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EDITED BY
Wei Zhang,
China University of Geosciences Wuhan, China

REVIEWED BY
Gal Hochman,
Rutgers, The State University of New Jersey, United States
Yang Wang,
Yunnan Normal University, China

*CORRESPONDENCE
Yong Liu,
jhly1007@zstu.edu.cn

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# Impact of environmental regulation on government subsides of public-private partnership waste-to-energy incineration projects: evidence from 66 cities in China

Ye Shen[1], Min Xu[1], Caiyun Cui[2], Bo Xia[3], Martin Skitmore[4], Matthew Moorhead[4] and Yong Liu[1]*

[1]School of Civil Engineering and Architecture, Zhejiang Sci-Tech University, Hangzhou, China, [2]School of Civil Engineering and Architecture, North China Institute of Science and Technology, Langfang, China, [3]School of Architecture and Built Environment, Queensland University of Technology, Brisbane, QLD, Australia, [4]Faculty of Society and Design, Bond University, Robina, QLD, Australia

**Introduction:** Environmental regulation, as a vital component of public regulation in China, plays a crucial role in coordinating regional eco-efficiency, while the traditional hypothesis, Porter hypothesis, and uncertainty hypothesis offer three different perspectives for understanding the relationship between industry performance and environmental regulations.

**Methods:** Based on the assumption of industry heterogeneity, 81 public-private partnership (PPP) waste-to-energy (WTE) incineration projects are analyzed using panel data from 66 cities within China during the period from 2013 to 2017 with the aims to reveal the underlying mechanism behind environmental regulation and the government subsides of public-private partnership waste-to-energy incineration projects by using multiple regression modeling.

**Results:** The results show that the impact of environmental regulation on government subsides of PPP WTE projects has demonstrated an "Inverted-U"-shaped relationship with an inflection point, of which an increase in environmental regulation is positively correlated with an increase in subsidies at first then a negative correlation developing later.

**Discussion:** The findings are significant in setting flexible environmental regulations according to the needs of regional economic and social development. In addition, they also supply a theoretical reference for promoting the WTE incineration industry's sustainable and healthy development.

KEYWORDS

**environmental regulation, public private partnerships, waste-to-energy incineration project, government subsides, impact**

# 1 Introduction

Waste-to-energy (WTE) technologies currently play a prominent role in the disposal of Municipal Solid Waste (MSW). First, they provide an effective and sustainable means of eliminating MSW and solve the problem of "garbage siege", hence alleviating pressure on urban land (Lu et al., 2018; Ding et al., 2021). Second, a large amount of heat is produced during waste combustion that further promotes renewable energy generation (heat and/or power, gases, etc.) (Francesco et al., 2018; Kamyab et al., 2022). Third, compared to anaerobic digestion and aerobic composting technology, WTE stands out as an optimal approach for efficiently treating MSW in a shorter time, at a lower cost and with well-established technology, and it excels in handling inorganic waste, which anaerobic composting and aerobic digestion technology cannot achieve (LoRe and Hurdle, 2013; Qazi et al., 2018). These advantages of WTE incineration have led to its worldwide popularity in recent decades, contributing greatly to the sustainable development of the circular economy and society (Leckner, 2015; Istrate et al., 2020; Peng et al., 2023). In China, almost all WTE incineration projects are constructed and developed through Public-Private Partnership (PPP) arrangements, which rapidly promotes the MSW disposal capacity while greatly improves their operational efficiency (Sastoque et al., 2016; Hou et al., 2022). It is estimated that 108 WTE incineration projects were deployed by PPPs from May 2012 to January 2017 in China with a total investment of CNY 489 billion, accounting for over 70% of the whole WTE incineration project library (Song et al., 2017).

Currently, revenue from PPP WTE incineration projects in China is mainly comprised of two parts: namely, government subsidies and the income from electricity sales. According to *the Notice of the National Development and Reform Commission on Adjusting Electricity Prices* (*No. 801 [2012]*) (National Development and Reform Commission, 2012), the benchmark price of electricity sold by these incinerators has been standardized to set level (0.65 CNY/kwh, 280kwh/t) since 2013. Correspondingly, the subsidies paid by the local government for MSW disposal have played a vital role in the financial feasibility of PPP WTE incinerators. Li et al. (2016) currently revealed that nearly half of the revenue generated by these projects is from government subsidies. However, there are huge differences between the government subsidies for different projects in different regions in China. For instance, the government subsidy for the Qingzhen PPP WTE incineration project in Guiyang was CNY 142/t in 2016, while it was CNY 54.6/t for the Xinyang PPP WTE incineration project in Henan in the same period (See www.ccgp.gov.cn). Thus, it is important to provide an insight into this phenomenon and clarify the influencing factors of the government subsidies involved, as well as studying the associated influencing mechanisms.

