



## Research article

## Can public participation promote regional green innovation?—Threshold effect of environmental regulation analysis

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## ABSTRACT

Green innovation is the fundamental approach to harmonize economic and environmental sustainability. Public participation plays a crucial role in solving the problems of “government failure” and “market failure” in regional green innovation. Based on three perspectives: direct public participation, indirect public participation, and ENGOs participation, this paper takes 30 provinces in China from 2010 to 2019 as samples, constructs panel fixed-effects models and adopts multiple linear regressions to investigate the impact of public participation on regional green innovation. The results show that all three types of public participation have a positive impact on regional green innovation, among which ENGOs’ participation has the greatest impact. The effect of direct public participation on green innovation is significantly positive in developed regions but insignificant in underdeveloped regions, while the impact of ENGOs participation is the opposite. The conclusion is still valid after a series of endogeneity and robustness tests. Besides, the threshold regression tests reveal that the impacts of public participation on green innovation shows a threshold effect depending on the intensity of environmental regulation, and only when the intensity of environmental regulation is greater than 0.7495 can public participation play the most effective role.

## 1. Introduction

It is widely accepted that the industrial economy in China has soared since the implementation of the reform and opening-up policy, creating an impressive growth miracle. Nevertheless, pursuing rapid economic development has caused numerous problems such as environmental pollution and energy waste, which have become bottlenecks limiting the sustainable development of China’s economy and environment (Liu et al., 2018). According to Agency Releases Global Energy Progress Report 2022 issued by International Energy, China had the highest energy growth rate from 2010 to 2019, with an average annual growth rate of 3.8%, making it one of the few countries with the fastest growing energy demand in recent years. China’s economic growth model of “speeding up first, increasing quality later” has caused many issues like over-consumption of natural resources, dramatic increase in contaminants emissions and damage to environmental restoration capacity (Danish and Wang, 2019), which seriously impacted the living environment and physical health of the public (Xu et al., 2018) and led to an increase in public environmental concern and green consumption demand year by year (Huang, 2015; Johnson et al., 2018; Zhang et al., 2019a,b,c,d). In

this context, as an essential means of improving energy utilization and meeting public demand for green consumption, green innovation has a strong contribution to the harmonization of economic development and environmental protection (Schiederig et al., 2012; Song et al., 2020; Song and Yu, 2018).

The diffusivity of environmental pollution is the leading cause of local governments and enterprises to take “free-riding” in environmental governance, and necessary environmental regulatory policies are important means to internalize environmental pollution and promote active local participation in environmental governance and green innovation (Cai et al., 2020; Fabrizi et al., 2018; Rubashkina et al., 2015). The Chinese Environmental Protection Agency has developed a series of environmental regulatory policies for example the New Environmental Protection Law and the Guidelines of Supporting the Green Development of Tax and Fee Preferential Policy, with the aim to accelerate the pace of environmental pollution control and green innovation development (Sun et al., 2020). However, the information asymmetry between government and enterprises makes it difficult for the local government to execute optimal environmental regulation according to enterprises’ pollution behaviors. Meanwhile, due to the mutual interests of government and

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enterprises, there may be rent-seeking and collusion between them, resulting in “government failure”, which is unfavorable to regional environmental governance and green development (Harmon, 1995; Zheng and Kahn, 2017). At this point, it is difficult to achieve the best governance effect by relying only on local governments to restrain the behavior of enterprises. In fact, the public is the direct victim of environmental pollution. Public opinion and sentiment play an important social role and can influence the actions of businesses and governments (Quesnel and Ajami, 2017). Extensive researches have revealed that public concern for the environment can significantly improve regional environmental governance performance and enterprises’ green innovation motivation (Du et al., 2019; Costa-Campi et al., 2017). Public participation, as a “soft instrument”, has the unique advantage of compensating for “government failure” and “market failure” (Jiang and Zhang, 2018). Although the effect of public involvement on green innovation has received a lot of scholarly attention, few studies have confirmed it at the regional level. In the event that this effect is confirmed, this research will serve as the first step in examining how regional green innovation is impacted by public participation and defining the intrinsic mechanism in the case of China. Therefore, this analysis has important theoretical relevance.

The worldwide movement appealing for the public to participate in environmental supervision and governance originated in developed countries in the 1950s and has matured over time. The United Nations issued the Rio de Janeiro Declaration on Environment and Development in the 1990s, in which Principle 10 highlighted the necessity for public participation in environmental governance and called on national governments to improve the level of public participation. With the advancement of technology and the increase in residents’ awareness of environmental protection, the public also began to express their opinions and demands through various ways and means to protect their environmental rights and interests. However, the development of public participation in environmental protection-related systems in some developing countries, such as China and India, is immature because of the late starting (Ogihara et al., 2016). And it is unclear that how public participation affects regional environmental management and green innovation in China (Li et al., 2018). That is, to some extent, there is space for further research on the mechanism of public participation for green innovation in China. With this perspective, following questions are proposed: can public participation facilitate regional green innovation development? If yes, what are the potential mechanisms? Moreover, do the different types of public participation play the same roles? And under what circumstances can public participation play the most effective role?

In order to answer the above questions and fill the research gap, this paper utilizes a sample of 30 provinces in China during 2010–2019 to study the impact of public participation on regional green innovation by constructing panel fixed-effects models and adopting multiple linear and threshold regressions. The contributions of this paper are as follows: First, the direct impact mechanisms that drive regional green innovation are explored from the perspective of pluralistic governance instead of monolithic government management, to address the “inertia” of local governments and enterprises. Second, this study categorizes public participation into direct participation, indirect participation, and NGOs participation, and explores the heterogeneous effects of different public participation on regions at different levels of economic development, providing a theoretical basis for formulating differentiated public participation policies in each region. Third, environmental regulation is introduced as a threshold variable to analyze the linear relationship between public participation and green innovation under different environmental regulation intensities.

