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Original Research

Green Innovation Effects of Ecological Civilization Pilot Policies

Yichuan Tian[1]*, Haojie Yang[2], Maoying Zhang[1], Jie Wang[1]

[1]School of Law, Anhui Normal University, Wuhu 241000, China
[2]School of Resources and Environmental Engineering, Hefei University of Technology, Hefei 230000, China

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Abstract

Green technological innovation has the dual benefit of promoting economic development and limiting environmental pollution and is critical to sustainable development in developing countries. This study assessed the green innovation effects of ecological civilization pilot policies by using the difference-in-differences approach, mediating effects model, and causal forest algorithm. The results showed that: (1) The ecological civilization pilot policy increased the level of green technology innovation in the pilot area by 27.9 %. (2) Urbanization partially mediated the impact process of ecological civilization pilot policies on green technology innovation, and the green innovation effect transmitted through urbanization was about 28%. (3) When energy structure and financial support were taken as the conditions, the green innovation effect of the ecological civilization pilot policy respectively showed an S-shaped curve and an inverted U-shaped curve. The above results can provide a new scientific basis for promoting green development in developing countries.

Keywords: ecological civilization, green technology innovation, causal forest, difference-in-differences

Introduction

How to achieve a balance between economic development and ecological protection has long been a hotly debated topic in academia [1, 2]. At present, one of the more popular views is achieving energy saving and emission reduction through technological progress [3, 4]. However, do all technological advances contribute to green development? At this point, the theory of externalities can be introduced into the discussion. From the perspective of externality theory, traditional technological advances sometimes generate negative externalities; that is, technological advances aimed at expanding the scale of production and economic growth may increase in energy demand and pollute the environment [4]. In contrast, there are positive externalities associated with green technology innovation. As the most critical component of green innovation, green technological innovation has a double benefit: it promotes the modernization of the economy while limiting environmental pollution [5]. Sustainable green technology is essential for effectively and economically controlling pollutant emissions [6], and only by promoting environmentally sound technological

*e-mail: tianyichuan@ahnu.edu.cn

innovations can we ensure that the SDGs are realized as soon as possible [7]. On 13 November 2021, nearly 200 countries reached an agreement at the 26th UN Climate Change Conference of the Parties (COP26), and one of the main initiatives was to fund green projects in less developed economies [8]. At the same time, Sustainable Development Goals (SDGs) and Increasing environmental issues are forcing countries to explore green innovation [9]. It is important to note that, despite the many benefits of green technological innovation, the road to green transformation of technological innovation in developing countries still needs to be improved at present [10], which makes it relevant to study green technological innovation in China.

Ecological civilization emphasizes the ecological view of "respecting nature, conforming to nature, and protecting nature," which considers the trade-off between economic development and environmental protection [11]. In order to promote the development of ecological civilization, the Chinese government established five provinces, namely Jiangxi, Fujian, Guizhou, Yunnan, and Qinghai, as provincial ecological civilization pilot zones in 2014 [12], which also provided a quasi-natural experimental environment for this study. The concept of ecological civilization has provided a basis of moral legitimacy for the actions of pilot ecological civilization policies to promote green technological innovation [13].

At the same time, according to the Porter Hypothesis, appropriate environmental regulation can induce firms to engage in more innovative activities and increase their productivity, thus offsetting the costs arising from environmental protection. Therefore, environmentally sound policies such as ecological civilization pilots can also promote green technological innovation at a theoretical level [14, 15]. Recently, a preliminary exploration of the relationship between ecological civilization pilot policies and green technological innovation was conducted in a study by Bai et al. [14], and their results provide a new empirical basis for the Porter hypothesis. The study by Hu et al. [16] likewise came to a similar conclusion. However, although it has become an academic consensus that ecological civilization pilot policies can promote green technological innovation, the transmission mechanisms still need to be clarified.

Urbanization is an essential basis for realizing green technological innovations. The theory of resource agglomeration emphasizes the concentration of factors such as labor, capital, and land in a specific geographical area, all critical resources needed to achieve technological innovation. Within the resource agglomeration theory framework, urbanization promotes the accumulation of factors such as labor, capital, and land, which in turn brings about positive technological spillover and diffusion effects [17], which is conducive to the formation of green technological innovation agglomerations. Due to the differences in economic development between different regions in China, urbanization and innovation capacity are also regionally heterogeneous, which has resulted in the benign interaction between urbanization and technological innovation not being fully unleashed [17]. The first question arises: Can ecological civilization pilot policies promote green technological innovation by promoting urbanization?

As machine learning algorithms have become increasingly popular in academic research, their black-box properties have begun to be criticized. At the same time, most machine learning algorithms aim at prediction, whereas scholars working on policy evaluation are more concerned with causation [18]. Because of this, causal machine learning is beginning to take off. In labor economics, Cockx et al. [19] used the causal forest algorithm to estimate the policy effects of labor training programs in Belgium and their heterogeneity. In the area of health policy, Kreif et al. [20] provided an in-depth assessment of the treatment effects of health insurance expansions in Indonesia by using the causal forest algorithm. Although simple heterogeneity analyses of the green innovation effects of ecological civilization pilot policies have been conducted, this grouped regression requires prior assumptions. It cannot directly deal with continuous variables. In addition, results based on grouped regressions can only be described as heterogeneous impacts, not heterogeneous treatment effects. Then, the second question arises: What kind of heterogeneous treatment effect does the green innovation effect of the ecological civilization pilot policies present?

Scientific answers to the above questions can help formulate differentiated environmental policies and balance economic development and ecological protection. Compared with previous literature, the marginal contribution of this study is mainly reflected in the following two aspects: (1) At the level of analytical methods, this study introduces the causal forest algorithm to discuss the heterogeneous treatment effect of the ecological civilization pilot policy on green technology innovation. The traditional linear regression model relies on interaction term processing for the heterogeneity analysis of continuous variables. However, this method has variable selection and model form limitations, while the causal forest algorithm overcomes these limitations with better estimation effects. (2) At the level of influence mechanism, previous literature mainly discusses based on technical and economic perspectives such as industrial upgrading and R&D investment. At the same time, this study provides a new way of analyzing the impact of ecological civilization pilot policy on green technological innovation by introducing the urbanization variable.