Previous studies indicate that the government subsides of PPP WTE incineration projects are influenced by multiple factors, such as project scale (Song et al., 2017; Cao et al., 2022), regional economic and social characteristics (Zhao et al., 2016), and environmental regulation (Li et al., 2015; Fu et al., 2021). Specifically, relevant studies show that environmental regulation plays a vital role in industry performance, especially in pollution-intensive industries (Zhou et al., 2017; Zou and Zhang, 2022). However, the specific impact of environmental regulation on the PPP WTE incineration industry's government subsides remains unclear. Meanwhile, despite ample research on the impact of environmental regulation on industrial performance, its underlying mechanism is debatable (Yuan et al., 2017; Zhang et al., 2019). Moreover, although the influencing mechanism of environmental regulation has been discussed intensively in similar industries, such as sewage treatment (Khaliq et al., 2017; Pan and Tang, 2021) and coal mines (Dzonzi-Undi and Li, 2015; Jia and Luo, 2023), further verification is still needed of the specific impact of environmental regulation on the PPP WTE incineration industry because the impact of environmental regulations on industrial performance varies between different industries (Liu et al., 2020; Luo et al., 2021).

To bridge this research gap, the present study aims to understand the impact of environmental regulation on government subsides of PPP WTE incineration projects using a multiple regression model based on panel data from 81 such projects distributed over 66 Chinese cities from 2013 to 2017. The findings enrich the literature related to environmental regulation and industrial performance in China, as well as addressing the research gap in the WTE incineration industry. Moreover, it is conducive to the developing of suitable policies, and beneficial for companies in formulating separate development strategies.

# 2 Literature review

## 2.1 Environmental regulation

Environmental regulation, as a vital component of public regulation, is an effective approach to adjust market failure and has made a significant approach towards the coordinated development of China's economic development and environmental protection (Galinato and Chouinard, 2018; Wang et al., 2020; Shi et al., 2023). Environmental regulation is necessary because of the negative externalities of environmental pollution and the nature of environmental public goods. It is generally categorized into three types: command-and-control instruments, market-based instruments, and voluntary instruments (Ren et al., 2016). Of these, the use of command-and-control instruments imposed by administrative agencies is the most widely adopted approach today (Kostka, 2016; Xie et al., 2017; Shen et al., 2019). In addition, due to the imbalance of regional environmental conditions in China and economic and social development, the stringency of environmental regulations differs in different regions (Zhang et al., 2019; Rong et al., 2023).

Under the constraints of environmental regulation, companies need to pay additional costs to ensure environmental compliance, which affects their market competitiveness (Zhao and Sun, 2016; Song et al., 2022). Hence, the impact of environmental regulation on different industries has attracted great interest in both academia and industry (Vormedal and Skjaerseth, 2020; Du et al., 2021). Currently, there are three mainstream theories regarding this issue: namely, the *traditional hypothesis*, the *Porter hypothesis*, and the *uncertainty hypothesis*. The traditional hypothesis suggests that environmental regulation has a negative impact on industry performance because high environmental standards may cause unemployment and a decline in productivity due to the additional costs incurred by environmental regulations (Conrad and Wastl, 1995; Jaffe and Stavins, 1995). Porter and Linde (1995), on the other hand, insist that environmental regulation is able to strengthen company innovation and then improve industry performance–arguing that properly designed environmental regulations can catalyze innovations, which may offset the cost of compliance costs and generate new competitive advantages (Porter and Linde, 1995). Moreover, according to Yuan and Xiang (2018) and Zhang et al. (2019), for instance, the relationship between environmental regulation and industry performance is non-linear, which should take various factors into consideration, such as innovation, capital, and industrial policies (Stavropoulos et al., 2018).