The remainder of this paper is organized as follows: Section 2 reviews the relevant studies and formulates the research hypotheses. Section 3 provides explanations for the variable selection and model setting. Section 4 analyzes the regression results. Section 5 conducts endogeneity and robustness tests. Section 6 presents conclusions, policy recommendations and proposes directions for future research.

## 2. Literature review and hypothesis

Environmental public participation theory asserts that obtaining environmental information, attending to environmental decisions and carrying out environmental regulation are the public’s fundamental rights (H. Zhang, 2015). As an empowered agent of public participation in environmental governance, the local government is also subject to public environmental scrutiny (Chu et al., 2022). The emergence of environmental problems propels the public to exert social pressure on local governments and enterprises, forcing local government to implement stricter environmental regulation policies to decrease the negative impact of environmental contamination. Meanwhile, the new institutionalism holds that institutions are designed to constrain the behavior of individuals who seek to maximize their subjects’ welfare or utility interests. In an open social system, enterprises pursuing profit must conform to universal ethical norms (Powell, 1983), it can only gain or enhance legitimacy if the public and society universally accept its behavior. As the subject of regional green innovation, enterprises’ behavior is also related to the intensity of government environmental regulation (Aguilera-Caracuel and Ortiz-de-Mandojana, 2013; Chan et al., 2016). Therefore, this paper constructs a comprehensive theoretical framework to explore the relationship between public participation and regional green innovation and further analyzes the pathway of the role of environmental regulation on it, as shown in Figure 1.

Direct and indirect public participation are individual manifestations of public involvement in environmental behavior, and their impact on regional green innovation has two paths: “regulatory pushback” and “demand enhancement”. Based on the dynamic perspective, pushback theory suggests that public participation can improve the performance of government environmental governance (Medalia, 1969) and put pressure on the government and enterprises to adopt cleaner production technologies and green innovation (Almeida et al., 2017; Liao, 2018) by exposing corporate violations (Bewley and Yue, 2000), environmental pollution (Cheng and Liu, 2018), and local government inaction. Enhancement theory, based on a static perspective, indicates that the deteriorating environment has increased public awareness of environmental protection and green consumption demand (Shan, 2012; Zhang and Chen, 2018), and the public is more inclined to buy or use more environmentally friendly and green products. In order to improve public satisfaction with the use of products, enterprises have increased their initiatives toward green innovation to enhance their core competitiveness (Abdullah et al., 2016; Lin et al., 2013; Stucki et al., 2018). In fact, there is a lag in the exchange of information between the government, enterprises and the public. Even if an enterprise causes environmental pollution, it has some time to cover it up, which makes it difficult for the local government to accurately detect the violations of the enterprise. As direct witnesses and victims of environmental pollution committed by enterprises, the public’s environmental complaints against enterprises are often more effective than the formal regulation imposed by the government in influencing enterprises’ behavior (Bing et al., 2008). Accordingly, this paper proposes Hypothesis 1.

**Hypothesis 1.** Both direct and indirect public participation may contribute to regional green innovation.

NGOs participation is the organizational manifestation of public participation in environmental behavior. With the emergence of global environmental issues, NGOs are growing at an increasing pace and playing an integral role in regional environmental governance and green development (Binder and Neumayer, 2005). On the one hand, NGOs can assist local governments in monitoring enterprises’ production and operation activities, reducing their environmental pollution practices and thus promoting sustainable development (Ringius, 1997; Yang et al., 2017). On the other hand, NGOs can provide environmental information to the public and disclose the environmental pollution behaviors of non-compliant enterprises, so that ordinary residents have more opportunities to participate in environmental governance (Wang et al., 2020).

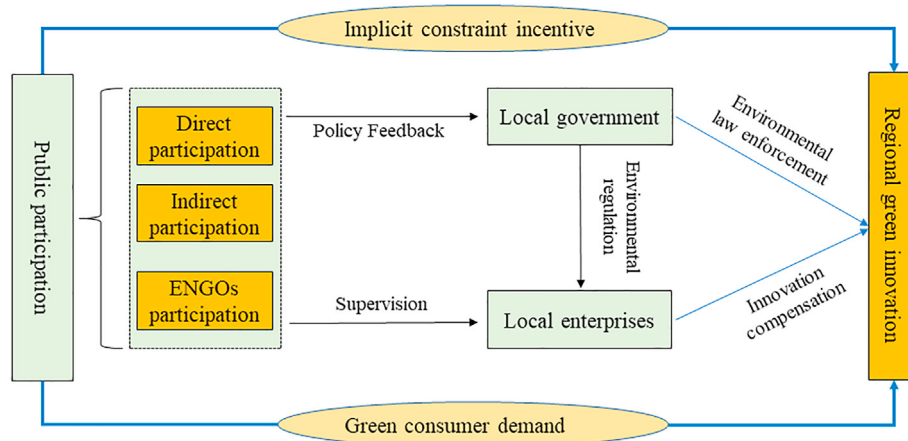


Figure 1. Theoretical analysis framework.

In developed countries, the government has given ENGOS the legal right to participate in environmental governance and prosecute environmental crimes, so as to play the role of ENGOS on regional green development (Boström et al., 2015). ENGOS in developing countries such as China started late and their initial environmental action was mainly environmental awareness promotion and environmental education training (Ru and Ortolano, 2009). However, with the increase in public awareness of environmental protection, the focus of ENGOS shifted to persuading people to adopt green lifestyles (Lee et al., 2018). In the last few years, ENGOS in China have grown in size and function, demonstrating growing importance in local environmental governance and green development (Zhao et al., 2022), for instance, intensely demanding that local governments shut down environmental pollution projects. Since the number of ENGOS in China continues to increase and the concept of public green consumption deepens, local governments and companies have faced increased pressure to carry out productive activities. Suppose enterprises do not control their pollution emissions or do not engage in green innovation activities. In that case, it will lower the public's evaluation of enterprises and lead to the shutdown of many projects, ultimately inhibiting the development of the regional economy and the environment. Thus Hypothesis 2 is proposed.

