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CASE STUDY

Spatial characteristic of environmental protection businesses: a study of A-Share Listed Environmental Companies in China

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Abstract

China's cross-border pollution problem has attracted a growing level of attention from the domestic and international community. The elimination of environmental pollution greatly depends on professional environmental protection companies. China's environmental protection industry has sustained a rapid growth with 26.9% annual growing rate of output value since 2011. To effectively discover the potential investment fields and regions, this study examines the spatial distribution of 53 A-Share Listed Environmental Companies (ASLEC) in China and their 927 subsidiaries. Methods of hot spot analysis, Pearson's correlation analysis and coarsened exact matching were employed in our paper to reveal the spatial distribution characteristics of environmental protection industry and their main influencing indicators. Results show that ASLEC invested over US$ 13 billion distributed in 210 cities in China in 2017. Treatment of wastewater and municipal solid waste related to traditional water supply, drainage and sanitation are the main businesses of the environmental protection industry in China. This is because these businesses belong to conventional urban municipal works with low technological requirement and high economic return. Therefore, the government should support those environmental protection businesses with fine technology, such as air pollution prevention and industrial waste control. Our study also reveals that there is a strong and positive correlation between municipal indicators and environmental protection investment. This indicates that the municipal works attract much more investment of environmental protection companies than heavy industries. The eastern region of China remains a hot spot for investment whereas the investment in the western region increased significantly in 2017. The potential of future development will be located in the central and western regions. For serious air pollution and large-scale industrial transfer from eastern regions to the central and western regions in China, there is lack of industrialization environmental protection capacity to fulfill the ambitious national pollution reduction target. This opportunity implies to attract more investments from international environmental protection companies.

Keywords A-Share Listed Environmental Companies · Causality · Coarsened exact matching · Correlation · Hot spot

1 Introduction

Environmental pollution and health challenges in China have attracted global attention. For example, PM2.5 pollution alone was linked to 3.45 million premature deaths worldwide in 2007. Moreover, PM2.5 pollution produced in China is linked to more than 64,800 premature deaths in regions other than China (Zhang et al., 2017). Environmental protection enterprises are the most direct way to deal with environmental pollution by means of treating pollutants in air, soil and water. China's environmental protection industry has developed rapidly in recent years. Statistics show that since 2011, the Chinese environmental protection industry has been growing at an average annual rate of 26.9% in terms of output value. In 2017, the sales revenue of the environmental protection industry reached US$ 200 billion, making it a "billion-level" industry in China (CAEPI, 2018). The environmental protection companies in China maintained a rapid growth due to the attention from both government and the general public. According to the "Fourth National Survey on the Basic Situation of Environmental Protection-related Industries" in China, the distribution of environmental protection-related industries in China shows a high degree of coincidence with the spatial distribution of China's economic development (Jia & Chen, 2019). The overall distribution characteristics of "one belt and one axis" are preliminarily formed, i.e., the "coastal development zone" around the Bohai Sea, the Yangtze River Delta and the Pearl River Delta, and the "development axis along the Yangtze River to Sichuan" in the central provinces from Shanghai to the Sichuan.

However, China has a wide range of territory and many western regions still lack environmental protection enterprises. Meanwhile, according to the target of government (SCPRC, 2016), the treated ratio of industrial gas emission, wastewater and municipal solid waste are required to reach 95% by each prefecture-level city in 2020. Currently, improvement is required in a large number of cities (Xu & Zhang, 2020). For example, the treated ratio of municipal solid waste in about 50 Midwest cities is under 95% (NBSC, 2017). For the treated ratio of wastewater, around 120 cities still failed to meet national targets.

The products of environmental protection industry are public goods. It is well recognized that the strict implementation of relevant laws and government policies is the key to promote the development of environmental protection industry. At present, the mainstream research focuses on the policy, regulation and technology that drive the development of environmental protection industry (Shunze, 2014; Xepapadeas & Zeeuw, 1999; Yunze, 2011; Zhang & Shang, 2010). The research on environmental protection investment mainly focuses on three aspects: investment subject, investment channel and mode, investment structure and efficiency (Bruvoll, 1998; Ling, 2013; Wu et al., 2015). However, very few studies have focused on understanding the investment demand of urban areas for environmental protection industries. Market demand is indeed the fundamental driver for the development of environmental protection industry.

In this paper, firstly, following the bottom-up approach, enterprises' micro-data were used to study the spatial characteristics and distribution of environmental protection companies in China. Secondly, we took 210 cities as the samples to explore the correlation between the investment of environmental protection companies and potential market demand indicators, such as municipal works, emissions, population and industry indicators. These indicators are related to the environmental market demand of cities. The main indicators affecting the distribution of environmental protection industry will be identified. These findings can provide empirical evidence for policymakers to design appropriate policies to support the sustainable development of environmental protection companies. In addition, this research will help to identify the niche market to invest on environmental protection businesses.

Considering the integrity and accuracy of data in order to represent the environmental industry in China, we assessed the information of A-Share Listed Environmental Companies (ASLEC). The data were consistent, transparent and systematic for our further research. The China Association of Environmental Protection Industry (CAEPI) is one of largest non-governmental organizations of environmental protection industry in China. To conduct an in-depth spatial analysis of environmental industry, the subsidiaries of ASLEC were evaluated in this study as well. As the society becomes increasingly focused on environmental protection issues, the disclosure of information about environmental companies has increased notably in the last few years in China (CAEPI, 2015, 2016, 2017a,b). Our data collection reflected a total of 53 A-Share Listed Environmental Companies and 927 subsidiaries which covers 210 prefecture-level cities in 30 provinces. According to the financial requirements of A-Share listing, the company's net profit of the current three fiscal years is positive and the total net profit is more than about US$ 5 million (MEEPRC, 2017), and the net cash flow generated by the current three fiscal years' operation is more than US$ 8 million (CEPI, 2017). Therefore, it is reasonable to assume that major environmental company information was accurately reported, as ALSEC and their subsidiaries represent China's leading environmental companies.

With the constant and rapid industrialization of urban development, the investment of environmental protection businesses is greatly enhanced in China. However, the regional disparities in pollution features and social indicators have led to an outcome of investment regions and fields unbalanced distribution. Since there is a lack of understanding of the spatial distribution of China's current environmental protection industry, the main objective of this study is to find economical, multi-field and prefecture city-level spatial distribution characteristics of environmental protection industry, and to provide references for environmental protection industry development by using hot spot analysis. Moreover, for the first time, the Pearson's correlation coefficient and coarsened exact matching methods are adopted in this study to reveal the correlation between the investment of environmental protection companies and potential environmental market demand indicators.