Materials and Methods

Policy Background

The basis for the legitimacy of China's ecological civilization pilot policies was first derived from the political report to the 18th National Congress of the Communist Party of China held in 2012. The report emphasizes that promoting ecological progress is vital to the people's well-being and China's future, a necessary condition for the lasting and sustainable development of the Chinese nation and global ecological security [21]. Guided by the concept of ecological civilization, the Chinese government officially established Fujian as the first ecological civilization pilot province in March 2014. Further, in the same year, it established Jiangxi, Guizhou, Yunnan, and Qinghai as ecological civilization pilot provinces to explore a typical paradigm of ecological civilization construction in line with China's national conditions [22]. As comprehensive experimental platforms for ecological civilization institutional reform, ecological civilization pilot provinces are playing a leading role in optimizing the spatial development pattern of the national territory, adjusting the industrial structure, and implementing low-carbon production patterns [23].

Variables

Firstly, the dependent variable in this study is green technology innovation (GTI). In earlier studies, patent data were widely used to measure technological innovation [24, 25]. In recent years, green patent data has become a favorite proxy variable at the beginning of green technological innovation research due to its focus on technological output and ease of data access [6, 26]. Meanwhile, considering that the number of green patent applications can only represent the active degree of green technological innovation in each province and cannot directly reflect the technological output, this study chose to use the number of green patents granted in each province to measure its level of green technological innovation.

Secondly, the policy variable in this study is a dummy variable for the ecological civilization pilot policies. The cross-multiplier term of the dummy variable is the core explanatory variable of this study when the sample region is Jiangxi, Fujian, Guizhou, Yunnan, and Qinghai, and the sample time is in 2014 and beyond.

Thirdly, the mediating variable in this study is urbanization (UR), which is measured by using the proportion of the urban population to the total population in each province.

Fourth, based on combing the previous literature, this study also controlled some of the observable factors that may affect green technology innovation. Specifically, the control variables include (1) Energy structure (ES), measured as the percentage of coal consumption in total energy consumption. Nowadays, the world's primary energy consumption is still dominated by fossil energy, and a higher proportion of coal consumption in a province means a higher possibility of fossil energy insecurity, which in turn forces green technology innovation [27]. (2) Industrial structure (IS), measured by the proportion of the added value of the tertiary industry to GDP. A green industrial structure can promote high-quality economic development and facilitate the greening of technological innovation [28]. (3) Foreign direct investment (FDI), measured as the proportion of foreign direct investment to GDP. Foreign direct investment is an important channel for technology diffusion, which can promote the inflow country's technological level and innovation capacity [29]. (4) R&D investment (RD), measured as the proportion of internal expenditure on R&D to GDP. The purpose of R&D investment is to innovate and create knowledge, which is a typical public good and, therefore, also likely to have positive externalities [30]. Such positive externalities can promote knowledge sharing and technological spillovers, promoting green technological innovation. (5) financial support (FS), measured by the proportion of financial environmental protection expenditure to GDP. Innovative activities of enterprises usually require a large amount of financial and policy support, and the structure of financial expenditure directly affects the funds required for enterprise development [4]. It can reflect the strength of policy support.

This study used a box plot to present the data distribution for each variable, as shown in Fig. 1.

Data Sources

Considering the availability and timeliness of the data, this study took 30 provinces in China (excluding Tibet, Taiwan, Hong Kong, and Macao) as the research sample, and the period of the data is 2011-2020. The dependent variable, green patent data, was obtained from the CNRDS database and logarithmically processed; the policy variable was a dummy variable constructed in the form of cross-multipliers; the mediating and control variables were mainly obtained from China Statistical Yearbook and China Energy Statistical Yearbook.

Methods

Drawing on Card and Kruger [31], this study regarded the establishment of China's 2014 ecological civilization pilot region as a quasi-natural experiment, and used difference-in-differences to assess the green innovation effects of the policy, with the model set up as follows:

$$GTI_{it} = \alpha + \beta DID_{it} + \phi Z_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

GTI_{it} denotes the level of green technology innovation in province i in year t; DID_{it} is a policy variable for the ecological civilization pilot; X_{it} is a set of control variables; μ_i is a province fixed effect; λ_t is a time fixed effect; ε_{it} is a random error term.

As the impact of ecological civilization pilot policies on green technology innovation will inevitably be interfered with by some unobservable factors

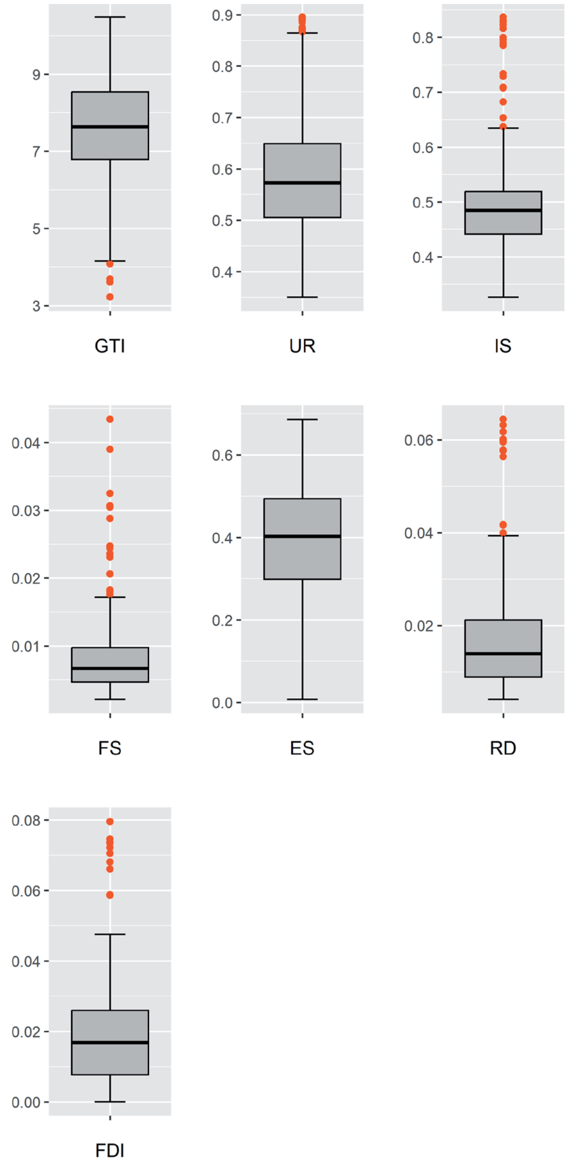

Fig. 1. Box plots of key variables.

in the actual study, the estimation results obtained at this time may be:

$$\hat{\beta} = \beta + \gamma \times \frac{cov(Treat \times Post, \varepsilon_{it}|W)}{var(Treat \times Post|W)} \quad (2)$$

w denotes all control variables with fixed effects; γ is the effect due to unobservables, and the estimates are unbiased only when γ–0. For this reason, this study chose to draw on the methodology of Zhou et al [32] to construct a spurious ecological civilization pilot policy variable in place of the real ecological civilization pilot policy variable. Since the actual policy effect of this spurious policy variable β–0, if the resulting, then it can be inverted to γ–0, that is, the estimates are unbiased.