To measure the intensity of environmental regulation in different regions, studies have developed a variety of indicator systems, mainly comprising input indicators, performance-based indicators, and exponential indicators (Chen and Wu, 2018). The *input indicators* emphasize the cost paid by companies to meet environmental regulation standards, such as the investment in pollution treatment, expenditure on pollution reduction, and the cost of supervision. Chen and Cheng. (2017) measures the stringency of environmental regulation experienced by various companies by operating costs and investment in equipment related to environmental protection. In contrast, *performance-based indicators* measure the stringency of environmental regulation through the environmental outcomes of a company. Domazlicky and Weber (2004), for instance, indicate that environmental regulation can be evaluated from different types of pollution, such as $SO_2$ and $NO_x$ emissions and waste-water discharge–holding that the higher the intensity of pollutants emission, the stricter will be the environmental regulation measures taken by the government (Ravetti et al., 2016; Li et al., 2022; Yang et al., 2022). Nevertheless, some studies contend that a comprehensive indicator system should be built to better reflect the stringency of environmental regulation (Botta and Koźluk, 2014; Wang et al., 2022). Tobey (1990), for example, conducted an empirical test to measure the stringency of environmental regulation in developing and developed countries by constructing *exponential indicators* and concluded that developed countries have stricter environmental standards in pollutant emissions. In 1997, Beers et al. (1997) further enriched the exponential indicators system by adding several narrow indicators. So far, a comprehensive set of exponential indicators have been developed and widely used to measure the stringency of environmental regulation (Zhao et al., 2019).

## 2.2 Government subsides of PPP WTE incineration projects

WTE face issues such as low processing efficiency and high construction and operation costs (Batista et al., 2021). To address the problems, the National Development and Reform Commission have issued the "the Implementation Plan of Domestic Waste Classification System" and "the National Action Plan for the Prevention and Control of Environmental Pollution by Solid Waste". The government attaches great importance to the problem of waste disposal, putting it on the national agenda, and setting up special subsidies. The purpose of government subsidies is to promote enterprises to invest and innovate by providing financial support. It becomes evident that government subsidies play a pivotal role in ensuring the sustainable development of waste management (Guo et al., 2022). Government subsidies of PPP WTE incinerators refer to the money paid by local government for every tonne of MSW disposed, this is one of the most important incomes derived by PPP WTE incinerators and is of great significance in the WTE industry's development (Li et al., 2015). In contrast with electricity prices, the waste disposal subsidy in China is mainly determined through market competition and bidding, and there is no uniform standard. Table 1 lists some representative PPP WTE incineration projects and their corresponding government subsidies.

As indicated, the government subsidies vary widely between different projects, with the largest difference being almost triple. In practice, the gap in government subsidies is even more prominent. Relevant research reveals that various key factors are involved, such as location, scale of incinerator, technological innovation, and environmental regulation (Zhang et al., 2014; Chen et al., 2021). Of those, the regional urbanization level and the level of economic development are recognized as crucial factors affecting the industry's performance. Some studies show that the government subsidies in China's eastern developed areas are generally higher than the central land western regions (Zhao et al., 2016; Yu et al., 2020). Meanwhile, the scale of the incinerator can also affect the government subsidy through daily waste treatment capacity (Song et al., 2015). In addition, compared with landfill, the WTE incineration industry is an important high-tech industry and Mi et al. (2018) points out that technological innovation can effectively improve the competitiveness of WTE incinerators, which is beneficial to industry performance. There are also some studies argue that the level of regional education development is significant in shaping the attitudes and actions of local communities (Liu et al., 2018), and the construction of WTE incinerators in low socioeconomic areas would increase their operating costs.

## 2.3 Association between environmental regulation and government subsidies of PPP WTE incineration projects

Currently, environmental regulations have proved to be an increasingly leading factor in the pollution-intensive industries (Zhang et al., 2020), with three different theoretical perspectives of the effect of environmental regulations upon industry performance-the traditional hypothesis, the Porter hypothesis and the uncertainty hypothesis. However, the heterogeneity of industries means that environmental regulations may have different effects between different industries (Martin, 2010; Shen et al., 2019), although many studies have already explored the association between environmental regulation and such pollution-intensive industries as the chemical industry (Wang et al., 2015) and sewage treatment (Khaliq et al., 2017), little attention in the literature has been paid to the PPP WTE incineration industry.

Over the past decade, to further develop the PPP WTE incineration industries, the Chinese government has issued a series of environmental regulations. In particular, in 2012, the "*Notice of the National Development and Reform Commission on*

**TABLE 1 The government subsidies of representative PPP WTE incineration projects.**

| Year | Province | Projects | Subsidies (CNY/t) |
|---|---|---|---|
| 2017 | Fujian | The Nanping PPP WTE incineration Plant | 76 |
| 2017 | Guangdong | The Xuwen BOT WTE incineration Plant | 80.5 |
| 2016 | Guizhou | The Qingzhen PPP WTE incineration Plant | 142 |
| 2017 | Jiangsu | The Jiangdu PPP WTE incineration Plant | 85 |
| 2017 | Jiangxi | The Yingtan PPP WTE incineration Plant | 68 |
| 2017 | Shandong | The Wendeng PPP WTE incineration Plant | 52 |
| 2014 | Zhejiang | The Hangzhou Jiufeng PPP WTE incineration Plant | 108 |