2 Methods and data

2.1 Hot spot analysis

Currently, research of the hot spot analysis has been based on the following aspects: grid (Schikuta & Erhart, 1997), division of technology (MacQueen, 1967), density technology (Kulldorff, 1997), space scanning technology (Zeng et al., 2004), support vector machine technology, hierarchical clustering and spatial autocorrelation (Johnson, 1967). We calculated the Getis-Ord G_i* for each city of ASLEC using the hotspot analysis tool of ArcGIS10.2. The Getis-Ord Gi* statistic of hot spot analysis was applied to locate the environmental protection companies cluster with high ASLEC number. Those cities with high or low values of ASLEC number may occur clustering. Getis-Ord G_i* statistic can be expressed as follows (Hu et al., 2019; Johnson, 1967; Parchomenko & Borsky, 2018; Zhang et al., 2020):

$$G_i^* = \frac{\sum_{j=1}^{n} W_{i,j}X_j - \overline{X}\sum_{j=1}^{n} W_{i,j}}{s\sqrt{\frac{\left[n\sum_{j=1}^{n} W_{i,j}^2 - \left(\sum_{j=1}^{n} W_{i,j}\right)^2\right]}{n-1}}} \tag{1}$$

where *Xj* is the property value of *j*, $W_{i,j}$ is spatial weight *between* the *i* and *j*, *n* is the total number of ASLEC and its subsidiaries:

$$\overline{X} = \frac{\sum_{j=1}^{n} X_j}{n} \tag{2}$$

Given a set of weighted features, identifies statistically significant hot spots and cold spots using the Getis-Ord G_i* statistic. The result of G_i* statistic will be represented as z-scores. For statistically significant positive z-scores, the larger the z-score is, the more intense the clustering of high values (hot spot). For statistically significant negative z-scores, the smaller the z-score is, the more intense the clustering of low values (cold spot).

This method identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots) (ESRI, 2019). It creates a new output feature class with a z-score, p value and confidence level bin for each feature in the input feature class. The z-scores are measures of statistical significance which tells you whether or not to reject the null hypothesis, feature by feature (Duczmal et al., 2006; Goovaerts & Jacquez, 2004; Lezzaik & Milewski, 2014). In effect, they indicate whether the observed spatial clustering of high or low values is more pronounced than one would expect in a random distribution of those same values.

A high z-score and small p value for a feature indicate a spatial clustering of high values. A low negative z-score and small p value indicate a spatial clustering of low values (Jacquez & Greiling, 2003). The higher (or lower) the z-score, the more intense the clustering. Typical confidence levels are 90, 95, or 99 percent. A confidence level of 99 percent would be the most conservative in this case, indicating the unwillingness to reject the null hypothesis, unless the probability that the pattern was created by random chance is really small (less than a 1 percent probability). Hence, this paper mainly uses the result from hot spot analysis (z-score) of each prefecture-level city in order to give further quantitative study.

2.2 Pearson's correlation coefficient

In statistics, Pearson's correlation coefficient (Williams, 1996; Zhang et al., 2020) is one of the methods used for a broad class of relationships among variables. It is based on the covariance matrix of the data to evaluate the strength of the relationship between two vectors. Normally, Pearson's correlation coefficient between two vectors X and Y is:

$$r(X, Y) = \frac{\mathrm{cov}(X, Y)}{\sigma x \sigma y} \tag{3}$$

where *r is* Pearson's correlation coefficient, cov(X, Y) is the covariance, σx is the variance of X and σy is the variance of Y.

The absolute values of both the sample and population Pearson correlation coefficients are less than or equal to 1. Correlations equal to 1 or -1 correspond to data points lying exactly on a line (in the case of the sample correlation), or to a bivariate distribution entirely supported on a line (Catalina, 2013). The Pearson correlation coefficient is symmetric: r(X, Y) = r(Y, X). In correlation analysis, we chose 15 urban statistical influencing indicators that may affect the market demand of environmental protection enterprises and the Pearson's correlations coefficient between the investment and these indicators were applied.

2.3 Coarsened Exact Matching (CEM)

The basic idea of CEM is to coarsen each variable by recoding so that substantively indistinguishable values are grouped and assigned the same numerical value (Iacus et al., 2012). Then, the "exact matching" algorithm is applied to the coarsened data to determine the matches and to prune unmatched units. Finally, the coarsened data are rejected and the original (uncoarsened) values of the matched data are retained.

After coarsening, the CEM algorithm generates a set of strata, said s $\in$ S, each with same coarsened values of **X**. Units in strata that contain at least one treated and one control unit are retained; units in the remaining strata are removed from this sample. We denote by T^s the treated units in stratum sand by $m_T^s = T^s$ the number of treated units in the stratum, similarly for the control units, that is,C^s and $m_C^s = C^s$. The number of matched units are, respectively, for treated and controls,$m_T = \cup_{s\in S} m_T^s$ and $m_C = \cup_{s\in S} m_C^s$. To each matched unit i in stratum s, CEM assigns the following weights (Blackwell et al., 2009):

$$w_i = \begin{cases} 1, & i \in T^s \\ \frac{m_C m_T^s}{m_T m_C^s}, & i \in C^s \end{cases} \tag{4}$$

Unmatched units receive weight $w_i = 0$.

CEM therefore assigns to matching the task of eliminating all imbalances (i.e., differences between the treated and control groups) beyond some chosen level defined by the coarsening. Imbalances eliminated by CEM include all multivariate nonlinearities, interactions, moments and other distributional differences beyond the chosen level of coarsening (Iacus et al., 2011). The remaining differences are thus all within small coarsened strata and so are highly amenable to being spanned by a statistical model without risk of much model dependence.

2.4 Data

The ASLEC income data were collected mainly by the China Association of Environmental Protection Industry (CAEPI, 2018). Besides, the subsidiaries investment data and geographical location of the ASLEC (parent companies) in 2017 were collected from "Tianyancha database" (Tianyancha, 2018). Tianyancha database has included more than 180 million social entity information based on the open data. It is the largest search engine for business survey in China. Furthermore, we chose 15 urban statistical indicators that relate to the businesses of environmental protection enterprises in each prefecture-level city from China's Urban Statistical Yearbook (NBSC, 2017). The description of these 15 indicators is presented in Table 1.