Secondly, based on the propensity score proposed by Rosenbaum and Rubin [33], this study matched the data with the propensity score and used the matched data again to construct the difference-in-differences model to address the selection bias of the ecological civilization pilot policies. Based on binary Logit regression, the potential probability (propensity score) of a province being selected as an ecological civilization pilot region is:

$$P_i = P(T = 1|Z_i) = \frac{1}{1 + e^{-Z_i X_i}} \quad (3)$$

T–1 represents that the sample belongs to the ecological civilization pilot region, Z_i has the same meaning as Equation (1); X_i is the parameter vector; P_i is the probability value derived through Logit regression.

Thirdly, in order to verify whether urbanization played a mediating role in the process of the impact of ecological civilization pilot policies on green technology innovation, this study constructed the following regression model, drawing on the method proposed by Baron and Kenny [34]:

$$UR_{it} = \rho + \delta DID_{it} + \phi Z_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

$$GTI_{it} = \alpha + \beta DID_{it} + \varphi UR_{it} + \phi Z_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

UR_{it} is the urbanization level, and the meaning of the rest of the variables is the same as Equation (1). Under the premise of proving that the pilot policy has a significant effect on green technology innovation, it is verified in turn whether the pilot policy of ecological civilization has a significant effect on urbanization and urbanization on green technology innovation, and if both are significant, then it means that urbanization played a mediating role in the main effect.

Finally, in order to discuss the heterogeneous treatment effect of the ecological civilization pilot policies, this study chose to draw on Athey and Wager [35] and Hu et al. [36] to construct the following causal forest model:

$$\hat{\tau} = \frac{\sum_{i=1}^{n} a_i(x)\left(GTI_i - \hat{m}^{(-i)}(Z_i)\right)\left(DID_i - \hat{e}^{(-i)}(Z_i)\right)}{\sum_{i=1}^{n} a_i(x)\left(DID_i - \hat{e}^{(-i)}(Z_i)\right)^2} \quad (6)$$

$a_i(x)$ is the kernel formed by the machine learning drive; $m(Z_i)$ is the predicted value of green technological innovation with the given control variables; $e(Z_i)$ is the propensity score; $-i$ denotes the out-of-bag estimation, that is, GTI_i is not used in the calculation of the $\hat{m}^{(-i)}(Z_i)$; and the rest of the variables are of the same meaning as Equation (1).

Result

Pre-Modeling Verification

To ensure the validity of the results, this study tested for multicollinearity and parallel trends before

Table 1. VIF test.

Variables	VIF
DID	1.08
UR	3.51
IS	3.67
ES	1.99
RD	3.75
FDI	1.54
FS	1.43
Mean VIF	2.42
Max VIF	3.67

constructing the difference-in-differences model. From Table 1, the Max VIF of the independent variables is 3.67 (<10), and the Mean VIF is 2.42 (<5), so it can be assumed that the potential problem of multicollinearity between the independent variables is weak.

Fig. 2 demonstrates the green technology innovation level of the treated group and the control group over time, where the red line represents the control group, the blue line represents the treated group, and the vertical dotted line represents the policy implementation year. From Fig. 2, before the implementation of the policy, the development trend of green technological innovation in the treated group and the control group remained consistent, satisfying the premise of the parallel trend test. Meanwhile, after the implementation of the policy, the green technology innovation level of the treatment group increased at a significantly higher rate than that of the control group, which laid the foundation for further analyses.

Benchmark Model Regression Results

Table 2 shows the results of the benchmark regression on the impact of ecological civilization pilot policies on green technology innovation. Columns (1) and (2) show the estimation results before and after adding control variables. Column (1) shows that the ecological civilization pilot policies positively affected green technology innovation at the 1% significance level with a regression coefficient of 0.355. Column (2) shows that the regression coefficient of the ecological civilization pilot policies decreases from 0.355 to 0.279 after the inclusion of control variables, but still exerts a positive influence at the 5% significance level. In other words, after controlling for two-way fixed effects and control variables, the ecological civilization pilot policies led to a 27.9% increase in green technology innovation in the pilot regions.

Robustness Test

(1) Placebo test. A potential problem with the findings of this study is that the increase in the level of green technology innovation may result from the influence of unobservable factors. For this reason, this study referred to Li et al. [37], randomly selected several samples as a dummy treatment group for a placebo test and regressed them again with the cross-multiplier term of the time dummy variable as the core explanatory variable. Fig. 3 reports the probability density distribution of the estimated coefficients of the cross-multiplication term based on 500 random samples,

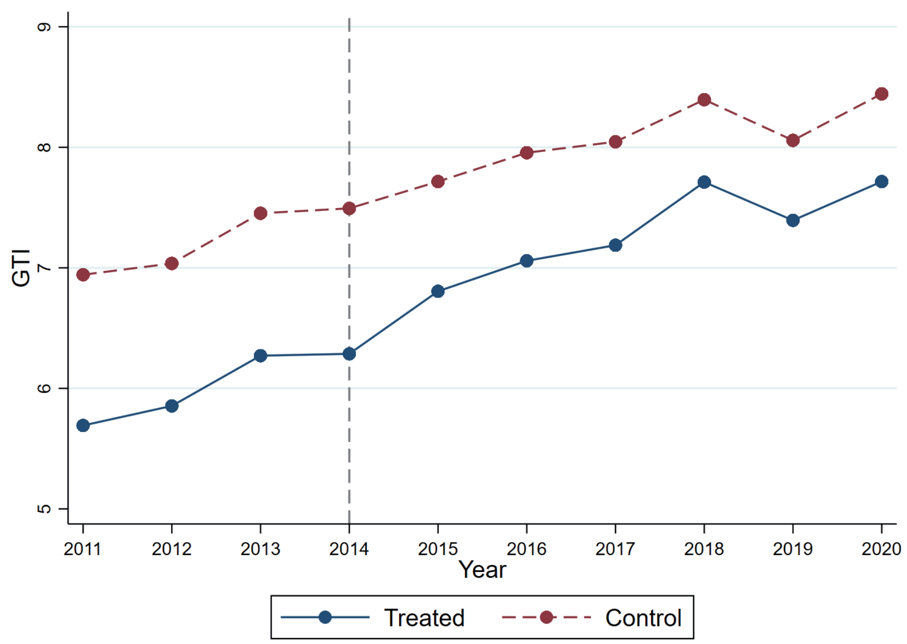

Fig. 2. Parallel trend test.