**TABLE 2 Definitions of the independent variables.**

| Type | Variable | Name | Definition |
|---|---|---|---|
| Independent variable | WW | Wastewater discharge intensity | Wastewater discharge intensity = Wastewater quantity/GDP |
| | WG | Waste gas emission intensity | Waste gas emission intensity = $SO_2$/GDP |
| | SW | Solid waste's comprehensive utilization rate | Solid waste's comprehensive utilization rate = utilization of solid waste/production of solid waste |

*Adjusting Electricity Prices* (*No. 801 [2012]*)" standardized the benchmark price of electricity sold by the industry. Now that electricity sales income is stable and the scale of PPP WTE incineration projects is clear, government subsidies have a key role in determining project performance (Zhao et al., 2016; He and Lin, 2019).

Given the above, the impact of environmental regulations on the PPP WTE incineration industry, especially on the government subsidies of incinerators, is a problem that deserves much attention. And importantly, as mentioned earlier, the impact of environmental regulations on industry performance involves three different theoretical perspectives with abundant research, which can provide a reference in revealing the underlying mechanism behind environmental regulation and the government subsides of PPP WTE incineration projects.

# 3 Methodology

A multiple regression model based on panel data is used to investigate the influence of different stringent environmental regulations on government subsidies of PPP WTE incineration projects and their underlying mechanisms. Panel data is used as it can not only show information and dynamic changes, but also reveal differences between subjects, which is beneficial to describe subject behaviors (e.g., Balestra and Nerlove, 1966; Mundalk, 1978).

## 3.1 Variable selection and measurement

Government subsidies are taken as the dependent variable, while environmental regulation serves as the main independent variable. The research is conducted at the provincial level. Considering data availability and industry heterogeneity, a performance-based indicator is used–the ratio of pollution charge to regional value-added—as the representative variable to define and measure the stringency of environmental regulations. Three typical pollution types of the WTE incineration industry are selected: namely, wastewater, $SO_2$ (representing waste gas), and solid waste (Olsthoorn et al., 2001; Boyd et al., 2002). Table 2 provides the definitions of the independent variable involved.

To ensure the accuracy of the results, some vital factors which influence the association between environmental regulations and government subsidies of PPP WTE incineration projects need to be controlled for. These include the urbanization rate (UR) and average urban GDP (AGDP), which reflect the level of social/economic development, respectively; and regional technological R&D (RD), representing regional innovation ability. Those three key factors are selected based on Stavropoulos et al. (2018), Zhang et al. (2017), and Piao and Lin. (2020). Table 3 provides the specific definitions of the variables involved.

## 3.2 Model setting

The square term of environmental regulation comprehensive index is employed to ascertain the presence of a nonlinear relationship between environmental regulation and government subsidies. And the logarithmic form of the variables is helpful to avoid heteroscedasticity and linearity problems. The model is

$$\ln GSI = C + \ln ER_{it} + \ln \overset{2}{ER}_{it} + \ln UR_{it} + \ln AGDP_{it} + \ln RD_{it} + \varepsilon \quad (1)$$

where i and t signify a city (i = Hangzhou, . . . , xxx) and the year (t = 1, 2, . . . , xxx), respectively. C is a constant term and $\varepsilon$ is the error term. lnGSI represents the logarithm of the government subsides of PPP WTE incineration projects. lnUR represents the logarithm of

**TABLE 3 Variable definitions.**

| Type | Variable | Name | Definition |
|---|---|---|---|
| Dependent variable | GSI | Government subsides of PPP WTE incineration projects | The tender price of PPP WTE incineration projects |
| Independent variable | ER | Comprehensive environmental regulation indicator (%) | Measured in Table 2 |
| Control variable | UR | Urbanization rate | Urbanization rate = urban population/total population |
| | AGDP | GDP *per capita* | GDP *per capita* = GDP/number of people |
| | RD | Proportion of R&D expenditure to urban GDP | Proportion of R&D expenditure to urban GDP = R&D expenditure/GDP |

the comprehensive environmental regulation indicator. lnAGDP represents the logarithm of the urbanization rate. lnRD represents the logarithm of the proportion of R&D expenditure to urban GDP.