Table 1 The urban statistical indicators relate to the businesses of environmental protection enterprises and all indicators are for city level

Indicator category	NO.	Urban statistical indicators	Abbreviation	Unit	Explanatory notes
General economy and society	1	Per capita GDP	GDP	China Yuan	The Gross Domestic Product (GDP) per capita (per person)
	2	Annual average population	AAP	10,000 persons	The total volume of the population
Municipal works	3	Total electricity supply	TES	10,000 kWh	The total volume of electricity provided for residents and industry
	4	Total gas supply	TGS	10,000 cubic meters	The total volume of gas provided by gas-producer
	5	Total water supply	TWS	10,000 tons	The total volume of water provided by water-producer
	6	Residential gas consumption	RGC	10,000 cubic meters	The total volume of gas consumed by the resident
	7	Residential water consumption	RWC	10,000 tons	The total volume of water consumed by the resident
Industry	8	Industrial output value	IOV	10,000 China Yuan	The final industrial products and services at market prices produced by industrial enterprises
	9	Industrial electricity consumption	IEC	10,000 kWh	The total volume of electricity consumed by the industry
	10	Industrial wastewater discharge	IWD	10, 000 tons	The aggregate of wastewater discharged to outsides through all factory drains by industrial enterprises
	11	Industrial water consumption	IWC	10,000 tons	The total volume of water consumed by the industry
Environmental	12	Emission of soot and dust for industrial	ESDI	ton	The aggregate of industrial soot and dust emission
	13	Emission of sulfur dioxide	ESD	ton	The total Emission of Sulfur Dioxide
	14	Ratio of municipal solid waste treated	RMS	%	The percentage ratio of municipal solid waste be treated
	15	Ratio of wastewater centralized treated of sewage work	RWC	%	The ratio of treated by wastewater treatment plants to reach the quantity

3 Results

3.1 Structural analysis of A-Share Listed Environmental Companies

We analyzed the time series data of major 53 environmental companies listed on A-Share in China from 1984 to 2012. Figure 1 shows that the year of 1992 and 2002 are the turning point for the entire environmental industry. Over 90% of ASLEC were founded, after 1992. Only 5 ASLECs were established before 1992. On average, 0.55 ASLEC were established per annum from 1956 to 1992. From the beginning of 1992, the trend of establishment of environmental companies was rapidly increasing until 2002. The average growth rate of ASLEC establishment from 1992 to 2002 was 3.7 percent per annum. After the year of 2002, it can be observed that the trend began to enter a stationary period and the average growth rate of ASLEC establishment was 0.9 percent per annum. These results showed that major leading enterprises in China's environmental protection industry were established at the beginning of this century.

The total environmental business income of ASLEC for 2017 is over US$ 15,000 million. According to Fig. 2, the environmental protection business income of municipal solid waste companies had the greatest proportion, owning more than 33%. However, the number of municipal solid waste companies only accounted for 19%. This indicated that the average income per company for municipal solid waste was higher than the other four fields. Secondly, the total income of water companies took up only 28.5% from the total proportion constituting the highest number of water companies (Fig. 2). This showed that the average income per company for water was relatively low, which is only higher than that of environmental monitoring and measuring companies. With regard to air environmental protection companies, the number of companies in all ASLECs took up 21%, and the income ratio in all ASLECs reached 24%. With less number of air companies compared to water companies, the average income per company of air environment protection is still higher than that of water environment protection (Table 2). This is the feedback from the

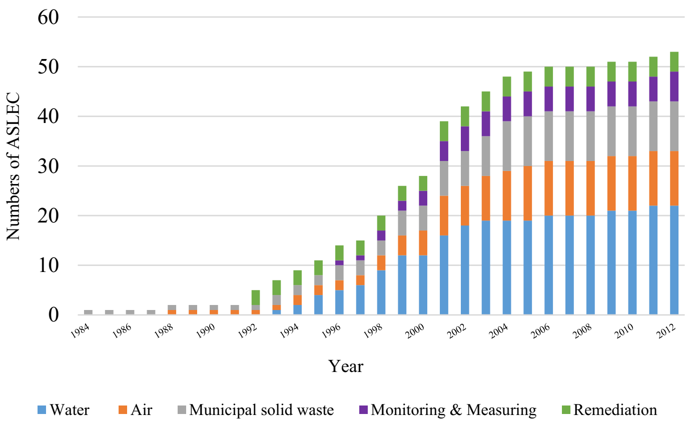

Fig. 1 The establishment time series of major 53 environmental companies listed on A-Share. According to the stock market description, the 53 ASLEC can be divided into five major fields: Water–Water environment protection companies; Air–Air environment protection companies; Municipal solid waste–Municipal solid waste environment protection companies; Monitoring & Measuring–Environmental monitoring and measuring companies; Remediation–Environmental remediation companies

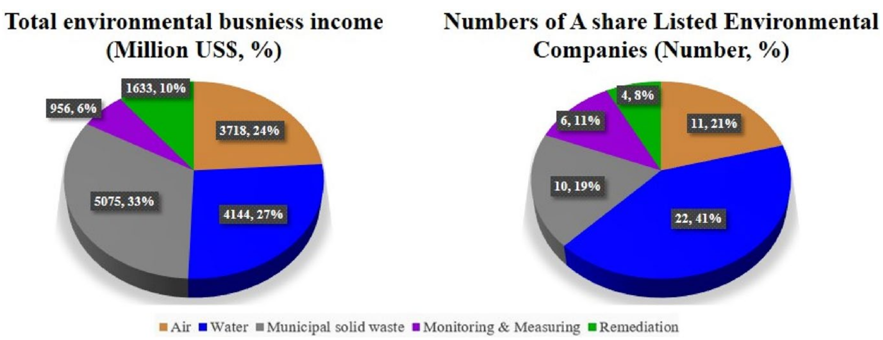

Fig. 2 The income proportion of ASLEC in 2017

Table 2 The average income per ASLEC

	Number of ASLEC	Business income (Million US$)	Income per company (Million US$)
Air	11	3718	338
Water	22	4144	188
Municipal solid waste	10	5075	508
Monitoring & Measuring	6	956	159
Remediation	4	1633	408

Table 3 The 53 environmental companies listed on A-Share and their 927 subsidiaries

	Air	Water	Municipal solid waste	Remediation	Monitoring and Measuring	Total
Parent company (ASLEC)	11	22	10	4	6	53
Subsidiaries	113	387	266	77	84	927
Average number of subsidiaries owned by each parent company	10.2	17.5	26.6	19.25	14	16
The ratio of the parent company and its subsidiaries in the same city	34.5%	17%	21%	25.9%	21.4%	25%

governments strictly established regulations of air pollution control (MEEPRC, 2017). The environmental remediation companies also reflected the same situation, although its number of companies in all ASLEC took up only 8%, and its income ratio in all ASLECs gave only 10%. In summary, these data show that the municipal solid waste companies, air environmental protection companies and environmental remediation companies have relatively good returns of investment (Table 2) and are likely to be the key areas for attracting investments in the future.

Moreover, our paper provided the statistics for 53 A-Share listed environmental companies and their 927 subsidiaries. In Table 3, the subsidiaries structure showed that the portion of water companies was the highest with 387 subsidiaries, followed by municipal solid waste and air companies with 266 and 113 subsidiaries, respectively. On the contrary, subsidiaries of the Monitoring & Measuring and Remediation accounted for the smallest portion. Furthermore, almost 25% of the subsidiaries and their parent companies are in the same city. The air environment protection companies have the largest ratio which is above 34.5%. According to the statistical data of subsidiaries, the water and municipal solid waste companies occupy the main market of environmental protection industry, especially for municipal solid waste companies, and the average number of subsidiaries owned by each parent company could reach 26.6. This result further demonstrates the expansion potential of municipal solid waste companies.