Table 2. Benchmark regression analysis.

	(1) GTI	(2) GTI
DID	0.355*** (0.107)	0.279** (0.101)
Control Variable	×	√
Province effect	√	√
Year effect	√	√
R2	0.911	0.922
N	300	300
Year effect	300	√
R2	0.911	0.922
N	300	300

Note: Standard errors in parentheses are clustered at the province level. *** p<0.01, ** p<0.05, *p<0.1.

from which the spurious estimated coefficients are centrally distributed around 0, suggesting that the green innovation benefits of the civilization pilot policies are less affected by unobservable factors and that the baseline conclusions are highly robust.

(2) PSM-DID. As the ecological civilization pilot policies are essentially a non-randomized experiment, there may also be selection bias, and a common solution to this problem is propensity score matching. With propensity score matching, the observables can be as close as possible to a randomized experiment. Therefore, a simple and efficient 1 to 1 nearest-neighbor matching was used to process the raw data. As shown in Fig. 4, the bias of the control variables improved considerably after matching, demonstrating the validity and necessity of using PSM-DID. Column (1) of Table 3 shows that after controlling for the sample selection problem, ecological civilization pilot policies still positively impacted green technology innovation, proving the robustness of the benchmark findings.

(3) Replace the dependent variable. Although the number of patent applications cannot represent the actual results of technological innovation, it can reflect the development trend of green technological innovation in each province to a certain extent. Therefore, this study chose to construct a regression model with the number of patent applications as the dependent variable to verify the conclusions' robustness further. Column (2) of Table 3 shows that after replacing the dependent variable, the ecological civilization pilot policies still had a positive impact at the 1% significance level.

(4) Control other policy. The Chinese government's Guiding Opinions on Promoting the Development of the Yangtze River Economic Belt by Relying on the Golden Waterways, released in 2014, signaled the official elevation of the Yangtze River Economic Belt as a major national development strategy [38]. In the study sample, Jiangxi, Guizhou, and Yunnan belong to the ecological civilization pilot region and the Yangtze River Economic Belt provinces. At this point, judging whether the Yangtze River Economic Belt development strategy has confounded the green innovation benefits of the ecological civilization pilot policies is difficult. Therefore, this study constructed a dummy variable for the development strategy of the Yangtze River Economic Belt and included it in the model for further testing. Column (3) of Table 3 shows that after controlling for the policy impact of the Yangtze River Economic Belt, the impact of the ecological civilization pilot policies on green technology innovation was significantly positive at the 1% level, and the robustness of the baseline conclusions was again verified.

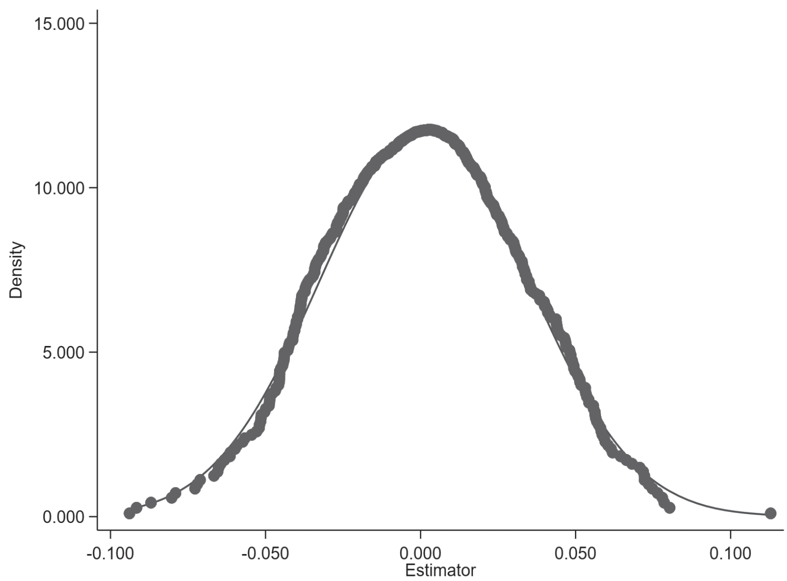

Fig. 3. Placebo test.

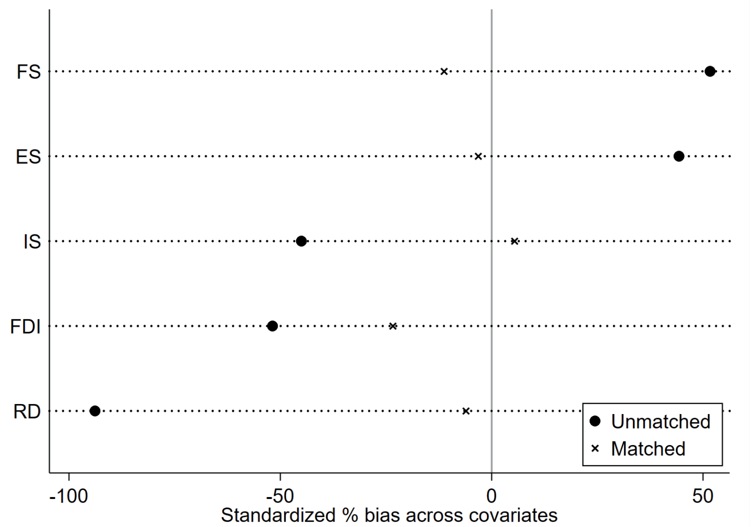

Fig. 4. Change in the bias of control variables.

Mediation Analysis

Table 4 reports the regression results with urbanization as the mediating variable. As seen in columns (1) and (2), the ecological civilization pilot policies can significantly promote urbanization, while urbanization also significantly positively impacts green technology innovation. According to the test method of Wen and Ye [39], it can be calculated that urbanization played a partial mediating role in the process of the impact of ecological civilization pilot policies on green technology innovation, and the mediating effect accounted for about 28%.