**Hypothesis 2.** The involvement of ENGOS in environmental behavior may have positive impact on regional green innovation.

In fact, environmental governance and green innovation is a multi-participant processes (Ansell and Gash, 2018), which cannot be achieved by local governments, the public, or enterprises alone. Therefore, the environmental behavior of local governments plays a crucial role in public participation in environmental governance (Chen et al., 2019). In developed countries, public environmental demands can be expressed through voting, and governments are forced to strictly implement environmental policies under public scrutiny. But in China, the environmental decentralization system and the unique promotion mechanism (GDP-only) have led some local governments, especially those in underdeveloped regions, to ignore the public's environmental demands and willingness, selectively implement the central government's environmental regulation policies and even condone environmental pollution by enterprises in order to pursue excessive economic growth (Deng et al., 2019; Wu et al., 2020a,b; Zhang et al., 2017a,b). In this case, even though the public discloses the environmental violations of local enterprises, it is hard for local government to impose severe penalties on these enterprises, which greatly weakens the public's zeal to participate in environmental governance. Hence Hypothesis 3 is drawn.

**Hypothesis 3.** There may be regional heterogeneity in the impact of public participation on regional green innovation, and the effect of public participation on green innovation may be greater in developed regions.

China's economy is in a critical period of developing from high speed to high quality. The mechanism of green innovation needs to be improved, which is also influenced by various factors such as environmental regulation. In reality, the relationship between environmental regulation and green innovation has always been a hot topic of academic research. Some scholars, based on neoclassical economics, have pointed out that the cost of pollution control for enterprises would increase with the improving of environmental regulation intensity, and producers will reduce green innovation inputs to control costs (Chen et al., 2021), thus hindering regional green development (Ouyang et al., 2020; Tang et al., 2020). Other scholars, in view of the Porter hypothesis, have argued that strict environmental regulations would force enterprises to conduct green innovation activities and offset the cost of pollution treatment through innovation compensation, thereby improving the level of green innovation (Du et al., 2021; Luo et al., 2021; Peng, 2020). Although the conclusions of the above studies are divergent, it is worth mentioning that under the high level of environmental regulation, the central government will pay more attention to the public's petition and reporting on environment, making local government's harboring behavior towards polluting enterprises have no place to hide. This will help enhance the public's motivation to protect the environment and monitor the environmental behavior of enterprises. From this Hypothesis 4 is proposed.

**Hypothesis 4.** Public participation under high standards of environmental regulation may have a stronger role in promoting regional green innovation.

### 3. Research design

#### 3.1. Model selection

The effect of public engagement on regional green innovation is examined in this paper using multiple regression analysis, which enables researchers to incorporate a wide range of additional variables that might also affect the explained variable.

Multiple regression model is used to analyze the regression correlation between several variables. In this model, one factor serves as the explanatory variables while the remaining factors are used as explaining variables. There are two types of relationships between variables: linear and nonlinear. And the multivariate regression models are a set of linear functions, logarithmic, power or other functions according to the variables' relationships.

The use of multiple linear regression is appropriate given the number of variables in this study and the complexity of their relationships. The major test in this article is firstly performed using a multiple linear regression model, as suggested by Fang et al. (2014) and other current research. The Hausman test (Fageda, 2014) is used to evaluate whether

to employ a random-effects model or a fixed-effects model for estimate because the data utilized in this research are panel data. Table 1 displays the outcomes of the Hausman test. The findings show that the original assumption is refused with a significant level of 1%, indicating that the fixed-effect model is applicable to this study.

### 3.2. Model construction

Based on the existing theoretical studies, in order to test the above research hypotheses, the double fixed-effects model applicable to the analysis of short panel data (Zhang et al., 2017a,b) is selected as the baseline model in this study. Meanwhile, Eqs. (1), (2), and (3) are constructed to investigate the influence of direct public participation, indirect public participation and ENGOS participation on regional green innovation, respectively.

$$GI_{it} = \beta_0 + \beta_1 DPP_{it} + \beta_2 Control_{it} + \mu_i + \delta_t + \varepsilon_{it} \tag{1}$$

$$GI_{it} = \beta_0 + \beta_1 IPP_{it} + \beta_2 Control_{it} + \mu_i + \delta_t + \varepsilon_{it} \tag{2}$$

$$GI_{it} = \beta_0 + \beta_1 EP_{it} + \beta_2 Control_{it} + \mu_i + \delta_t + \varepsilon_{it} \tag{3}$$

In the above models,  $GI_{it}$  represents the level of regional green innovation,  $DPP_{it}$ ,  $IPP_{it}$  and  $EP_{it}$  denote the intensity of direct public participation, indirect public participation and ENGOS participation respectively,  $\beta_0$  is a constant term,  $\beta_1$  and  $\beta_2$  are the correlation coefficients of explanatory and control variables,  $\mu_i$  and  $\delta_t$  denote the unobservable individual fixed effects and time fixed effects, respectively, and  $\varepsilon_{it}$  is a random disturbance term.