3.2 Spatial distribution characteristics

This study mapped the spatial location of parent companies and subsidiary companies. The investment of subsidiaries is set as the linkage indicator between parent company and subsidiary company (Fig. 3). The 53 parent companies and their 927 subsidiaries are distributed in 210 cities in China. Most parent companies are located in the coastal area. The Beijing–Tianjin, Yangtze River Delta Urban Agglomeration, Chongqing–Chengdu and Shenzhen are the four regions with the largest number of parent companies. Most parent companies are in these four regions. The subsidiaries of parent companies in Beijing–Tianjin cover the broadest scope. According to the investment statistics for 2017 (Tianyancha, 2018), in the region of Beijing–Tianjin, US$261million was invested in the water corporations with 134 subsidiaries which had the largest investment and number of subsidiaries in the four key regions. For the Yangtze River Delta, municipal solid waste companies

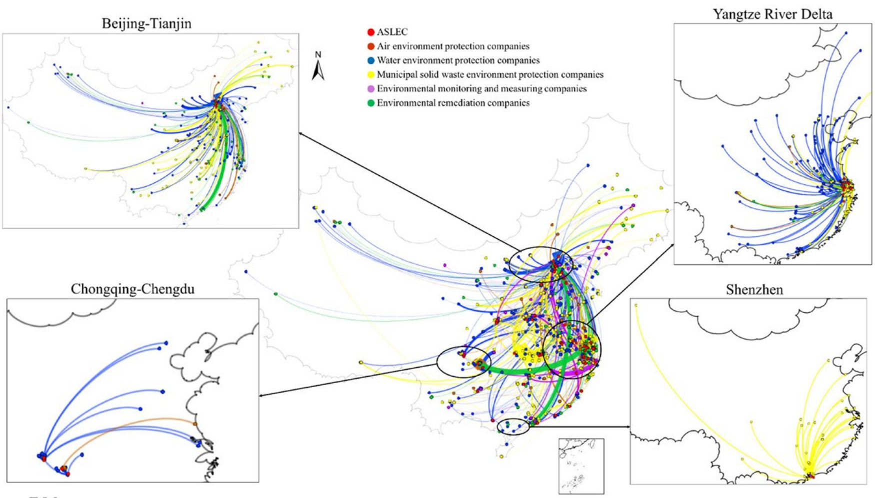

Fig. 3 The prefecture-level city investment network of ASLEC and its subsidiaries. The red nodes represent the locations of ASLEC. The size of an edge represents the investment between ASLEC (parent companies) and its subsidiary. A thick sized edge indicates that more money was invested. The color of a node indicates the field of environmental protection company it belongs to. The edge color is determined by the color of the subsidiary nodes. To give a clear illustration of Fig. 3, the investment of ASLEC area from Beijing–Tianjin, Yangtze River Delta, Chongqing–Chengdu and Shenzhen was amplified

had invested 943 million which covered over 45% of total investment in Yangtze River Delta. Next, the water-related environmental protection companies had invested roughly 580 million in Yangtze River Delta. Although the Yangtze River Delta part has more water company's investment than municipal solid waste companies, in fact, the location for most subsidiaries of municipal solid waste companies is close to the Yangtze River Delta and their total investment is more than water companies'.

For the Chongqing–Chengdu area, there were only 34 subsidiaries. However, over US$1,291 million was invested and the water corporations accounted for the largest proportion. Furthermore, Shenzhen area mainly contained 52 subsidiaries with US$1,248 million investment and the municipal solid waste companies account for the largest proportion.

The top 10 investment relationship between cities where the parent companies and their subsidiaries are located is highlighted in Table 4. Most of the investments in 2017 were focused on the treatment of municipal solid waste. The major investment paths are from the eastern regions to central or western regions in China.

Irrespective of number or the investment, hot spot analysis (Figs. 4 and 5), the cities with the highest z-score are concentrated in a few urban agglomerations, such as in Yangtze River Delta urban agglomeration, Beijing and surrounding cities. As shown in the number hot spot map (Fig. 4 (a)–(e)), the Chongqing–Chengdu agglomeration in the southwest of China is not the significant hot spot area. However, according to the investment hot spot map (Fig. 5 (a)–(e)), the Chongqing–Chengdu agglomeration became a worth noting area in 2017.

The spatial distribution of remediation companies is notably different from the other four types of companies. Some hot spot areas are in western China. These include Xinjiang, South of Tibet, and the part of Inner Mongolia near Beijing, because some remediation companies' business is about afforestation for restoring the arid and fragile ecological environment in western China. To amplify the hot and cold spot area in China, we also conducted the Cluster and Outlier Analysis of the number and investment volume of environmental companies (Fig. S1).

Table 4 shows that among the top 10 highest investment key paths of environmental protection company, the major investment paths are from the eastern regions to central or

Table 4 Top 10 highest investment key paths and the category of environmental protection company

Rank	Path	Investment (Million US$)	Environmental protection company
1	Shenzhen (Guangdong) → Jingmen (Hubei)	518	Municipal solid waste
2	Wuxi (Yangtze River Delta) → Chongqing	217	Remediation
3	Ningbo (Yangtze River Delta) → Nanchang (Jiangxi)	182	Monitoring & Measuring
4	Beijing → Changsha (Hunan)	145	Municipal solid waste
5	Beijing → Zhongshan (Guangdong)	137	Remediation
6	Beijing → Baoding (Hebei)	107	Municipal solid waste
7	Beijing → Cangzhou (Hebei)	98	Water
8	Anqing (Yangtze River Delta) → Beijing	94	Municipal solid waste
9	Shenzhen (Guangdong) → Yichun (Jiangxi)	88	Municipal solid waste
10	Shenzhen (Guangdong) → Wuhan (Hubei)	85	Municipal solid waste