Heterogeneity Analysis: New Evidence from Causal Forest Algorithm

In further analysis, the causal forest model in generalized random forest [40] was used in this study to identify the impact of ecological civilization pilot policies on green technological innovation and its heterogeneous treatment effect, with default values for all relevant parameters. As can be seen from Table 5, as the number of trees used to construct the model continues to increase, the standard error gradually settled around 0.067 and the average treatment effect fluctuated less. Although the results obtained from the causal forest model are slightly lower than the difference-in-differences, they are all significantly positive at the 1% level, which again validates the robustness of the benchmark findings.

Fig. 5 demonstrates the distribution of the estimated treatment effect of the ecological civilization pilot policies on green technology innovation. From Fig. 5, although the treatment effects of the sample are relatively concentrated on the left side, the overall range of values is extensive, suggesting that the treatment effects of the ecological civilization pilot policies varied considerably in different regions. Therefore, this study will address the heterogeneous treatment effect of the ecological civilization pilot policies for further analysis.

Table 3. Robustness test.

	(1) GTI	(2) GTI_Robust	(3) GTI
DID	0.161* (0.093)	0.327*** (0.098)	0.317*** (0.107)
YREB	×	×	√
Control Variable	√	√	√
Province effect	√	√	√
Year effect	√	√	√
R^2	0.938	0.931	0.924
N	217	300	300

Note: Standard errors in parentheses are clustered at the province level. *** p<0.01, ** p<0.05, * p<0.1.

Table 4. Mediation analysis.

	(1) UR	(2) GTI
DID	0.018* (0.009)	0.218** (0.099)
UR		3.387**
		(1.271)
Control Variable	√	√
Province effect	√	√
Year effect	√	√
R^2	0.902	0.928
N	300	300

Note: Standard errors in parentheses are clustered at the province level. *** p<0.01, ** p<0.05, * p<0.1.

Table 5. Casual forests analysis.

	(1) GTI	(2) GTI	(3) GTI
ATE	0.285*** (0.067)	0.289*** (0.069)	0.256*** (0.067)
Tree numbers	500	1000	2000
N	300	300	300

Note: *** p<0.01, ** p<0.05, * p<0.1.

In analyzing the heterogeneous treatment effect, due to space constraints, most studies chose to filter the "conditions" by the importance of the variables. Fig. 6 gives the order of importance of the variables in the causal forest model constructed in this study, from which energy structure and financial support are found to be the two most important variables.

Fig. 7 illustrates the change in treatment effects of the ecological civilization pilot policies when conditioned on energy structure. As the proportion of coal consumption in the energy consumption structure increases, the treatment effect of the ecological civilization pilot policies shows an S-shaped relationship. On the other hand, Fig. 8 shows the fitted curves for the heterogeneity of the conditional treatment effects when conditional on financial support. The green innovation effects of the ecological civilization pilot policies show an inverted U-shaped curve trend with the increasing proportion of local financial environmental protection expenditures to GDP. For presentation purposes, this study excluded a small number of extreme values when plotting the fitted curves conditional on financial support, and the sample loss rate was 2%, which is within a manageable range.

Discussion

Firstly, this study calculated a specific value of 27.9% for the green innovation benefits of the ecological civilization pilot policies; this result is higher than the 20.2% derived by Hu et al. [16]. The main reason for this phenomenon may be the difference in the choice of proxy variables. Specifically, this study used green patent grants as a proxy variable for green technology innovation, whereas the study by Hu et al. [16] used green patent applications. At the same time, the results from the baseline regression also imply that

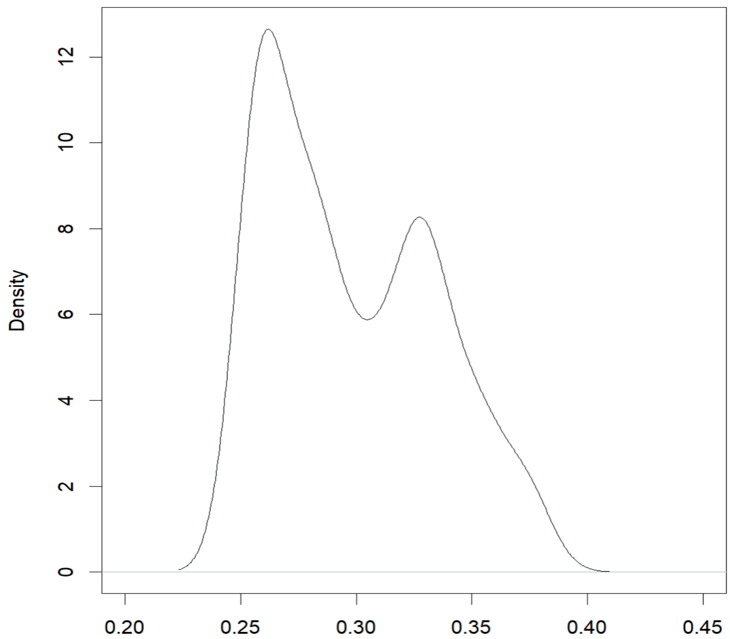

Fig. 5. Distribution of treatment effects.

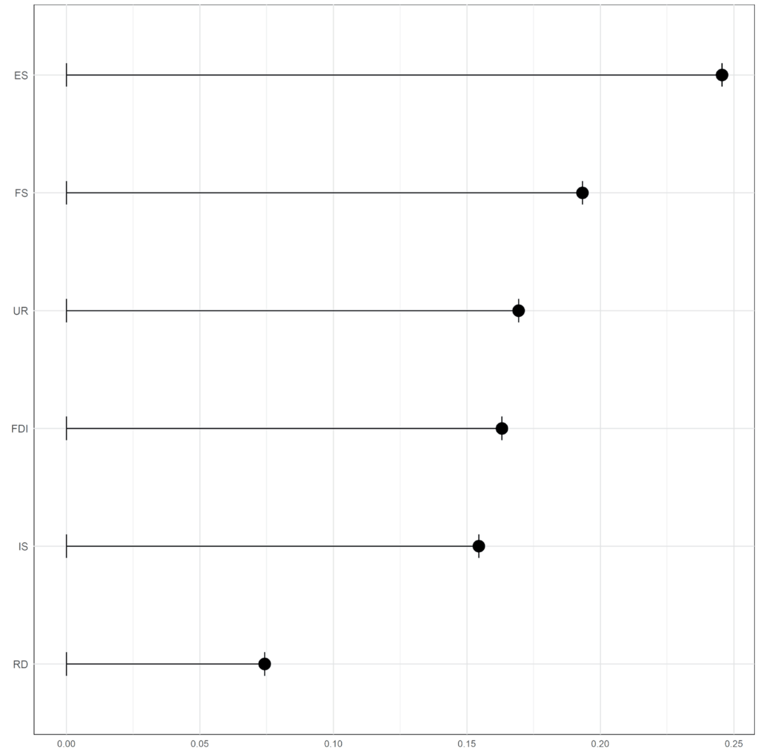

Fig. 6. Importance of variables.

the ecological civilization pilot policies can play an all-rounded role in promoting sustainable development and that the policies can not only significantly reduce carbon dioxide emissions [12] and promote ecological efficiency [41], but also bring about considerable benefits of green innovation.