## 3.3 Sample selection and data collection

By the end of 2017, there were 286 PPP WTE incineration plants distributed in more than 180 cities in China (Lee et al., 2020). In order to ensure the study's accuracy and credibility, the samples were screened according to the following inclusion criteria:

(1) Before 2013, the benchmark price of electricity sold by incinerators was not standardized, which may affect the government subsidies of incinerators (Arias and Beers, 2013). Thus, to improve the accuracy of this study, the WTE incinerators established before 2013 were excluded.
(2) To obtain a complete set of urban pollutant emissions data, WTE incinerators that lack official city-scale pollutant emission data in provinces (autonomous regions) such as Yili and Hotan in Xinjiang are excluded.
(3) In China, especially in some large cities or municipalities, a minority of WTE incinerators (such as the Hangzhou Jiufeng PPP WTE Incineration Plant) were built in accordance with European standards instead of national standard (Liu et al., 2019). In such cases, stricter emission standards are usually adopted, which cannot accurately reflect the national emission standards. Thus, WTE incinerators that do not match the requirement of local regional environmental regulation are excluded.
(4) In China, competition in the WTE incinerator market is becoming increasingly fierce, and few investors enter the PPP WTE incinerator market with a low-price competition strategy (Song et al., 2017). For example, in 2017, the Jiangsu Gaoyou PPP WTE incinerator's tender price was CNY 26.5/t, which is far lower than its actual cost price. For the accuracy of this study, WTE incinerators with abnormally low data are therefore omitted, together with those with very low government subsidies of less than CNY 30/t.

According to these standards, a total of 81 PPP WTE incineration projects established in 66 cities in China from 2013 to 2017 are taken to be a valid sample. The panel data at the regional urbanization level, regional economic, and social development level are derived from the China Statistical Yearbook (2013–2017), and the statistical bulletin of national economic and social development in various regions. The environmental regulation data are derived from the China Environmental Statistics Yearbook (2013–2017) and National Bulletin of environmental statistics. The data related to the government subsidies of PPP WTE incineration projects are primarily derived from the China Public Private Partnerships Center, E20 Environment Platform, and E20 Institute of Environment Industry. Data that cannot be obtained through the above channels are usually obtained by telephone contact with specific incinerators.

**TABLE 4 Variable descriptive statistics.**

| Variable | Mean | Std. Dev | Min | Max |
|---|---|---|---|---|
| GSI | 4.18 | 0.27 | 3.43 | 4.74 |
| WW | 0.97 | 0.88 | −1.11 | 2.87 |
| WG | −6.73 | 1.05 | −10.23 | −4.25 |
| SW | 4.46 | 0.24 | 3.03 | 4.61 |
| UR | 4.01 | 0.29 | 3.34 | 4.55 |
| AGDP | 10.96 | 0.55 | 9.73 | 11.94 |
| RD | −1.08 | 0.89 | −2.63 | 1.75 |

## 3.4 Data processing

The data (see Supplementary Material) are processed in three steps. First, stationery checking is carried out to analyze whether the whole data meets the panel data standard. Second, the endogenous problem is tested, excluding the endogenous problems of the core explanatory variables and the explained variables. Third, the multiple linear regression model, widely used in sociological research, is used to verify the impact mechanism of environmental regulation on the government subsidies. Fourth, a robustness analysis is conducted to test the reliability of the results of the multiple linear regression model and to verify the influence of environmental regulation on the PPP WTE incineration industries.

# 4 Results

## 4.1 Descriptive statistics of variables

Table 4 provides the descriptive statistics of the variables, showing there are significant differences between the minimum

**TABLE 5 Test results of the stationarity analysis.**

| Variable | Intercept term | | Intercept term and trend term | | No intercept term and no trend term | |
|---|---|---|---|---|---|---|
| | LLC | PP | LLC | PP | LLC | PP |
| | Same root hypothesis | Hetero root hypothesis | Same root hypothesis | Hetero root hypothesis | Same root hypothesis | Hetero root hypothesis |
| lnGSI | −9.473 | 18.421 | −9.934 | 18.421 | −10.646 | 263.391 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| lnER | −8.647 | 18.421 | −9.330 | 18.421 | −9.369 | 263.391 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| $ln^2ER$ | −7.635 | 18.421 | −7.974 | 18.421 | −9.383 | 263.391 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| lnWW | −10.135 | 18.421 | −10.600 | 18.421 | −11.881 | 263.391 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| lnWG | −6.375 | 18.421 | −6.325 | 18.421 | −9.835 | 263.391 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| lnSW | −4.459 | 18.421 | −4.123 | 18.421 | −8.878 | 263.391 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| lnUR | −10.070 | 18.421 | −10.702 | 18.421 | −12.060 | 263.391 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| lnAGDP | 15.147 | 18.421 | 15.003 | 18.421 | −6.844 | 263.391 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| lnRD | −4.435 | 18.421 | −4.177 | 18.421 | −8.426 | 263.391 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |

Note: the values in brackets indicate the corresponding estimated *p*-value.

and maximum of all variables, as expected, therefore, there are sizeable differences in the indicators between different projects.