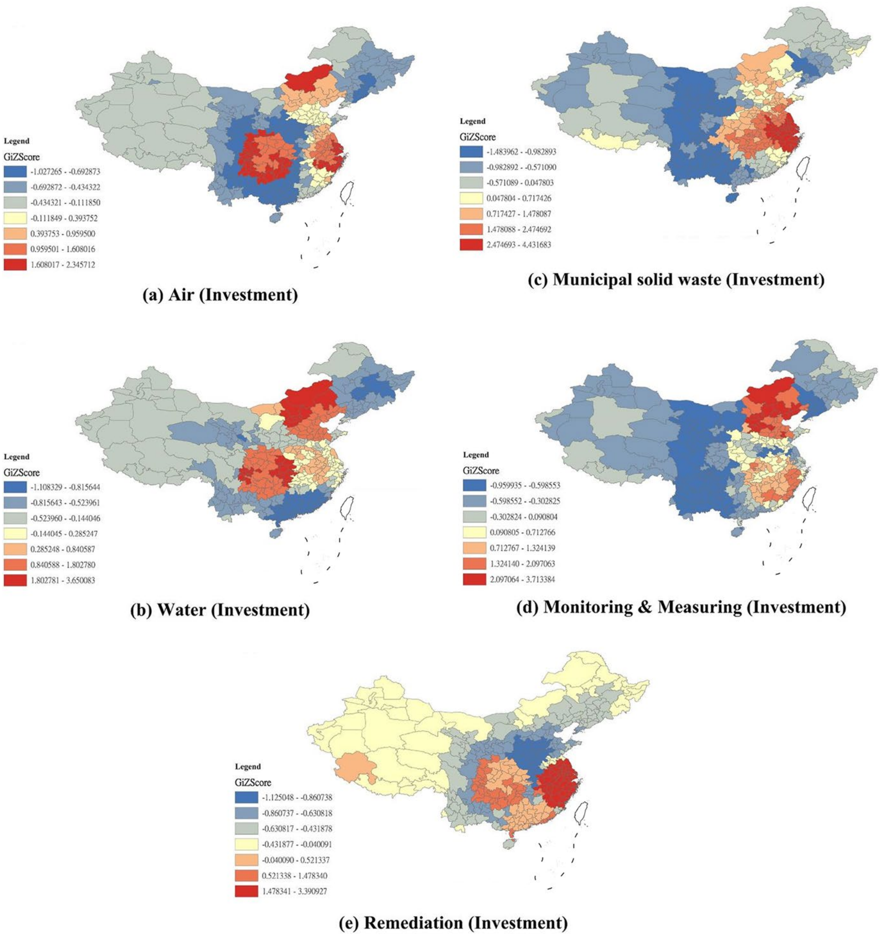

Fig. 4 The hot spot analysis of environmental companies' number. The result of Gi* statistic is represented as z-scores. For statistically significant positive z-scores, the larger the z-score is, the more intense the clustering of high values (hot spot). For statistically significant negative z-scores, the smaller the z-score is, the more intense the clustering of low values (cold spot)

western regions in China. Also, from the hot spot analysis given in Figs. 4 and 5, it shows that the western and central regions are the cold spots in terms of environmental companies' investment and number. Thus, based on results presented in Table 4 and Figs. 4 and 5, it implies that the central and western regions have the greatest investment potential.

3.3 Influencing indicators

In order to further examine the correlations between investment and their influencing indicators, taking 210 cities as samples, we calculated the correlation matrix for the investment of the five company categories and those indicators that may affect them.

A number of indicators may affect the investment of environment companies. These indicators were analyzed from the perspective of unban market demand. According to the

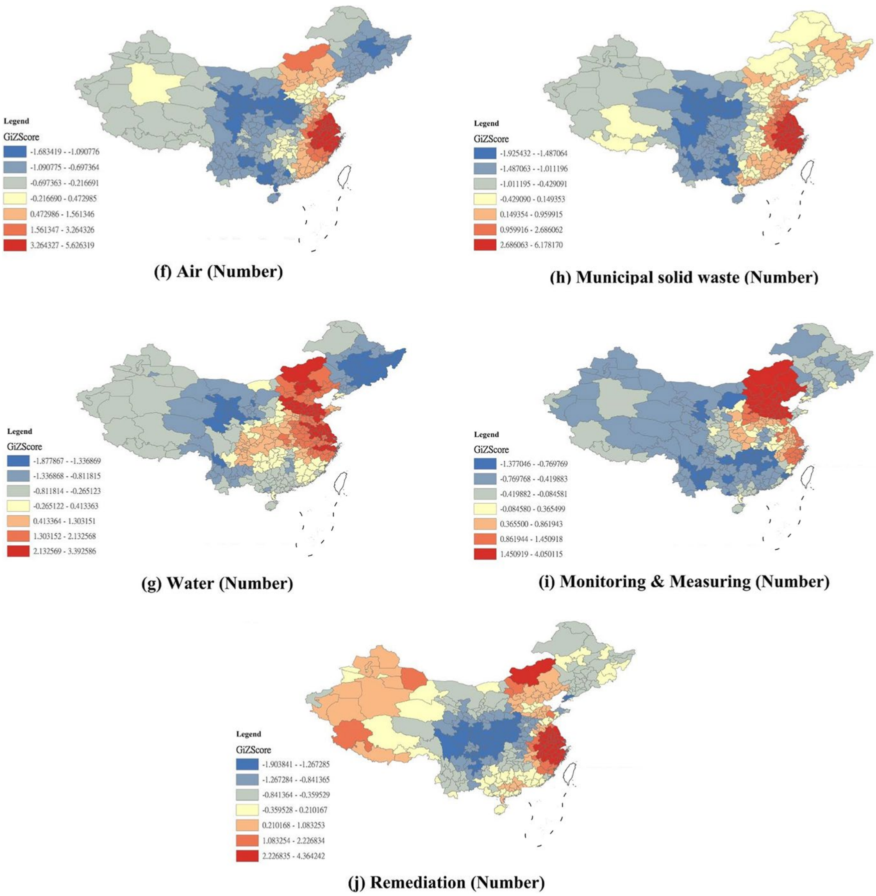

Fig. 5 The hot spot analysis of environmental companies' investment. The result of Gi* statistic is represented as z-scores

main business introduction from the 53 ASLEC in China and their 927 subsidiaries, the businesses of these environmental protection companies include water supply and drainage, sanitation for municipal solid waste, afforestation and landscaping, energy conservation and air pollution control. These businesses are related to those urban environmental and municipal works statistical indicators, such as pollutants emissions, water, gas and electricity supply and consumption for residents and industry. Moreover, some economic and social indicators may affect the investment from the macro perspective. As there are limited government statistics available to the public, we chose 15 urban statistical indicators that may relate to the businesses of environmental protection enterprises from China Urban Statistical Yearbook (NBSC 2017) according to previous analysis. The detailed description of these 15 indicators is described in Table 1. These indicators include the information of general economy and society, municipal works, industry and environment for a city from government open statistics perspective. Figure 6 presents Pearson's r correlation analysis between the ASLEC investment and all the aforementioned indicators. It shows that RGC ($r=0.736$) and TGS ($r=0.684$) are the top 2 indicators most strongly positively correlated