Secondly, urbanization played a positive mediating role in the impact of ecological civilization pilot policies on green technology innovation, possibly for two reasons. On the one hand, cities are essential for constructing ecological civilization. Promoting ecological city construction based on green development is one of the objectives of the ecological civilization pilot policies. On the other hand, urbanization also provides a broader market for green technologies. For instance, while urbanization leads to higher per capita energy consumption [42], the energy consumption structure of highly urbanized areas is generally more advanced than that of low urbanized areas [43]. In China, rapid urbanization is driving the application and development of renewable energy technologies [44].

Finally, the different trends in treatment effects conditional on energy structure and financial support also reflect some real problems. Even though more than half of the current installed coal power capacity is in China, the country has embarked on an ambitious coal phase-out program [45]. Therefore, the higher the regional share of coal consumption, the stronger the policy regulation will be. Moreover, to alleviate the energy pressure, the market will spontaneously drive the vigorous development of renewable energy technology innovation activities, which in turn will promote the improvement of green technology innovation. However, when the proportion of coal consumption reaches a certain peak, the market's ability to drive innovation is weaker than the resistance of the coal industry's interest groups, as in the case of Poland. Poland's energy transition has not been smooth as a significant coal energy producer in the European Union. The political economy of Poland, where most coal companies have state-owned attributes, their trade unions are highly involved in political decision-making, and where tax revenues and employment generated by the coal industry influence election outcomes, is hindering Poland's coal transition [46]. The inverted U-shaped fitted curve plotted conditional on financial support is also worthy of discussion. To a certain extent, the expenditure structure of government finance can represent the distribution structure of government attention, and the proportion of local governments' financial expenditure on environmental protection to GDP essentially reflects the degree of local governments' attention to environmental issues. Empirical studies have shown a tipping point in the government's environmental attention. When the attention is overly focused, the resulting accountability pressure will cause local governments to avoid responsibility, leading to a decline in the strength of environmental regulation [47]. According to the Porter Hypothesis, a decline in environmental regulation is not conducive to promoting technological innovation activities or adopting innovative technologies by firms [15, 48], and ultimately curtails green technological innovation.

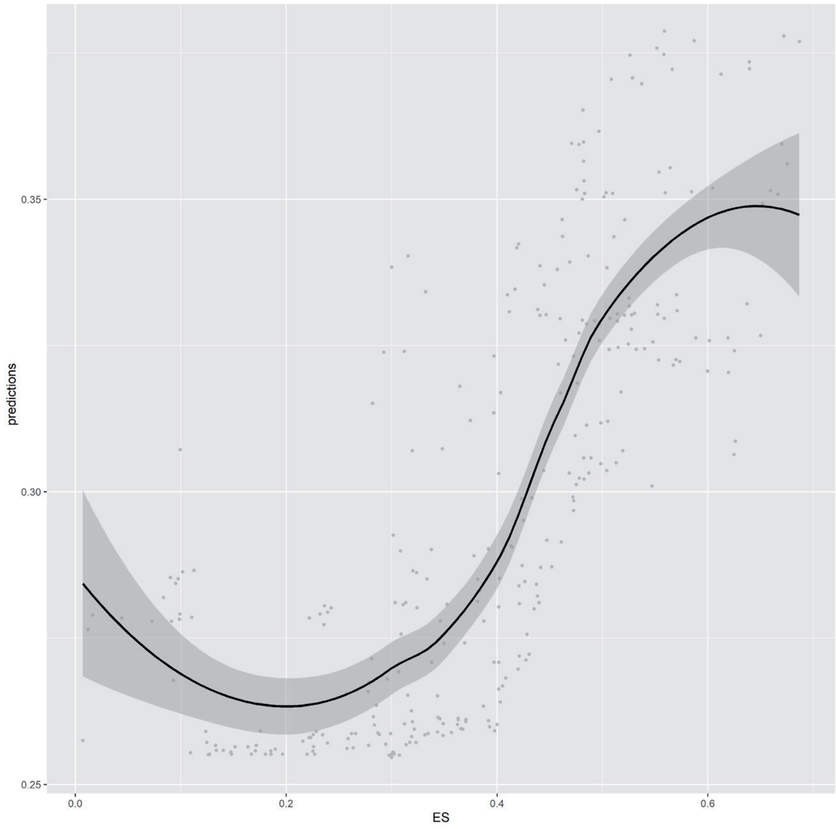

Fig. 7. Changes in the treatment effect of ECP conditioned by energy structure.