To further test the threshold effect of environmental regulation, based on Eq. (1), the threshold regression model indicated as Eq. (4) with regional green innovation as the dependent variable, public participation as the independent variable, and environmental regulation as the threshold variable is developed in this study to explore the nonlinear effect of public participation on regional green innovation when environmental regulation is at different threshold values.

$$GI_{it} = \beta_0 + \beta_1 PP_{it} I(ER_{it} \leq \gamma_1) + \beta_2 PP_{it} I(\gamma_1 \leq ER_{it} \leq \gamma_2) + \beta_3 PP_{it} I(ER_{it} \geq \gamma_2) + \beta_m Control_{it} + \varepsilon_{it} \tag{4}$$

where  $I(\cdot)$  is the indicator function,  $\gamma_1$  and  $\gamma_2$  are the value of thresholds,  $\beta_1$ ,  $\beta_2$  and  $\beta_3$  are the impact coefficients of the independent variables in different intervals,  $\beta_m$  is the correlation coefficient of each control variable.

### 3.3. Variable selection

#### 3.3.1. Dependent variable

**3.3.1.1. Green innovation (GI).** Green innovation aims to follow ecological principles and eco-economic laws, focusing on pollution control and prevention, eco-processes, green products and other methods to minimize energy consumption and pollution emissions of enterprises. Currently, there are two main methods to measure green innovation: one is comprehensive indicators measured by data envelopment analysis (DEA) (Kofi, 2019), and the other is green patent statistics (Hong et al., 2021; Zhang et al., 2019a,b,c,d). Although patents do not directly create high returns to the social production process of the region, it is undeniable that they are the main output of green innovation activities and the best manifestation of the innovation results. Besides, green patents can not only better measure the overall level and scale of green innovation activities in a region (Qian, 2015), but also reflect the degree of regional emphasis on green and sustainable development. Therefore, this paper refers to Wurlod and Noailly (2016) and adopts green patent application data to characterize the level of regional green innovation. Figure 2 shows the distribution of green patent applications by region in China in

Table 1. Hausman test.

	(b) fe	(B) re	(b-B) Difference	sqrt (diag (V_b-V_B)) S.E.
DPP	-0.0036	0.0679	-0.0715	
IPP	0.1298	0.1430	-0.0132	
EP	0.2623	0.3639	-0.1016	0.0338
PGDP	0.0287	0.0375	-0.0088	
ECS	-0.8042	-0.4836	-0.3206	0.1265
ST	1.2926	2.0756	-0.7830	
FDI	0.0486	0.1261	-0.0774	0.0193
UR	6.0731	4.2788	1.7943	0.1213

Test: Ho: difference in coefficients not systematic chi 2(8) = (b-B)'[(V\_b-V\_B)(-1)] (b-B) = 29.32.  
Prob > chi 2 = 0.0003.

2010 and 2019. It shows that the overall level of green innovation has improved significantly, but there are prominent differences between regions, with developed regions having a higher level than underdeveloped regions.

#### 3.3.2. Independent variables

**3.3.2.1. Direct public participation (DPP).** Under China's specific policy system, the National People's Congress (NPC) is the most direct and effective way for residents to participate in politics. NPC suggestions reflect citizens' evaluation, constructive opinions or criticism of the work of state organs. Therefore, this paper uses the number of NPC suggestions on the environment in each region to represent the level of direct public participation.

**3.3.2.2. Indirect public participation (IPP).** In previous studies, most scholars tended to select the number of letters and reports on environmental issues to measure indirect public participation in environmental governance (Zhang and Chen, 2018). However, with the development of the internet and new media technologies, the environmental participation behaviors of letter-writing and direct petitions are out of fashion, and the data on environmental letters published by the National Bureau of Statistics has changed abruptly since 2010, which are no longer suitable for conducting empirical analysis. Given the stability of data and the effectiveness of indirect public participation, this paper discards the above indicators and adopts the number of environment-related CPPCC (Chinese People's Political Consultative Conference) proposals to characterize the level of indirect public participation (Ge et al., 2021; Zhang et al., 2019a,b,c,d).

**3.3.2.3. ENGOS participation (EP).** ENGOS participation is mainly manifested in the development of ENGOS. In China, Non-government organizations mainly include social groups, foundations, and private non-businesses. As factors such as data availability and environmental policies, this paper draws on Wu et al. (2020c) and selects the sum of the number of unofficial organizations in the environmental category to measure ENGOS participation.

#### 3.3.3. Threshold variable

**3.3.3.1. Environmental regulation (ER).** At present, there are mainly the following methods to measure environmental regulation. First, a single indicator method like environmental administrative penalty cases and pollution control amount is selected to measure it (Ran et al., 2020). The second is the integrated indicator method, which uses the emissions of different pollutants to construct environmental regulation indicators by applying the weighting or entropy value method (Li et al., 2021). However, single indicators cannot measure the overall level of regional environmental regulation, and the statistical sources and calculation