## 4.2 Endogenous analysis

In this study, the causal relationship between environmental regulation and government subsidies could potentially be bidirectional, thus requiring a further examination of endogeneity. In endogenous testing, other control variables are treated as exogenous. Accordingly, Hausman test was conducted by using Stata17 software to check the endogeneity in the model.

In particular, three instrumental variables (Martens et al., 2006) were identified: air circulation coefficient, PM2.5 index, and urban wastewater discharge. If the null hypothesis is rejected ($p$-value <0.1), it suggests that environmental regulation is an endogenous explanatory variable. Conversely, if the null hypothesis is not rejected, it indicates the absence of endogeneity issues (Chetty et al., 2014). The results of the Hausman test showed the $p$-value of 0.2171, which is greater than 0.1. Therefore, it can be concluded that ER is not an endogenous variable, and there is no endogeneity in the model.

In addition, it is necessary to conduct an overidentification test and a weak instrument test on the three instrumental variables to examine their validity and reliability. In the overidentification test, if the $p$-value corresponding to the Sargan-Basman statistic is greater than 0.05, it indicates that all instrumental variables are exogenous and effective. Otherwise, they are considered ineffective. In this study, the results of over identification test reveals that the Sargan (score) chi2 (2) = 1.35774 ($p$ = 0.5072), with a $p$-value greater than 0.05, indicating that the instrumental variables are effective.

In the weak instrument test, if the probability value of the statistic obtained after using the "estat firststage" command is less than 0.05, it suggests that the instruments are appropriate. Otherwise, there may have the problem of weak instruments (Hahn et al., 2011). As a result, Shea's partial R-squared is 0.0269, which is less than 0.05, suggesting that the instrumental variables are appropriate for the model.

## 4.3 Stationarity analysis

Table 5 summarizes the unit root test results of panel data stationery analysis, showing all variables to be highly significant irrespective of the inclusion of the intercept term, intercept term and trend term, or no intercept term and no trend term. The sample

**TABLE 6 Results of the multiple regression analyses.**

| Variables | (1) GSI | (2) GSI |
|---|---|---|
| lnER | 0.466* | 0.988* |
| | (0.124) | (0.226) |
| $ln^2ER$ | | −0.656* |
| | | (0.415) |
| lnUR | 0.377* | 0.500* |
| | (0.098) | (0.116) |
| lnAGDP | 0.079 | 0.034 |
| | (0.037) | (0.038) |
| lnRD | −0.386* | −0.541* |
| | (0.025) | (0.032) |
| Constant | −0.494 | 0.193 |
| | (0.218) | (0.320) |

Note: *, **, *** indicates significance at the 5%, 1% and 10% level, respectively; the values in brackets indicates the standard deviation.

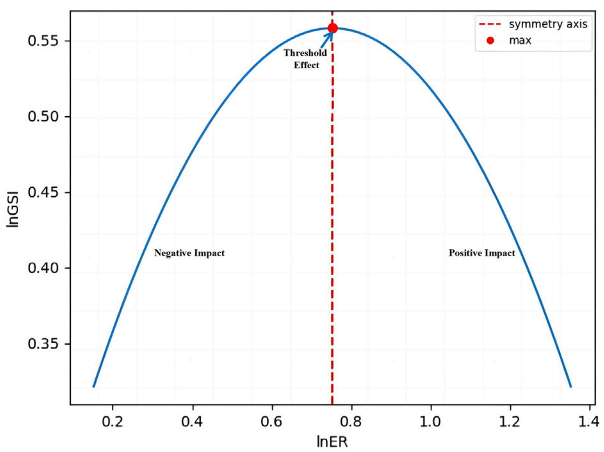


**FIGURE 1**
Schematic diagram of the model results.

data, therefore, meets the requirements for panel data regression analysis.

## 4.4 Multiple regression analysis

Table 6 presents the results of the linear and non-linear multiple regression analyses, showing that the linear coefficient of environmental regulation is 0.466, indicating that environmental regulation has a significant positive effect on the government subsidies, i.e., the stricter the environmental regulation, the higher the government subsidies.

