < 0.01$.

Table 7 shows the heterogeneity of the mediating effect of ISC. In the temporal heterogeneity, EBT has a significant impact on ISC in both stages, indicating that EBT can enhance industrial structure cleanliness and then improve inclusive green growth. This influence is more significant in 2005–2011 compared to 2012–2020. In terms of regional geographic heterogeneity, the impact of EBT on the IGG of the southeastern provinces is greater than that of the northwestern provinces. It has been found that EBT in the frontrunner, follower, and pursuer regions contributes significantly to ISC in inclusive green growth heterogeneity. The degree of impact shows the characteristic of "frontrunner region > pursuer region > follower region". In other words, the most substantial mediating effect of industrial structure cleanliness occurs in regions with higher inclusive green growth.

Table 7. Heterogeneous results of EBT on ISC.

Variable	Time Heterogeneity		Geographical Heterogeneity		IGG Heterogeneity		
	2005–2011 (1)	**2012–2020 (2)**	**Southeast (3)**	**Northwest (4)**	**Frontrunners (5)**	**Followers (6)**	**Pursuers (7)**
EBT	−0.3555 ***	−0.0555 ***	−0.2856 ***	0.0057	−0.6045 ***	−0.0408 **	−0.0686 **
	(−5.66)	(−2.77)	(−7.92)	(0.71)	(−5.34)	(−2.02)	(−2.59)
Constant	0.4055 ***	0.0555 ***	0.3404 ***	0.0044	0.7319 ***	0.0831 ***	−0.0486
	(7.86)	(2.80)	(9.97)	(0.46)	(6.20)	(4.32)	(−1.58)
Control	YES	YES	YES	YES	YES	YES	YES
Observations	210	210	400	80	96	224	160
R-squared	0.566	0.125	0.526	0.425	0.663	0.309	0.136

Notes: ** represents $p < 0.05$; *** represents $p < 0.01$.

6.3. Robustness Test

For the effect of EBT on IGG, in order to strengthen the validity of the conclusion, we use four methods to test the robustness (as shown in Table 8). Firstly, we referred to the approach of [98] to calculate the difference in the marginal output growth rate of energy and capital (EKT) as a proxy for EBT for robustness testing, and the results are shown in column (1) EKT is significantly and negatively related to inclusive green growth. Secondly, principal component analysis was used to re-measure inclusive green growth to obtain the results for IGG2. As shown in column (2), there is no substantial change in the direction and coefficient. Thirdly, in order to avoid the effects of the 2008 financial crisis, we removed the data for 2008 and 2009. The results are shown in column (3), with no substantial change in the main results. Finally, we excluded the best and worst EBT development provinces, Henan and Inner Mongolia. The results are presented in column (4), and the correlation regression results are identical to those of the previous paper. In conclusion, these results indicate that the empirical findings presented in this research are reliable, and that the more technological progress is biased toward energy conservation, the higher the level of IGG.

Table 8. Robustness test results of EBT on IGG.

Variable	(1)	(2)	(3)	(4)
	IGG	IGG2	IGG	IGG
EBT		−0.4347 ***	−0.0146 **	−0.0153 **
		(−4.24)	(−2.06)	(−2.25)
EKD	−0.0177 ***			
	(−2.63)			
PD	0.0300	9.8770 ***	−0.0063	0.0085
	(0.19)	(4.07)	(−0.04)	(0.05)
PC	0.0176 ***	0.4379 ***	0.0177 ***	0.0143 ***
	(4.16)	(6.81)	(3.84)	(2.93)
OP	0.0039	−1.2738 ***	0.0017	0.0039
	(0.46)	(−9.87)	(0.19)	(0.46)
Constant	0.3041 ***	−0.3774 ***	0.3069 ***	0.3139 ***
	(48.63)	(−3.96)	(45.44)	(47.11)
Observations	480	480	420	448
R-squared	0.050	0.312	0.045	0.030

Notes: ** represents $p < 0.05$; *** represents $p < 0.01$.