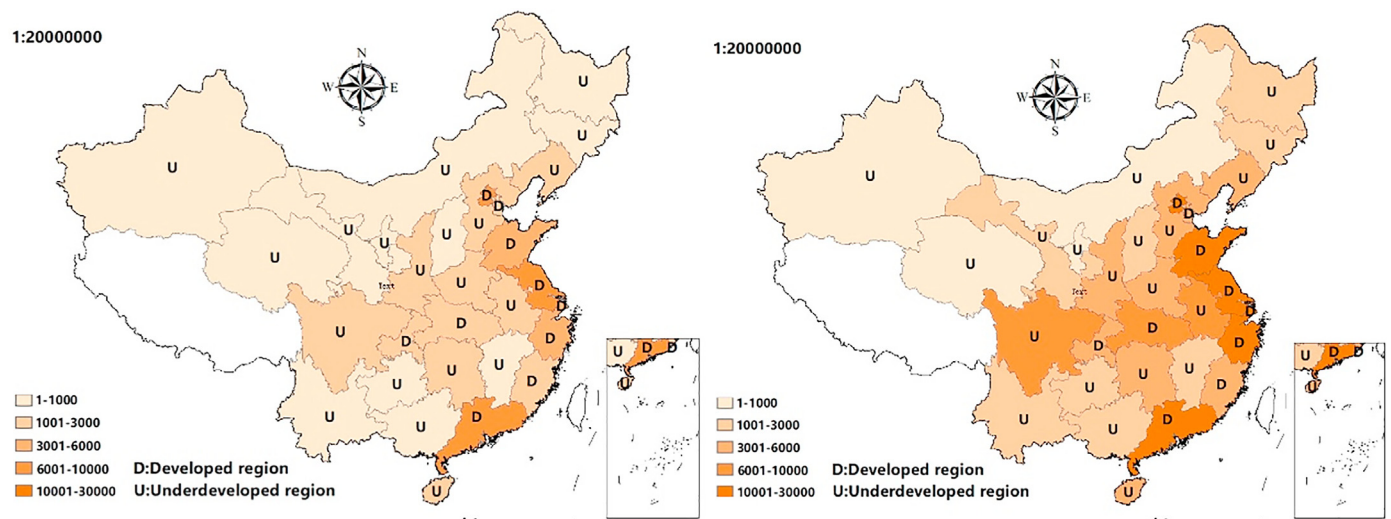


Figure 2. Spatial distribution of GI in China (L:2010, R:2019) Data source: (CNRDS [www.cnrds.com](http://www.cnrds.com)).

process of the integrated indicator are subject to large errors. Therefore, this study adopts the method of [Khedher and Zugravu \(2008\)](#) to represent the intensity of environmental regulation by using [Eq. \(5\)](#).

$$ER = \frac{GDP}{Energy} \tag{5}$$

where *GDP* represents gross regional product and is deflated using 2010 as the base period, *Energy* denotes total regional energy consumption.

### 3.3.4. Control variables

Referring to previous studies ([Lin and Zhu, 2019](#); [Tang and Li, 2022](#)), this study chooses the following variables as control variables. *Level of economic development (PGDP)*: Economic development is a key factor affecting regional green innovation. On the one hand, economic development creates material conditions for regional green innovation activities. On the other hand, economic development provides a suitable environment for enterprises to carry out innovation activities. Besides, the more developed the economic level is, the higher the residents' demand for environmental safety and green consumption needs. In this study, regional GDP per capita measures PGDP, with 2010 as the base

period for deflation. *Urbanization level (UR)*: Urbanization is conducive to the agglomeration of capital and the development of science and technology, which also provides talent resources for enterprises to conduct green innovation. The urbanization rate of each region is adopted to represent UR. *Superiority of industry (ST)*: For a long time, although the rapid development of industry has contributed to the fast-growing of China's economy, it has also exacerbated China's energy consumption and environmental pollution. Facing the growing demand for green development, improving the development of the tertiary industry is more conducive to green innovation in all regions of China. ST in each region is measured by the proportion of tertiary industry to GDP. *Foreign direct investment (FDI)*: While foreign investment brings superior technology to the region, it also brings environmental pressure. Thereby it has a significant influence on regional green development. FDI is measured by the number of foreign direct investment. *Energy consumption structure (ECS)*: The energy consumption structure reflects the practical application of clean energy as well as clean technology in each region, which influence the development of green innovation. ECS is measured by the proportion of coal consumption to total energy consumption. This paper selects data from 30 Chinese provinces from 2010 to 2019 for an empirical study. The data sources and variables are shown in [Table 2](#).

Table 2. Variables and data sources.

Variable	Definition	Data source
GI	Logarithm of the number of green patents	CNRDS database
DPP	Logarithm of the number of NPC suggestions on the environment	China Environment Yearbook
IPP	Logarithm of the number of environment-related CPPCC proposals	China Environment Yearbook
EPP	Logarithm of the number of unofficial organizations in the environmental category	China Civil Affairs Statistical Yearbook
ER	Ratio of GDP to energy consumption	China Energy Statistical Yearbook
PGDP	Logarithm of regional GDP per capita	National Bureau of Statistics
UR	Urbanization rate	National Bureau of Statistics
ST	The proportion of tertiary industry to GDP	National Bureau of Statistics
FDI	Logarithm of the number of foreign direct investment	National Bureau of Statistics
ECS	The proportion of coal consumption to total energy consumption	China Energy Statistical Yearbook

## 4. Empirical analysis

### 4.1. Descriptive statistics and correlation analysis

The results of the descriptive statistical analysis of all variables in this study are shown in [Table 3](#). It can be seen that the mean value of the regional green innovation level is 7303, which is much lower than its maximum value of 67,258, indicating that the level of green technology innovation in most regions of China is lower than the national average. The maximum value of EP is 1000, indicating that the number of ENGOs in China is not large enough, and they are still in the development stage. PGDP has the most significant standard deviation among other variables, which may impact regional green innovation differently.

The correlation coefficients between the variables are shown in [Table 4](#). It shows that regional green innovation (GI) is significantly and positively correlated with direct public participation (DPP), indirect public participation (IPP) and ENGOs participation (EP) ( $\beta = 0.410, p < 0.01$ ;  $\beta = 0.192, p < 0.01$ ;  $\beta = 0.149, p < 0.01$ ). These results preliminary confirm the study hypotheses. The correlation coefficients between most variables are less than 0.7, indicating that the model does not suffer from multicollinearity.