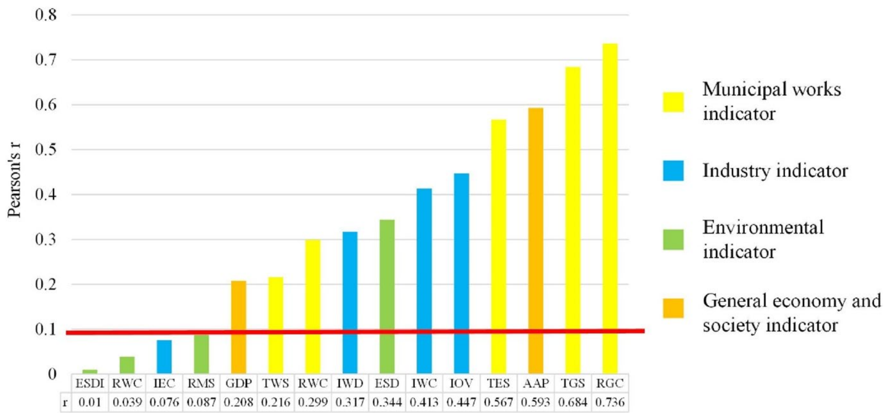

Fig. 6 The correlation analysis of different influencing indicators with ASLEC investment. The influencing indicators under the red line demonstrate that the correlation is not significant. Most of them are the environmental category. Only the IEC belongs to the industry category

with ASLEC investment and both belong to municipal works category. The Pearson's r of all five municipal works category indicators are positive and significant (Table S1). The AAP (r = 0.59) is the third strong correlated indicator which is under general economy and society category. Another indicator which belongs to general economy and society category is GDP (r = 0.20) and it is not a strong correlated indicator. The IOV, IWC, ESD and IWD indicators under industry or environmental category have Pearson's r ranging from 0.31 to 0.45 which are much less correlated with ASLEC investment than expected.

Although industry is a source of pollution that the government and the public are very concerned about, it appears that municipal works show higher correlation with investment of environmental company in most cities of China than that of industry. There are four indicators of RMS, IEC, RWC and ESDI which have no statistical relevance with the investment of environmental company. Although these industry and environmental indicators seem to be closely linked to environmental investment, the statistical result shows these indicators have little correlation with environmental investment. This is because treatment ratio indicator does not reflect the direct market demand of environmental protection. These indicators are only the environmental indicators that government is concerned about. ESDI also shows weak correlation with any environmental investment. However, the ESD has a strong positive correlation with investment from air environmental protection companies. This is because the nonmetal products sector was the largest contributor to dust, while the sulfur dioxide is emitted from power sector. Most customers who need air environmental companies are power plants. In general, we find that most indicators which Pearson's r over 0.5 are related to municipal works. It reflects the effect of municipal works category is intensely correlated to the ASLEC investment.

3.4 Inferring causality

In order to investigate the casual relationship between ASLEC investment and influencing indicators, the coarsened exact matching (CEM) method which is commonly used to infer causality in observational research is adopted in this study (Iacus et al., 2012; Catalin et al., 2015). CEM can be used to match the control and treatment groups with respect to the identified confounding indicators to eliminate the effect of these indicators on the investigating causality (AlShebli et al., 2018). The indicators of annual average population (AAP), total gas supply (TGS) and residential gas consumption (RGC) are the top 3 indicators with high value of Pearson's r for the ASLEC investment (Table S1). Therefore, three most influencing indicators of AAP, TGS and RGC are selected to be examined by CEM for inferring the causality between investment and indicators. During the test of each indicator, the other two indicators are considered as the confounding indicators in CEM analysis. This study chooses top 10% (highest value) of each indicator as the treatment group and bottom 10% (lowest value) of each indicator as the control group. The CEM process is repeated for 10%, 20%, 30%, 40% and 50% for both treatment (T) and control (C) groups of each examined indicator. In this study, TGS $_{T10}$ and TGS $_{B10}$ are denoted as the top 10% and bottom 10% of "total gas supply" indicator, respectively. Similar symbols are denoted to represent the treatment and control groups of other indicators (i.e., AAP and TGS).

After the CEM analysis, all the aforementioned three indicators are subjected to a t test to investigate the significant difference of their corresponding average ASLEC investment between the treatment and control groups. The CEM and t test results for RGC and TGS indicators are represented in Table 5.

Table 5 Coarsened exact matching of residential gas consumption (RGC) and total gas supply (TGS)

	T	T	T_{CEM}	C_{CEM}	M	P
T: RGC_{T10} C: RGC_{B10}	14	14	9	14	4.51	0.001**
T: RGC_{T20} C: RGC_{B20}	28	28	22	28	4.61	0.004**
T: RGC_{T30} C: RGC_{B30}	42	42	36	42	3.59	0.0005***
T: RGC_{T40} C: RGC_{B40}	56	56	50	56	1.99	0.0005***
T: RGC_{T50} C: RGC_{B50}	73	73	65	73	1.76	0.044*
T: TGS_{T10} C: TGS_{B10}	14	14	4	12	7.76	0.002**
T: TGS_{T20} C: TGS_{B20}	28	28	16	28	6.29	0.002**
T: TGS_{T30} C: TGS_{B30}	42	42	24	42	2.70	0.0009***
T: TGS_{T40} C: TGS_{B40}	56	56	40	56	2.86	0.0002***
T: TGS_{T50} C: TGS_{B50}	73	73	54	73	1.86	0.021*

Treatment (T) and control (C) populations are represented before CEM analysis; Treatment (T_{CEM}) and control (C_{CEM}) populations are represented after CEM analysis; M = (Average of T_{CEM} group's corresponding ASLEC investment)/ (Average of C_{CEM} group's corresponding ASLEC investment); P: p values of t test with 95% confidence interval ($CI_{0.95}$) of corresponding ASLEC investment of T_{CEM} and C_{CEM}

*** $p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Since M (Average of T_{CEM} group's corresponding ASLEC investment/Average of C_{CEM} group's corresponding ASLEC investment) for both RGC and TGS are all greater than 1, all the treatment group's average corresponding ASLEC investment is larger than the control groups'. It indicates that increasing the indicator's value gap between the treatment and control group is often resulted in a greater difference between their average corresponding ASLEC investments. The maximum treatment and control group's average corresponding ASLEC investment ratio (M) is 1.68 for indicator AAP under top 10% and bottom 10%, 4.61 for indicator RGC under top 20% and bottom 20%, and 7.76 for indicator TGS under top 10% and bottom 10%, whereas the differences for indicator RGC and TGS are all statistically significant.

Thus, the indicator RGC and TGS are the major influencing indicators for the ASLEC investment compared with other investigated indicators, whereas the CEM results of difference between treatment and control group's average corresponding ASLEC investment for indicator AAP are not statistically significant as seen in Table S2. This reflects that although the AAP has the highest Pearson's r, the causality between AAP and its ASLEC investment is not significant compared to RGC's and TGS's. Therefore, taking prefecture-level cities as samples, the CEM method proves that there is a causal relationship between municipal work indicators and ASLEC investment. However, there is still uncertainty in this method. If more confounding indicators are added in CEM method, this kind of causal relationship may be weakened. Due to the lack of enough data, a more in-depth and accurate causality proof needs more data in future research. But in this case, CEM is still useful to prove causal relationships between municipal indicators and ASLEC investment.

In sum, most municipal work indicators have high correlation coefficient over 0.5 (significance level 95%) with the investment of major environmental protection companies. The CEM results also prove that the investment and municipal indicators (e.g., RGC and TGS) have a statistically significant causal relationship. This is because municipal work with low technology and high return is the main businesses of environmental protection industry of China.