To test the validity of the relationship between EBT, industrial structure upgrading, and IGG, the three methods above were still used to examine the reliability of the results (as shown in Table 9). Firstly, we calculated EKT as a proxy for EBT for robustness testing, and columns (1) and (2) show that EKT is significantly and negatively related to the advanced and clean industrial structure. Secondly, we excluded the effect of the 2008 financial crisis. The results are shown in columns (3) and (4), with no substantial change in the main results. Finally, we excluded the best and worst EBT development provinces, Henan and Inner Mongolia. The results are shown in columns (5) and (6), and the conclusions are robust.

Table 9. Robustness test results of EBT on ISA and ISC.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	ISA	ISC	ISA	ISC	ISA	ISC
EBT			−0.1593 *	−0.1593 ***	−0.1518 *	−0.1583 ***
			(−1.71)	(−5.31)	(−1.78)	(−5.52)
EKT	−0.1818 **	−0.1661 ***				
	(−2.16)	(−5.86)				
PD	5.1780 ***	1.6544 **	5.0447 **	1.3925 *	5.0499 **	1.6884 **
	(2.59)	(2.46)	(2.30)	(1.92)	(2.49)	(2.48)
PC	−0.0916 *	−0.0683 ***	−0.1589 ***	−0.0621 ***	−0.1324 **	−0.0806 ***
	(−1.73)	(−3.83)	(−2.81)	(−3.18)	(−2.17)	(−3.93)
OP	−1.3060 ***	−0.5193 ***	−0.9923 ***	−0.5384 ***	−1.3141 ***	−0.5198 ***
	(−12.28)	(−14.52)	(−8.84)	(−13.74)	(−12.24)	(−14.39)
Constant	1.4306 ***	0.2234 ***	1.4268 ***	0.2295 ***	1.5115 ***	0.2348 ***
	(18.31)	(8.50)	(11.16)	(8.02)	(18.18)	(8.39)
Observations	480	480	420	420	448	448
R-squared	0.308	0.427	0.296	0.426	0.324	0.444

Notes: * represents $p < 0.1$; ** represents $p < 0.05$; *** represents $p < 0.01$.

7. Discussion

7.1. Discussion of the Impact of EBT on IGG

As shown in Table 3, energy-biased technological progress can positively contribute to inclusive green growth. In previous studies, it has been demonstrated that EBT promotes inclusive green growth in ECOWAS [11], G7 [99], and newly industrializing nations [1], and our findings are consistent with these studies. The reason may be that energy-biased technological progress increases factor productivity and boosts output and economic growth, which leads to job creation and economic inclusion [100]. Moreover, the improvement of marginal productivity promotes the decrease in energy use, thus fostering inclusive green growth. Therefore, energy-biased technological progress is the ideal way to promote inclusive green growth and achieve sustainable development.

The results in Table 4 show that there is heterogeneity in the study of the impact of energy-biased technological progress on inclusive green growth. In terms of temporal heterogeneity, the effect of EBT on IGG was insignificant in 2005–2011 and significant in 2012–2020, which is related to the promotion of ecological civilization in China in 2012. EBT has an impact on IGG in the area south of the Hu Huanyong Line, but not in the area north of the Hu Huanyong Line, according to the division of the Hu Huanyong Line. It has been demonstrated that factor endowments significantly affect the direction of technological progress [69]. The region north of the Hu Huanyong Line is more energy-rich, so technological progress is biased toward energy utilization by market forces and has a smaller impact on inclusive green growth. From the regional heterogeneity of IGG characteristics, EBT is significantly negatively correlated with IGG in the frontrunner regions, indicating that energy-biased technological progress has a significant impact on regions with higher levels of IGG. This finding is consistent with that of Yang and Zha, who found that the EBT in APEC countries has a greater impact on IGG in economically developed regions [45]. The primary reason is that the frontrunner regions have relatively limited resource endowments and rely heavily on technology-driven advantages for inclusive green growth [101]. Since the follower regions are concentrated in the west, where infrastructure allocation and economic growth are relatively lagging and investment in technological improvements is minimal [102], the impact of EBT in the follower regions on IGG is small. Finally, the effect of catcher regions' EBT on IGG is not significant, indicating that energy-biased technological progress does not have a significant impact on areas with low inclusive green growth. Among the pursuers, the provinces of Hunan, Jiangxi, Guizhou, and Guangdong are located in the Pan-Pearl River Delta region, which has prioritized the development of the light industry for numerous years. However, the impact on inclusive green growth has been uncertain in recent years, as industrial shifts have made matching technological progress with resource consumption rates a challenge for these provinces [103,104].