**Table 3.** Descriptive statistics of variables.

variables	Mean	Med	Std. Dev.	Min	Max	Obs.
GI	7303	3641	10445	31	67258	300
DPP	226.4	185.5	176.6	11	1196	300
IPP	321.9	247	394.8	11	5567	300
EP	238.4	166.5	205.7	20	1000	300
ER	1.572	1.539	0.726	0.459	4.806	300
PGDP	32343	27746	20214	141.4	99820	300
UR	0.577	0.557	0.126	0.338	0.896	300
ST	45.74	44.86	9.763	28.60	83.50	300
FDI	80.44	57.34	78.61	0.0450	357.6	300
ECS	0.945	0.859	0.444	0.0250	2.461	300

**4.2. Overall estimation results**

In this study, Stata 16.0 is adopted to estimate models (1), (2), and (3), and the regression results are shown in Table 5. It can be seen that the estimated coefficients of direct public participation, indirect participation and ENGOs participation are significantly positively correlated with green innovation, and are statistically significant at least at the 10% level. Hypotheses 1 and 2 are verified. Specifically, the estimated coefficients of the three are 0.0810, 0.0949, and 0.126, respectively, and the comparison reveals that the estimated coefficient of ENGOs participation is the largest, indicating that ENGOs are the main contributors to the role of public participation in regional green innovation.

There are two possible reasons for the above results. On the one hand, compared with individual public participation, ENGOs have an extensive network organizational system that can collect the public's environmental needs and transmit them to all levels of government and suggest adjustments to environmental policies. In addition, ENGOs can gather environmental protection professionals and organize various experts to participate in the research and development of environmental affairs, which enables environmental governance behavior to be more rational (Liu et al., 2022). On the other hand, environmental protection publicity and education by ENGOs can reach the masses and raise residents' awareness of environmental protection, which encourages enterprises and residents to adopt greener production methods and living habits, thus better promoting the development of green innovation.

**4.3. Regional estimation results**

When conducting regional heterogeneity studies, most scholars divided China into three regions, i.e., the east, the central, and the west, based on geographical location. However, this division cannot adequately reveal the environmental differences and development levels among the provinces. Therefore, this study adopts the method of Liu et al. (2020), and classifies regions with per capita GDP greater than the

**Table 4.** Correlation coefficients.

Variables	GI	DPP	IPP	EP	ER	PGDP	UR	ST	FDI	ECS
GI	1.000									
DPP	0.410***	1.000								
IPP	0.192***	0.539***	1.000							
EP	0.149***	0.438***	0.343***	1.000						
ER	0.699***	0.312***	0.113*	-0.005	1.000					
PGDP	0.499***	0.074	-0.008	-0.143**	0.576***	1.000				
UR	0.470***	-0.019	-0.111*	-0.295***	0.594***	0.777***	1.000			
ST	0.458***	-0.065	-0.150***	-0.188***	0.595***	0.614***	0.745***	1.000		
FDI	0.646***	0.527***	0.303***	0.195***	0.569***	0.486***	0.492***	0.239***	1.000	
ECS	-0.331***	-0.170***	-0.078	-0.131**	-0.566***	-0.332***	-0.348***	-0.385***	-0.313***	1.000

\*Significant at the 10% level. \*\* Significant at the 5% level. \*\*\* Significant at the 1% level.

national average in 2019 as developed regions and the rest as underdeveloped regions.

Table 6 shows the estimation results at the regional level. It can be seen that the estimated coefficient of direct public participation is significantly positive in developed regions but insignificant in underdeveloped regions, indicating that direct public participation plays a positive role in green innovation only in developed regions. The estimated coefficients of indirect public participation are significantly positive in all regions, although the values are more outstanding in developed regions. This result is similar to the findings of Fu and Geng (2019) and validates research Hypothesis 3. This is because residents generally have higher economic power and environmental awareness in developed regions. According to Maslow's needs theory, their need for environmental security outweigh their physiological needs. Conversely, in underdeveloped areas, the public's need for environmental safety may be lower than their physiological needs. When faced with enterprise environmental pollution and local government inaction, the public in developed areas are more enthusiastic about environmental participation, and enterprises in developed areas face greater environmental pressure. As a result, direct and indirect public participation positively affects green innovation in developed areas.

The estimated coefficient of ENGOs participation is insignificant in developed regions but significantly positive in underdeveloped regions, indicating that ENGOs play a more prominent role in underdeveloped regions, and this finding rejects research Hypothesis 3. One possible reason for this is that, unlike individual participation, the participation of ENGOs in environmental governance is of public interest, and their main purpose is to raise residents' awareness of environmental protection and improve the regional environmental level. In underdeveloped areas, environmental pollution is often a major problem, but the residents' ability and willingness to participate in environmental management is relatively weak, so it is necessary to rely on environmental protection

**Table 5.** Overall estimate results.

Variables	GI		
	(1)	(2)	(3)
DPP	0.0810** (0.0409)		
IPP	0.0949*** (0.0345)		
EP	0.126* (0.0744)		
Control	Yes	Yes	Yes
Constant	-5.744 (3.922)	-5.371 (3.948)	-5.334 (3.956)
Year	Yes	Yes	Yes
Province	Yes	Yes	Yes
Obs.	300	300	300
R <sup>2</sup>	0.879	0.877	0.877

Notes: t-statistics in parentheses. \*\*\*p < 0.01. \*\*p < 0.05. \*p < 0.1.