4 Discussion

China's extensive economic development has resulted in environmental pollution and causing great concern of economic and social cost to both the government and the public. Accordingly, there is an increasing environmental demand in China for cost-effective solutions to this issue, which has formed a great market for environmental protection industry. In this paper, we examined the spatial distribution and the drivers of market demand of environmental protection industry in China based on open database. According to these data from enterprises and prefecture-level cities, we found the treatment of wastewater and municipal solid waste are still the main businesses of environmental protection industry. Although air pollution is a particular environmental concern in China recently, the income share of air pollution control-related companies is still lower than that of water and solid waste treatment companies. The industrialization process of air pollution treatment still lags water and solid waste treatment.

In terms of regional distribution, Beijing and Shanghai are the main concentrations, followed by Shenzhen and Chongqing–Chengdu. The Yangtze River Delta with Shanghai as the core is the most concentrated and developed area of environmental protection industry.

Other central and western regions in China are still relatively lacking in the environmental protection industry.

At present, most of the air-related environmental protection companies concentrated on the energy sector. The higher national target of air pollution control has been set in China recently. As specified in this target, by 2020, the average $PM_{2.5}$ concentration in those cities not complying with the national standard cities will be reduced by 18% than that in 2015, and the number of days with satisfying air quality will account for 80% of the entire year. However, the number of air-related environmental protection companies is far less than that of wastewater and municipal solid waste treatment companies. Compared with wastewater and municipal solid waste, air-related environmental protection still lacks mature industrialization and marketization. There is not enough of capacity for air-related environmental protection companies to fulfill the high national target of air pollution control.

Other environmental protection industry-related studies have similar results, but lack of more quantitative special analysis (CEPI, 2019; CEPI, 2020; HKTDC, 2019). Previous quantitative studies of environmental protection industry are mainly applied by the economic-related methodology such as using input–output model and other economic model to study the interact impact between environmental protection industry and economy (Fan et al., 2019; Zhao et al., 2020). However, there are few papers examined the environmental protection businesses by applying the methodology of spatial characteristic.

This paper was conducted numbers of different analytical tools, including Pearson's correlation coefficient analysis and coarsened exact matching. Broadly, we found that municipal work indicators were positively correlated with investment, though the statistical significance of the observed effect varied significantly depending on the class of diversity and field of study. Overall, the category of environmental indicator was the least correlated with investment. Conversely, RGC, TGS and AAP had the strongest correlation. However, after the CEM analysis the results of AAP are not significant. The CEM method proves that there is a causal relationship between municipal work indicators and ASLEC investment.

Due to the data limitation, only 53 A-Share Listed Environmental Companies (ASLEC) in China and their 927 subsidiaries in 210 cities are selected for spatial characteristic analysis. When China's pollutant statistics are more standardized and the sharing mechanism is more complete, we could achieve further detailed and accurate research in the future.

5 Conclusion

The year 2002 was a turning point in the history of ASLEC development. After 2002, the development of ASLEC (numbers of enterprise) tends to be stable. However, the output value from ASLEC was increased dramatically since 2015. Hence, understanding which kind of environmental protection companies should be developed and what is the fundamental demand for environmental protection companies in city level is particularly critical. This study will assist decision makers to identify and address characteristics and distribution of environmental companies on A-Share Listed and guide them to wisely invest in the environmental companies for sustainable development of environmental protection.

We found that the municipal works had the strongest correlation with investment of ASLEC, and the treatment of wastewater and municipal solid waste are still the main businesses of environmental protection industry. To bridge the gap between the current performance and national target of air pollution control, we suggest that the air pollution control industry should be given the priority consideration for the investment of environmental protection companies to advance national environmental profit of China. Furthermore, the eastern region of China remains a hot spot for investment whereas the investment in the western region increased significantly in 2017. Moreover, our findings demonstrate that municipal work indicators and ASLEC investment have high positive correlation. With the increasing requirement of life function in the central and west region, e.g., the residential gas consumption raised gradually with change rate of 25% from 2010 to 2019 (NBSC, 2017), it implies that the central and western regions have the greatest investment potential. The potential of future development will be located in the central and western regions. For serious air pollution and large-scale industrial transfer from east regions to central and western regions in China, there is lack of industrialization on environmental protection capacity to fulfill the stipulated national pollution reduction target.

5.1 Policy implication

The last decade witnessed the rapid growth and expansion of environmental protection industry in China due to the increasingly stringent environmental management and the continuous improvement of public awareness of environmental protection. Although it is difficult to measure the level of environmental management and public awareness, the nexus of ASLEC and their geographical location could be reflected through other statistical indicators of a city. To explore the reason for the distribution of environmental protection industry, the correlation coefficient between company investment and urban statistical data was calculated. The results showed that the urban municipal works for public attract more investment of environmental protection companies. This is because municipal work with low technology and high return is the main businesses of environmental protection industry of China. However, industry, commonly recognized as the major source of pollution, received less attraction from environmental protection industry. Environmental protection enterprises with higher technology level are needed to deal with the emission of pollutants from very complex industrial sources. It seems that Chinese environmental protection enterprises do not have such scale and capability. We suggest that corresponding policies should be made by the government to support those environmental protection companies that provide services to industrial enterprises. The mainstream media in China concluded that China's environmental protection industry has progressed from environmental protection 1.0, which mainly focuses on construction of municipal infrastructure and pollution control for industries, to environmental protection 3.0. In other words, environmental protection 3.0 places more focus on ecological civilization and marketization (CEPI, 2017). However, according to the analysis of big data conducted in this paper, the environmental protection industry of China is still too concentrated on the municipal works at the moment. Even market-oriented investment in the industrial pollution control remains very weak. Therefore, China is still in the era of environmental protection 1.0.

These findings have valuable policy implications for the future of China's environmental protection industry. The opportunity for future investment lies in the field of air pollution control. The central and western regions have the greatest investment potential. In addition, there will still be significant future demands on the pollution control for industrial sources. China government should implement effective policies, such as investment subsidies, tax reduction and administrative simplification to attract more enterprises to invest in environmental protection industry to relieve the negative pollution impacts especially in central and western regions of China. From the perspective of environmental protection industry, the government should encourage environmental protection enterprises to invest in industrial pollution control by adopting innovated technologies, not just in the field of traditional municipal engineering.

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Author contributions LL and YW conceived and designed the research, performed model simulations and data analysis and wrote the manuscript in collaboration with JZ and GZ. Moreover, YW, GM and JZ designed the framework of geospatial hot spot analysis of ASLEC to the environmental pollution treated ratio. ZW, YS and TX collected the data from Tianyancha database. MJS and GZ whose native language is English checked language and grammar usage in manuscripts. All authors suggested analysis, interpreted the data, discussed their implications and contributed to the manuscript.

Data availability and material The data that support the findings of this study are available from the corresponding author [Y. Wang] upon reasonable request.

Code availability Not applicable.