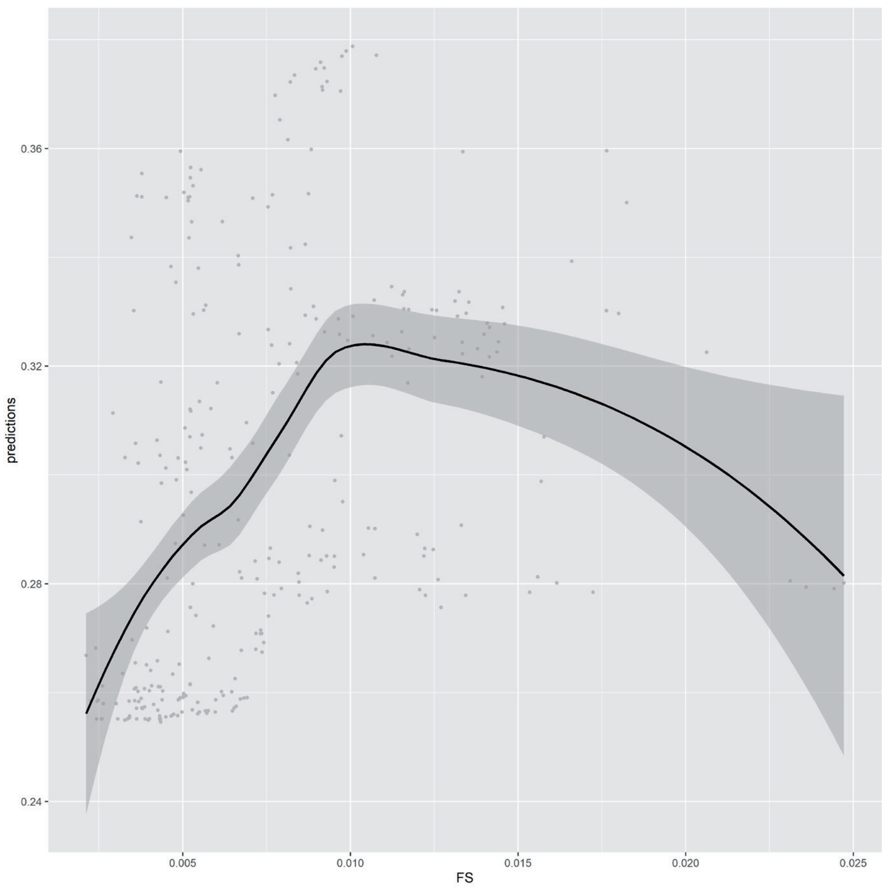

Fig. 8. Changes in the treatment effect of ECP conditioned by financial support.

Conclusions

This study systematically examined the green innovation effects of ecological civilization pilot policies by using 30 provinces in China from 2011 to 2020 as research samples, and using the differences in differences model, the mediated effects model, and the causal forest algorithm. The following are the results of the analyses. Firstly, after controlling for two-way fixed effects and control variables, the ecological civilization pilot policy increased the level of green technological innovation in the pilot region by 27.9%. At the same time, the green innovation benefits of the ecological civilization pilot policies passed a series of robustness tests such as the placebo test, PSM-DID, replacing the dependent variable, and controlling other policies. Secondly, urbanization partially mediated the impact of ecological civilization pilot policies on green technological innovation, with approximately 28% of the benefits of green innovation transmitted via urbanization. Finally, conditional on energy structure and financial support, the green innovation effect of the ecological civilization pilot policies shows an S-shaped curve and an inverted U-shaped curve.

Based on the above conclusions, the following policy implications are proposed. Firstly, it should consolidate and expand the green innovation effect of the existing ecological civilization pilot policies and, at the same time, actively summarize and publicize the typical cases and development models of the pilot provinces to accelerate the formation of replicable and generalizable reform experiences. Secondly, it should further develop the positive impact of urbanization on industrial agglomeration and green innovation and actively promote the green and intelligent transformation of urbanization. Thirdly, differentiated supporting policies should be formulated according to local conditions, and a path of cooperation and win-win situation should be actively explored during the evolutionary game between the government, society, and interest groups. In addition, the financial expenditure structure of local governments should be maintained and rationalized, and the ecological civilization governance effect of financial environmental protection expenditure should be actively promoted towards maximization.

The study also has some limitations. For instance, are there other undiscovered transmission mechanisms between ecological civilization pilot policies and green technology innovation? When analyzed by using firm data, do ecological civilization pilot policies still promote green technology innovation in firms? How do conditions other than energy structure and financial support affect the treatment effects of the ecological civilization pilot policies? These limitations provide ideas and directions for future research.

Data Availability Statement

The datasets used or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. LI X., LI X., ZHU X., HUANG Y., LIU X., DENG W. Dynamic relationship between resource endowment, financial agglomeration, innovation-driven, and green total factor productivity. Energy & Environment. 0958305X231155495, **2023**.
2. YU C., GAO Y., WANG C., CHEN T., WANG J., LU Q. “Targets-Plans-Decision”: A framework to identify the size of protected areas based on the balance of ecological protection and economic development. Journal of Environmental Management. **304**, 114302, **2022**.
3. LI X., LONG H. Research Focus, Frontier and Knowledge Base of Green Technology in China: Metrological Research Based on Mapping Knowledge Domains. Polish Journal of Environmental Studies. **29** (5), 3003, **2020**.
4. WEI L., LIN B., ZHENG Z., WU W., ZHOU Y. Does fiscal expenditure promote green technological innovation in China? Evidence from Chinese cities. Environmental Impact Assessment Review. **98**, 106945, **2023**.
5. RENNINGS K., ZIEGLER A., ANKELE K., HOFFMANN E. The influence of different characteristics of the EU environmental management and auditing scheme on technical environmental innovations and economic performance. Ecological Economics. **57**, (1), 45, **2006**.
6. WANG Q., QU J., WANG B., WANG P., YANG T. Green technology innovation development in China in 1990-2015. Science of The Total Environment. **696**, 134008, **2019**.
7. SUN Y., LU Y., WANG T., MA H., HE G. Pattern of patent-based environmental technology innovation in China. Technological Forecasting and Social Change. **75** (7), 1032, **2008**.
8. WEN J., YIN H.-T., JANG C.-L., UCHIDA H., CHANG C.-P. Does corruption hurt green innovation? Yes – Global evidence from cross-validation. Technological Forecasting and Social Change. **188**, 122313, **2023**.
9. YIN J., GONG L., WANG S. Large-scale assessment of global green innovation research trends from 1981 to 2016: A bibliometric study. Journal of Cleaner Production. **197**, 827, **2018**.
10. ABDULLAH M., ZAILANI S., IRANMANESH M., JAYARAMAN K. Barriers to green innovation initiatives among manufacturers: the Malaysian case. Review of Managerial Science. **10** (4), 683, **2016**.
11. CHEN P., SHI X. Dynamic evaluation of China’s ecological civilization construction based on target correlation degree and coupling coordination degree. Environmental Impact Assessment Review. **93**, 106734, **2022**.