**Table 6.** Regional estimate results.

Variables	Developed regions			Underdeveloped regions		
DPP	0.0836** (0.0410)			0.0684 (0.0589)		
IPP	0.107** (0.0432)			0.0805* (0.0459)		
EP	-0.000166 (0.0922)			0.190* (0.107)		
Control	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.657 (4.366)	-1.669 (4.370)	0.804 (4.655)	-20.75*** (5.691)	-21.04*** (5.645)	-20.95*** (5.645)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	100	100	100	200	200	200
R <sup>2</sup>	0.966	0.967	0.965	0.848	0.850	0.850
Num.	10	10	10	20	20	20

Notes: t-statistics in parentheses. \*\*\*p < 0.01. \*\*p < 0.05. \*p < 0.1.

organizations to achieve environmental publicity and education for the public. Besides, unlike developed regions, the main objective of local governments and enterprises in underdeveloped regions is to pursue economic growth. Collusion between government and enterprises may lead to environmental degradation, making it particularly important for ENGOs to monitor the environmental behavior of governments and enterprises.

#### 4.4. Threshold effect analysis

The threshold number test results are shown in Table 7. It can be seen that the test with environmental regulation as a threshold variable passed the significance test for the single threshold, indicating that there is a single threshold effect of environmental regulation in the influence of public participation on regional green innovation. The threshold values of environmental regulation under direct public participation, indirect participation and ENGOs participation are 0.7495, 0.6939 and 0.6894, respectively.

Table 8 shows the threshold regression results. It can be seen that the whole sample is divided into two threshold intervals when taking environmental regulation (ER) as the threshold variable. The impact of public participation on regional green innovation shows a nonlinear effect with the increase of the degree of environmental regulation. In particular, when environmental regulation is less than the minimum threshold (ED < 0.6894), the coefficient of direct public participation in green innovation is 0.158 and significant, the coefficient of indirect public participation in green innovation is 0.0585 but insignificant, and the coefficient of ENGOs participation on green innovation is 0.0665 but insignificant. When environmental regulation is greater than the maximum threshold (ED > 0.7495), the coefficients of direct public participation, indirect participation and ENGOs participation in green innovation are 0.236, 0.163 and 0.167, respectively, and all pass the 1% significance test. It

**Table 7.** Threshold number test results.

Variables	Threshold number	F-value	P-value	Threshold	95% confidence interval
EP	Single threshold	36.69	0.0267	0.7495	(-0.0127, 0.3287)
	Double Threshold	21.21	0.1400	2.6758	(0.0756, 0.3965)
DPP	Single threshold	45.04	0.0233	0.6939	(-0.0378, 0.1549)
	Double Threshold	16.72	0.1867	2.6758	(0.0787, 0.2467)
IPP	Single threshold	43.67	0.0167	0.6894	(-0.0146, 0.1477)
	Double Threshold	16.98	0.2167	2.6758	(0.0979, 0.2368)

**Table 8.** Threshold regression results.

Variables	DPP	IPP	EP
PGDP	0.0323** (0.0141)	0.0269* (0.0139)	0.0232* (0.0139)
ST	1.326*** (0.281)	1.158*** (0.272)	1.315*** (0.271)
FDI	0.0571 (0.0435)	0.00449 (0.0417)	0.00577 (0.0410)
UR	5.649*** (0.466)	5.379*** (0.441)	5.310*** (0.441)
ECS	-0.752*** (0.219)	-0.894*** (0.216)	-0.965*** (0.215)
$\beta_1$	0.158* (0.0867)	0.0585 (0.0489)	0.0665 (0.0412)
$\beta_2$	0.236*** (0.0815)	0.163*** (0.0427)	0.167*** (0.0353)
Constant	5.282*** (1.408)	6.534*** (1.273)	5.929*** (1.278)
Obs.	300	300	300
R <sup>2</sup>	0.839	0.844	0.847

Notes: t-statistics in parentheses. \*\*\*p < 0.01. \*\*p < 0.05. \*p < 0.1.

follows that only by maintaining the intensity of environmental regulation at a high level can the role of public participation be entirely played in promoting regional green innovation.

One possible reason for this is that under a loose intensity of environmental regulation, local governments may “turn a blind eye” to the polluting behavior of enterprises in pursuit of economic growth, resulting in severe formalism and local protectionism (Sjoberg and Xu, 2018). Additionally, public environmental petitions and reports are not given sufficient attention under weak environmental regulation, and public environmental suggestions are not effectively fed back and implemented, making it difficult to put pressure on polluting enterprises to carry out green technology innovation activities.

## 5. Endogeneity and robustness tests

### 5.1. Endogeneity tests

Bidirectional causality between explanatory and explained variables is an important cause of endogeneity in econometric models. The presence of endogeneity can lead to biased and inconsistent results. While public environmental participation affects green innovation, the increase in the level of green innovation reduces the level of regional pollution to some extent, thus affecting the intensity of public participation, i.e., there may be a bidirectional causal relationship between public participation and green innovation. Although this paper adopts a two-way fixed-effects model controlling time and province, which overcomes the problem of omitted variables to some extent, and controls other factors affecting green innovation as much as possible, some other influencing factors may still be overlooked and the measurement error of variables may lead to the existence of endogeneity. In this regard, this study uses two-stage least squares (2SLS) to control possible endogeneity problems, treats public participation as an endogenous variable, and uses lagged one-

**Table 9.** 2SLS estimate results.

Variables	GI		
DPP	0.474*** (0.0803)		
IPP	0.608*** (0.0967)		
EP	0.351*** (0.0499)		
Control	Yes	Yes	Yes
Constant	-7.029*** (1.369)	-9.516*** (1.675)	-6.070*** (1.428)
Obs.	270	270	270
R <sup>2</sup>	0.781	0.778	0.779

Notes: t-statistics in parentheses. \*\*\*p < 0.01.