Table 6 also shows that the primary term coefficient of environmental regulation is positive. In contrast, the quadratic term coefficient is negative, both of which are significant at the 5% level, indicating the impact of environmental regulation on government subsidies is not a simple linear relationship, but an "inverted-U" relationship, as shown in Figure 1.

**TABLE 7 Robustness test based on multiple control variables.**

| Variables | (1) GSI | (2) GSI |
|---|---|---|
| lnER | 0.302* | 0.157* |
| | (0.172) | (0.093) |
| $ln^2ER$ | | −0.423* |
| | | (0.153) |
| lnUR | 0.386* | 0.333* |
| | (0.103) | (0.104) |
| lnAGDP | 0.064 | 0.056 |
| | (0.036) | (0.035) |
| lnRD | −0.334* | −0.295* |
| | (0.028) | (0.029) |
| lnDC | 0.019 | 0.013 |
| | (0.088) | (0.087) |
| lnEDU | −0.340* | −0.335* |
| | (0.100) | (0.099) |
| Constant | 0.608 | 0.533 |
| | (0.235) | (0.236) |

## 4.5 Robustness test

While many indicators can be used to measure the economic and social development of a region, only one is used here as a control variable. It is necessary, therefore, to verify the validity and reliability of the empirical analysis results by a robustness test. This is done by adding the control variables of incineration plant size and regional educational development (Zhou et al., 2017; Liu et al., 2018). These are proxied by the daily treatment capacity of the projects (DC) and the number of college students per 10,000 residents (EDU), respectively.

Table 7 shows the test results, indicating that the primary coefficient of environmental regulation is 0.157 and secondary coefficient is −0.423, both of which are significant at the 5% level. This demonstrates the relationship between environmental regulation and government subsidies to be still an "inverted-U" shape. The robustness test results of control variables UR, AGDP, and RD are also consistent with those in Table 6, and measurement results are therefore reliable.

# 5 Discussion

The multiple regression analysis results show that environmental regulation and government subsidies of PPP WTE incineration projects have an "inverted-U"-shaped relationship: environmental regulation first has a negative impact on government subsidies, that subsequently turns into a positive impact. When environmental regulation is lax, the projects' government subsidies have an upward trend; when environmental regulations are stringent, there is a downward trend. These results are consistent with the uncertainty hypothesis that environmental regulation has an uncertain impact on industry performance (Tan et al., 2017; Yuan and Xiang, 2018).

As described, the government subsidies of PPP WTE incineration projects can be regarded as a kind of "product/service price" paid by the local government (buyer), which is determined by market competition and bidding to attract the private sector (provider) to invest, construct, and operate the incineration plant. In general, from an industrial market perspective, high government subsides of projects means that the industry has insufficient ability to offer a superior "product", reflecting the industry's low performance level (Wang and Shen, 2016). Thus, due to the significant role of government subsides of PPP projects in reflecting the WTE incineration industry, the "inverted-U"-shaped relationship between environmental regulation and government subsidies can be explained as follows.

The regression results show that environmental regulations firstly have a negative impact on the government subsidies: this is because, when environmental regulations are lax, most incineration plants are insufficiently motivated towards technological innovation and emission reduction due to the reasons given by Porter (Mbanyele and Wang, 2022). This leads to the industry weakening its competition, resulting in a high "product price" - the government subsidies of projects. As the further strengthening of environmental regulations, there is a turning point where environmental regulations no longer has a negative impact on government subsidies, which has become a threshold effect. Subsequently, the decreasing trend suggests that increasing environmental regulation after the turning point reduces the amount of government subsidies. According to Stavropoulos et al. (2018), strict environmental regulation can downsize the capital stock and modernize the machines, leading to an average increase in productivity and, ultimately, result in the reduction in the "product price".

Indeed, the threshold effect in this study has a deeper reason. Be specific, China is currently undergoing a transition towards a novel form of industrialization, which is characterized by a win-win balance between economic advancement and environmental protection (Wang and Feng, 2021). The development of industries is normally considered in the formulation of environmental regulation. The famous concept of "cost effect" pointed out that during the initial stage of industrial development, environmental laws and regulations tend to raise the cost of pollution control for enterprises (Song et al., 2021). Consequently, the government may control energy-saving and emission-reduction measures to ensure the sustainable development of the environment (Lin and Zhu, 2019). Even in the absence of significant technological innovations, pollution-intensive enterprises inevitably incur certain pollution control costs. As environmental regulation becomes more stringent, a turning point is reached where the high cost of pollution control starts to impede normal project operations (Porter and Linde, 1995). At this time, some enterprises are compelled to invest in technological innovation to improve project operational efficiency, thereby reducing pollution control costs (Yin et al., 2022). The arrival of the turning point hinges on a project's capacity to withstand increasingly stringent environmental regulations. Enterprises with weaker resistance will encounter the turning point earlier, while those with stronger resistance will delay the arrival (Zeng et al., 2022). However, given the continual escalation of environment regulation, the arrival of the turning point is inevitable.