7.2. Discussion of the Mechanism of Action of EBT on IGG

From the first and second columns of the results in Table 5, it can be seen that energy-biased technological progress can promote inclusive green growth through industrial structure advancement. This conclusion is consistent with that of Er et al. [48] and Sochirca et al. [105] who found that EBT can significantly contribute to an advanced industrial structure and thus increase inclusive green growth in their studies on Malaysia and European countries, respectively. According to industrial structure theory, biased technological progress encourages the restructuring of supply and demand and improves advanced industrial structures, thus affecting the degree of environmental friendliness. From columns (3) and (4) of the results in Table 5, it can be seen that energy-biased technological progress can contribute to inclusive green growth through industrial structure cleanliness. The main reason is that energy-biased technological progress leads to a change in factor allocation resulting in a decrease in the proportion of polluting industries, which promotes a cleaner industrial structure and further increases inclusive green growth.

Table 6 shows the heterogeneity of the mechanism of action of industrial structure advancement. From the division region of the Hu Huanyong Line, the mechanism of action of industrial structure advancement is more evident in the region south of the Hu Huanyong Line because of the advanced economy, greater technological investments, and greater impact of investments on ecosystem natural capital restoration [106]. From the regional heterogeneity of IGG characteristics, the mechanism of the effect of industrial structure advancement has been more obvious in the follower regions, because most of the follower regions in this paper belong to energy-abundant regions with relatively backward economies, which have large development space for the industrial structure and strong catching-up ability.

Table 7 shows the heterogeneity of the mechanism of action of industrial structure cleanliness, and the degree of influence is characterized as "frontrunner region > pursuer region > follower region". In comparing the two channels of action—industrial structure advancement and cleanliness—the mediating effects of both are found to be complementary. For the frontrunner regions, the mediating effect of industrial structure cleanliness is the best. For the follower regions, industrial structure advancement has the best mediating effect. This indicates that with the high level of IGG in the frontrunner regions, the industrial structure has gradually evolved from advanced to clean, with a growing emphasis on green and low-carbon development [107]. Therefore, energy-biased technological progress first promotes the development of industrial structure cleanliness, then drives industrial structure advancement, and finally promotes inclusive green growth. The majority of follower provinces are located in the west, with limited autonomous innovation capabilities and backward scientific and technological progress [108]. Consequently, energy-biased technological progress will focus on enhancing the level of industrial structure advancement, followed by industrial structure cleanliness and low-carbon development after ensuring stable economic growth. This research indicates that places with more developed economies and better environmental management can promote economic inclusion and green development by increasing the development of industrial structure cleanliness. In contrast, regions with relatively underdeveloped economies achieve inclusive green growth by first modernizing their industrial structure advancement.

8. Conclusions and Policy Implications

This paper explores the direct effects of energy-biased technological progress on inclusive green growth based on panel data from 30 Chinese provinces from 2005 to 2020. Furthermore, it analyzes their action mechanisms of industrial structure advancement and cleanliness. The conclusions are as follows: (1) China's technological progress is energy-biased, and EBT is best in the region south of the Hu Huanyong Line and worse in the region north of the Hu Huanyong Line. (2) Inclusive green growth is on a steady upward trend, showing the distribution characteristics of the highest level of inclusive growth in the east and the lowest level of inclusive green growth in the center. (3) In terms of temporal heterogeneity, the impact of EBT on inclusive green growth is mainly reflected in 2012–2020, which is related to the construction of ecological civilization. In terms of regional heterogeneity, the impact of EBT on inclusive green growth is mainly reflected in the economically developed regions north of the Hu Huanyong Line and the frontrunner regions. (4) Energy-biased technological progress can influence inclusive green growth through industrial structure advancement and industrial structure cleanliness, and the mediating effects of the two are complementary.