**Table 10.** Robustness test results.

Variables	Exclusion of singular values			Replace explained variable		
	DPP	IPP	EP	DPP	IPP	EP
	0.0828** (0.0414)	0.107*** (0.0371)	0.126* (0.0746)	0.0958** (0.0423)	0.0874** (0.0358)	0.192** (0.0766)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-15.01*** (3.851)	-15.38*** (3.819)	-15.90*** (3.886)	-13.15*** (3.982)	-13.63*** (3.979)	-14.42*** (4.001)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	300	300	300	300	300	300
R <sup>2</sup>	0.877	0.879	0.877	0.867	0.867	0.867

Notes: t-statistics in parentheses. \*\*\*p < 0.01. \*\*p < 0.05. \*p < 0.1.

period values or two-period values as instrumental variables to estimate the model. Public participation in the lagged period is ex-ante and there is no reverse causality between it and the current green technology innovation. The model estimation results are presented in Table 9. It shows that public participation can still significantly contribute to regional green innovation, which is consistent with the previous findings and excludes the endogeneity problem from interfering with the empirical results.

**5.2. Robustness tests**

Exclusion of outliers. In order to mitigate the interference of outliers on the study results, the main explanatory variables were subjected to tailoring below the 1% quantile and above the 99% quantile in this paper then regressed again, and the results are shown in columns 2 to 4 in Table 10. It can be seen that the coefficients of the main explanatory variables passed the significance test after the tailoring process, so the results above are reliable.

Replace the core dependent variables. Since green utility patents are the main means to meet the public's green consumption demand and can reflect the utility level of regional green innovation, the number of green utility patent applications (GUP) in each province is used as a proxy for regional green innovation (GI) to test robustness in this study. The results are reported in columns 5 to 8 in Table 10, and it can be seen that they are generally consistent with the above research results, which again verifies the reliability of this study.

**6. Conclusions**

**6.1. Research findings and implications**

In the context of accelerating China's environmental pluralistic governance system, the impact of public participation on regional green innovation has attracted extensive attention from both political and academic circles (Ju et al., 2019; L. Wu and Liu, 2022). Based on panel data from 30 provinces in China during 2010–2019, this study empirically tested how public participation affects regional green innovation by

constructing a double fixed effects model and a panel threshold model with environmental regulation as the threshold variable. The following research conclusions were drawn. First, direct public participation, indirect participation, and ENGOs participation all positively impact regional green innovation, among which ENGOs participation, with an impact coefficient of 0.126, has the greatest impact, indicating that ENGOs play an important role in promoting the development of regional green innovation. Second, the effect of direct public participation on green innovation is significant in developed regions but not underdeveloped regions, while the effect of ENGOs participation is just the opposite. This result suggests that the effect of public participation in underdeveloped regions needs to be enhanced with the help of ENGOs.

Third, public participation can have a significant positive impact on regional green innovation only when the intensity of environmental regulation is greater than 0.7495, indicating that increasing the intensity of environmental regulation can better utilize the role of public participation.

**6.2. Policy recommendations**

Firstly, the central government should pay full attention to the role of public participation in regional environmental protection and green development (Sun et al., 2016), and improve the channels and ways of public participation. On the one hand, the government should make the environmental information of enterprises public to increase residents' concern about environmental problems and advocate for them to defend their environmental rights and interests. Simultaneously, the government need to properly guide the public to monitor the environmental behavior of enterprises, thus forcing them to actively implement green production technology. On the other hand, the government should improve the incentive mechanism for residents to report environmental issues, and enhance its own efficiency in handling public complaints, thereby increasing the motivation and efficiency of public participation.

Secondly, differentiated environmental public participation policies need to be formulated for regions with different levels of economic development. For developed regions, local governments should guarantee the effective implementation of the NPC deputies' selection system and ensure the universality and fairness of the selection. For underdeveloped regions, the government should strongly support the development of ENGOs. Playing an important role in green innovation in underdeveloped regions, ENGOs in China still suffer from insufficient funding and staff shortages (Zhan and Tang, 2016), which greatly limit the effective functioning of ENGOs. Therefore, the government should ensure the establishment and operation of ENGOs through necessary funding and technology support.

Finally, the findings of this paper suggest that the positive effect of public participation on green innovation is not significant under low environmental regulation intensity, so it is necessary for the central government to appropriately increase the intensity of environmental



regulation. On the one hand, the government can increase the environmental tax and emission fee levied on heavily polluting enterprises and formulate and implement environmental regulation policies regarding public supervision. On the other hand, the central government should improve the promotion mechanism for local officials, include environmental governance performance in the assessment, and strengthen the supervision of local governments to avoid strategic interaction between local governments and polluting enterprises. Moreover, the centralized management of local environmental authorities need to be enhanced to minimize the negative intervention of environmental decentralization. It is also important to deepen the application of digital technology in environmental monitoring, which can improve the efficiency and accuracy of environmental monitoring to ensure the accurate implementation of environmental regulation.

### 6.3. Limitations and future research directions

Firstly, the method and indicators selected to measure indirect public participation need to be improved. Although the number of environment-related CPPCC proposals can reflect the public's willingness to participate in environmental governance to a certain extent, it may ignore the role of grassroots residents in environmental protection activities, such as online complaints and direct petitions. Due to the continuity and stability of data, this paper failed to study this issue. Future study can try to integrate the number of resident complaints with the number of CPPCC proposals, so that we can judge the effect of public participation more clearly and accurately.

Secondly, the findings of this paper would be more solid if the sample size was larger. Due to the availability of data, only provincial panel data are used in this study. Future research can reach down to the prefecture-level city to obtain more research data. In addition, this paper only takes the provincial-level administrative regions of China as the study sample, without considering the special situations of other emerging economies. In future studies, the sample size can be expanded, and comparative analyses of different countries can be conducted so as to gain broader insights.

### Declarations

#### Author contribution statement

Jing Tang: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Shilong Li: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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#### Data availability statement

The data presented in this study are available on request from the corresponding author.

#### Declaration of interests statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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