At present, due to China's unique circumstances, WTE incineration projects stand as the primary waste treatment method. According to our research findings, as the environmental regulations become more stringent and a threshold effect is reached, these enterprises engage in technological innovation within their projects. This innovation serves to lower the costs associated with pollution control, ultimately enabling businesses to attain greater economic returns. However, the existing incineration technologies still come with certain environmental costs, including contributions to the greenhouse effect and air pollution (Tait et al., 2020; Cudjoe and Acquah, 2021). As these environmental costs contribute to mount, health-related expenses also rise. Therefore, in line with the government's implementation of environmental regulations, it is imperative for relevant authorities to reasonably adjust the intensity of subsidies for corporate innovation and guide businesses towards more environmentally innovative development. Also, enterprises should increase technological innovation and adopt eco-friendlier waste treatment methods. Promising options include drawing upon international experiences in anaerobic digestion (Anukam et al., 2019) and aerobic composting (Tran et al., 2021) technologies. The aim should be to achieve a balance between environmental and economic benefits.

# 6 Conclusion and policy recommendations

Taking the allocation of 81 PPP WTE incineration projects in 66 cities in China as the unit of research, this study aimed to explore the mechanism behind the impact of environmental regulations on the subsidies of PPP WTE incineration projects using multiple regression models. The results show that the relationship between environmental regulation and the subsidies is an "inverted-U″ shape. With the strengthening of environmental regulation, the subsidies tend to first rise and then fall. Furthermore, before crossing the inflection point, the higher the intensity of environmental regulation, the higher the government subsidies; when the regulation intensity reaches a high level or exceeds a certain threshold value, continuing to increase the environmental regulation intensity promotes the project's technological innovation, and then reduces the subsidies. This conclusion is consistent with the uncertainty hypothesis in the related theories of environmental regulation; that is, the effect of environmental regulation on the government subsidies is non-linear.

These findings suggest the following environmental regulation policy implications.

(1) In the stage of positive impact, the government needs to centrally manage resources, and hence guide and integrate the advantages of regional companies to strive to maximize operational efficiency (Jones et al., 2010; Zhao et al., 2015). The PPP WTE incinerators need to further adopt advanced management methods and update technology and equipment to achieve sustainable long-term development.
(2) In the negative impact stage, the government should support and guide the WTE incineration industry with well-designed policies. Additionally, through the establishment of a good order of the market and using scientific administrative methods to reduce the environmental cost of companies, the government can accelerate technology innovation in companies, especially newly started incineration plants in the central and western regions of China, so as to help them quickly pass through the negative impact stage of environmental regulation (Zhu et al., 2014; Yasmeen et al., 2020). On the other hand, the PPP WTE incinerators need to enhance their anti-risk ability. It is meaningful for incinerators, whether large, medium, or small in size, to give full play to their own advantages, as well as the adoption of diversified development strategies in combination with multi-field advantages.

This study is beneficial for both the public and private sectors in fully understanding the impact of environmental regulation on the WTE incineration industry. Furthermore, it proposes strategic suggestions for companies to meet the change of environmental regulation intensity, and also provides a reference for the government to guide the development of regional companies. Additionally, it accelerates the sustainable development of the WTE incineration industry and establishes a foundation for further associated scientific research in China. Therefore, clarifying the mechanism influencing environmental regulation on the government subsidies of PPP WTE incineration projects will make considerable contribution to the industry's sustained and healthy development.

Although the effect of environmental regulation on the government subsidies is verified empirically, only projects established during 2013–2017 were selected, and thus more cases need to be studied in the future. Moreover, more studies are required in order to explore other control variables involved in the issues affecting government subsidies of the PPP WTE incineration industries.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

## Author contributions

YS: Formal Analysis, Software, Writing–original draft. MX: Data curation, Investigation, Resources, Writing–original draft. CC: Writing–review and editing. BX: Software, Visualization, Writing–review and editing. MS: Methodology, Supervision, Validation, Writing–review and editing. MM: Conceptualization, Validation, Writing–review and editing. YL: Conceptualization, Funding acquisition, Methodology, Project administration, Writing–original draft.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.



## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1288851/full#supplementary-material

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