Based on the above analysis results, the study highlights several policy recommendations for improving inclusive green growth. China should invest more in energy-saving technological progress to promote inclusive green growth. As important areas with a high degree of economic development and inclusive green growth, the southeastern and forerunner regions should leverage the strengths of native talent to advance the development of energy-saving technological progress. The western and pursuer areas need to concentrate on the clean usage of non-renewable energy, duce the gap with technological progress in other regions, and promote inclusive green growth by means of clean energy-biased technological progress.

Industrial structure upgrading should be taken as an essential means of China's inclusive green growth. Promote the integration of modern service industries and advanced manufacturing industries to form a tertiary industry-based industrial structure, especially in the follower region. In addition, more attention should be paid to industrial structure cleanliness. The carbon trading system should be improved, and prices should be used to regulate the relative market demand for high-carbon and low-carbon products, ultimately promoting the industrial structure cleanliness from the level of need, especially in the frontrunner region.

Firstly, the research in this study finds that energy-biased technological progress can significantly promote inclusive green growth. Therefore, other countries, especially developing countries, should increase the research and development of energy-biased technological progress in the process of economic development to avoid pollution emissions and to achieve the coordinated development of economic growth, social equity, and the ecological environment. Secondly, the results also show that regions with more developed economies and better environmental governance promote inclusive green economic growth mainly through industrial structure cleanliness, while regions with relatively backward economies ensure economic growth through industrial structure advancement first before promoting inclusive green growth, which is consistent with the actual situation of developing countries. Therefore, developing countries should learn to introduce the technological progress of developed countries in the process of industrialization, narrow the gap to the technological progress of other regions, promote the integrated development of modern service industries and advanced manufacturing industries, and form an industrial structure dominated by the tertiary industry, in order to promote inclusive green growth.

9. Limitations and Outlook

Although our study provides some information, it still has limitations. The use of China as the study subject leads to a narrow scope of the study. It is recommended that future studies extend the study to countries with large emerging economies, analyze the study of the impact of energy-biased technological progress on inclusive green growth from an international perspective, and explore the differences in impact across countries.

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Appendix A

Table A1. Comprehensive index system of Inclusive green growth level.

Dimension	First Level Indicator	Secondary Indicator	Nature	Indicator Unit
Economic growth	Economic output	Per capita GDP	+	Yuan
		The proportion of fiscal revenue	+	%
		The proportion of secondary industry	−	%
		The proportion of tertiary industry	+	%
	Income level	Net income of rural residents	+	Yuan
		Per capita disposable income of urban residents	+	Yuan
		Per capita income ratio of urban and rural residents	−	Multiple

Table A1. *Cont.*

Dimension	First Level Indicator	Secondary Indicator	Nature	Indicator Unit
Social opportunity fairness	Fair employment opportunities	The employment rate of secondary and tertiary industries	+	%
		The registered urban unemployment rate	−	%
	Fair educational opportunities	The intensity of investment in education	+	%
		The student-teacher ratio in general universities	+	Multiple
	Fair medical opportunities	Number of health technicians per thousand population	+	Person
		Number of beds in medical and health institutions per thousand population	+	Unit
	Fair opportunities for social security	The proportion of essential endowment insurance fund expenditure	+	%
		The proportion of expenditure of primary medical insurance fund	+	%
	Fair infrastructure conditions	Length of transport lines per 10,000 people	+	Km
		The number of buses per 10,000 people	+	Unit
Green production and consumption	Green production	Energy consumption per unit of output value	−	Ton
		Wastewater emissions per unit of output	−	Ton
		Sulfur dioxide emissions per unit of output value	−	Ton
		CO_2 emissions per unit of output	−	Ton
	Green consumption	Energy consumption per capita	−	Ton
		Wastewater discharge per capita	−	Ton
		Sulfur dioxide emissions per capita	−	Ton
		CO_2 emissions per capita	−	Ton
Ecological environmental protection	Ecological resource endowment	Water resources per capita	+	Cubic meter
		Nature reserve area share	+	%
		Public green space per capita in cities	+	Square meter
	Ecological environment control	Investment intensity of environmental pollution control	+	%
		Harmless treatment rate of municipal solid waste	+	%
		Urban sewage treatment rate	+	%
		The comprehensive utilization rate of solid waste	+	%
		The proportion of soil and water loss control area	+	%

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