12. ZHANG Y., FU B. Impact of China's establishment of ecological civilization pilot zones on carbon dioxide emissions. Journal of Environmental Management. **325**, 116652, **2023**.
13. HEURTEBISE J.-Y. Sustainability and Ecological Civilization in the Age of Anthropocene: An Epistemological Analysis of the Psychosocial and "Culturalist" Interpretations of Global Environmental Risks. Sustainability. **9** (8), 1331, **2017**.
14. BAI D., HU J., IRFAN M., HU M. Unleashing the impact of ecological civilization pilot policies on green technology innovation: Evidence from a novel SC-DID model. Energy Economics. **125**, 106813, **2023**.
15. PORTER M.E., VAN DER LINDE C. Toward a New Conception of the Environment-Competitiveness Relationship. Journal of Economic Perspectives. **9** (4), 97, **1995**.
16. HU J., HU M., ZHANG H. Has the construction of ecological civilization promoted green technology innovation? Environmental Technology & Innovation. **29**, 102960, **2023**.
17. CHEN J., WANG L., LI Y. Natural resources, urbanization and regional innovation capabilities. Resources Policy. **66**, 101643, **2020**.
18. KREIF N., DIAZORDAZ K. Machine learning in policy evaluation: new tools for causal inference. arXiv preprint. **2019**.
19. COCKX B., LECHNER M., BOLLENS J. Priority to unemployed immigrants? A causal machine learning evaluation of training in Belgium. Labour Economics. **80**, 102306, **2023**.
20. KREIF N., DIAZORDAZ K., MORENO-SERRA R., MIRELMAN A., HIDAYAT T., SUHRCKE M. Estimating heterogeneous policy impacts using causal machine learning: a case study of health insurance reform in Indonesia. Health Services and Outcomes Research Methodology. **22** (2), 192, **2022**.
21. HUAN Q. National Ecological Civilization Pilot Zone: From Theory to Practice. Springer Singapore, Singapore, **2021**.
22. WANG K., XU R., ZHANG F., MIAO Z. Impact of ecological civilization demonstration areas on carbon emission intensity. China population, resources and environment. **32** (7), 57, **2022**.
23. XIN B., GAO F. Is the ecological civilization pilot reform conducive to the improvement of ecological total factor productivity? China population, resources and environment. **31** (5), 152, **2021**.
24. ARCHIBUGI D. Patenting as an indicator of technological innovation: a review. Science and Public Policy. **19** (6), 357, **1992**.
25. GRILICHES Z. Patent Statistics as Economic Indicators: A Survey. National Bureau of Economic Research Working Paper Series. **No. 3301**, **1990**.
26. SHEN F., LIU B., LUO F., WU C., CHEN H., WEI W. The effect of economic growth target constraints on green technology innovation. Journal of Environmental Management. **292**, 112765, **2021**.
27. YANG H.-C., FENG G.-F., ZHAO X.X., CHANG C.-P. The impacts of energy insecurity on green innovation: A multi-country study. Economic Analysis and Policy. **74**, 139, **2022**.
28. LV C., SHAO C., LEE C.-C. Green technology innovation and financial development: Do environmental regulation and innovation output matter? Energy Economics. **98**, 105237, **2021**.
29. SIVALOGATHASAN V., WU X. The Effect of Foreign Direct Investment on Innovation in South Asian Emerging Markets. Global Business and Organizational Excellence. **33** (3), 63, **2014**.
30. DIETZENBACHER E., LOS B. Externalities of R&D Expenditures. Economic Systems Research. **14** (4), 407, **2002**.
31. CARD D., KRUEGER A.B. Minimum Wages and Employment: A Case Study of the Fast-Food Industry in New Jersey and Pennsylvania: Reply. American Economic Review. **90** (5), 1397, **2000**.
32. ZHOU M., LU Y., DU Y., YAO X. Special economic zones and region manufacturing upgrading. China Industrial Economics. **3**, 62, **2018**.
33. ROSENBAUM P.R., RUBIN D.B. The central role of the propensity score in observational studies for causal effects. Biometrika. **70**, (1), 41, **1983**.
34. BARON R.M., KENNY D.A. The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. Journal of Personality and Social Psychology. **51** (6), 1173, **1986**.
35. ATHEY S., WAGER S. Estimating Treatment Effects with Causal Forests: An Application. Observational Studies. **5** (2), 37, **2019**.
36. HU Z., GU J., CHEN Y. "Biased" Policy, Changes of Production Sectors and Development Gap between the North and the South in China: Causal Inference from Machine Learning. Journal of Finance and Economics. **48** (01), 93, **2022**.
37. LI P., LU Y., WANG J. Does flattening government improve economic performance? Evidence from China. Journal of Development Economics. **123**, 18, **2016**.
38. PANG Q., DONG X., ZHANG L., CHIU Y.-H. Drivers and key pathways of the household energy consumption in the Yangtze river economic belt. Energy. **262**, 125404, **2023**.
39. WEN Z., YE B. Analyses of Mediating Effects: The Development of Methods and Models. Advances in Psychological Science. **22** (5), 731, **2014**.
40. ATHEY S., TIBSHIRANI J., WAGER S. Generalized random forests. The Annals of Statistics. **47** (2), 1148, **2019**.
41. CHAI Z., GUO F., CAO J., YANG X. The road to eco-efficiency: can ecological civilization pilot zone be useful? New evidence from China. Journal of Environmental Planning and Management. 1, **2022**.
42. FRANCO S., MANDLA V.R., RAM MOHAN RAO K. Urbanization, energy consumption and emissions in the Indian context A review. Renewable and Sustainable Energy Reviews. **71**, 898, **2017**.
43. SUN C., OUYANG X., CAI H., LUO Z., LI A. Household pathway selection of energy consumption during urbanization process in China. Energy Conversion and Management. **84**, 295, **2014**.
44. YANG J., ZHANG W., ZHANG Z. Impacts of urbanization on renewable energy consumption in China. Journal of Cleaner Production. **114**, 443, **2016**.
45. CUI R.Y., HULTMAN N., CUI D., MCJEON H., YU S., EDWARDS M.R., SEN A., SONG K., BOWMAN C., CLARKE L., KANG J., LOU J., YANG F., YUAN J., ZHANG W., ZHU M. A plant-by-plant strategy for high-ambition coal power phaseout in China. Nature Communications. **12** (1), 1468, **2021**.

46. BRAUERS H., OEI P.-Y. The political economy of coal in Poland: Drivers and barriers for a shift away from fossil fuels. Energy Policy. **144**, 111621, **2020**.
47. ZHANG K. An inverted U-shaped relationship between environmental Attention and local government policy implementation. China Public Administration Review. **3** (04), 132, **2021**.
48. JAFFE A.B., PALMER K. Environmental Regulation and Innovation: A Panel Data Study. National Bureau of Economic Research Working Paper Series. **No. 5545**, **1996**.