Declaration

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

AlShebli, B. K., Rahwan, T., & Woon, W. L. (2018). The preeminence of ethnic diversity in scientific collaboration. *Nature Communications, 9*(1), 1–10. https://doi.org/10.1038/s41467-018-07634-8.

Analysis of Present Situation and Future Development Trend of China's Environmental Protection Industry in 2017 (CEPI). (2017). China Industrial Information Network. Available online at: http://www.chyxx.com/industry/201712/590548.html. (Accessed 19 May 2019)

Blackwell, M., Iacus, S., King, G., & Porro, G. (2009). Cem: Coarsened exact matching in Stata. *The Stata Journal, 9*(4), 524–546. https://doi.org/10.1177/1536867x0900900402.

Bruvoll, A. (1998). Taxing virgin materials: An approach to waste problems. *Resources, Conservation and Recycling, 22*(1–2), 15–29. https://doi.org/10.1016/s0921-3449(97)00040-2.

Catalina, T., Iordache, V., & Caracaleanu, B. (2013). Multiple regression model for fast prediction of the heating energy demand. *Energy and Buildings, 57*, 302–312. https://doi.org/10.1016/j.enbuild.2012.11.010.

China Association of Environmental Protection Industry (CAEPI). (2015). Development Index Report of China Environmental Protection Industry 2015. Available online at: http://www.caepi.org.cn/epasp/website/webgl/webglController/view?xh=1521103614566083353600. (Accessed 19 May 2019).

China Association of Environmental Protection Industry (CAEPI). (2016). China Environmental Protection Industry Development Index Report 2016. Available online at: http://www.caepi.org.cn/epasp/website/webgl/webglController/view?xh=1521103455012084561920. (Accessed 19 May 2019).

China Association of Environmental Protection Industry (CAEPI). (2017a). Environmental Industry Climate Index: A Share Listed Environmental Companies (EICl-2017Q1). Available online at: http://www.caepi.org.cn/epasp/website/webgl/webglController/view?xh=1521101964316059629568. (Accessed 19 May 2019).

China Association of Environmental Protection Industry (CAEPI). (2017b). Environmental Industry Climate Index: A Share Listed Environmental Companies (EICl-2017Q2). http://www.caepi.org.cn/epa/resources/pdfjs/web/viewer.html?file=/epa/platform/file/filemanagecontroller/downloadfilebyid/1521102396725060624896. (Accessed 19 May 2019).

China Association of Environmental Protection Industry (CAEPI). (2018). Available online at: http://www.caepi.org.cn/. (Accessed 19 May 2019).

China Association of Environmental Protection Industry (CAEPI). (2018). The Development of China's Environmental Protection Industry Report 2018. Available online at: http://www.caepi.org.cn/epasp/website/webgl/webglController/view?xh=1548321329625036356096. (Accessed 19 May 2019).

China Association of Environmental Protection Industry (CAEPI). (2019). The Development of China's Environmental Protection Industry Report 2019. Available online at: http://www.caepi.org.cn/epasp/website/webgl/webglController/chnlnewsList/W_XXZX_NDFZBG. (Accessed 19 January 2021).

China Association of Environmental Protection Industry (CAEPI). (2020). The Development of China's Environmental Protection Industry Report 2020. Available online at: http://www.caepi.org.cn/epasp/website/webgl/webglController/chnlnewsList/W_XXZX_NDFZBG. (Accessed 19 January 2021).

Duczmal, L., Kulldorff, M., & Huang, L. (2006). Evaluation of spatial scan statistics for irregularly shaped clusters. *Journal of Computational and Graphical Statistics, 15*(2), 428–442. https://doi.org/10.1198/106186006x112396.

Environmental Systems Research Institute (ESRI). (2019). Inc. "ArcGIS Resource Center," Hot Spot Analysis (Getis-Ord Gi*). Available online at: http://desktop.arcgis.com/en/arcmap/. (Accessed 19 May 2019).

Fan, Y., Wu, S., Lu, Y., & Zhao, Y. (2019). Study on the effect of the environmental protection industry and investment for the national economy: An input-output perspective. *Journal of Cleaner Production, 227*, 1093–1106.

Hong Kong Trade Development Council (HKTDC). (2019). China's Environmental Market. Available online at: https://hkmb.hktdc.com/en/1X002L45/hktdc-research/China%E2%80%99s-Environmental-Market. (Accessed 19 January 2021).

General Office of the State Council of People's Republic of China (SCPRC). (2016). The 13th five-year plan for ecological and environmental protection. Available online at: http://www.gov.cn/zhengce/content/2016-12/05/content_5143290.htm. (Accessed 19 May 2019).

Goovaerts, P., & Jacquez, G. M. (2004). Accounting for regional background and population size in the detection of spatial clusters and outliers using geostatistical filtering and spatial neutral models: the case of lung cancer in Long Island, New York. *International Journal of Health Geographics, 3*(1), 14.

Hu, B., Shao, S., Fu, Z., Li, Y., Ni, H., Chen, S., & Shi, Z. (2019). Identifying heavy metal pollution hot spots in soil-rice systems: A case study in South of Yangtze River Delta, China. *Science of the Total Environment, 658*, 614–625.

Iacus, S. M., King, G., & Porro, G. (2011). Multivariate matching methods that are monotonic imbalance bounding. *Journal of the American Statistical Association, 106*(493), 345–361. https://doi.org/10.1198/jasa.2011.tm09599.

Iacus, S. M., King, G., & Porro, G. (2012). Causal inference without balance checking: Coarsened exact matching. *Political analysis, 20*(1), 1–24. https://doi.org/10.1093/pan/mpr013.

Jacquez, G. M., & Greiling, D. A. (2003). Local clustering in breast, lung and colorectal cancer in Long Island, New York. *International Journal of Health Geographics, 2*(1), 3. https://doi.org/10.3133/wri924038.

Jia, K., & Chen, S. (2019). Could campaign-style enforcement improve environmental performance? Evidence from China's central environmental protection inspection. *Journal of environmental management, 245*, 282–290. https://doi.org/10.1016/j.jenvman.2019.05.114.

Johnson, E. L. (1967). Optimality and computation of (σ, S) policies in the multi-item infinite horizon inventory problem. *Management Science, 13*(7), 475–491. https://doi.org/10.1287/mnsc.13.7.475.

Kulldorff, M. (1997). A spatial scan statistic. *Communications in Statistics-Theory and Methods, 26*(6), 1481–1496. https://doi.org/10.1080/03610929708831995.

Lezzaik, K., & Milewski, A. M. (2014). A Global Hot Spot Analysis (Getis-Ord Gi*) of Groundwater Storage Change using GRACE Satellite and GIS-Based Spatial Statistical Analysis. In 2014 GSA Annual Meeting in Vancouver, British Columbia.

Ling-yun, H., et al. (2013). Research on the effect of china's environmental protection investment to the environmental protection industry development. *Soft Science, 27*, 37–41 (in Chinese with English abstract).

MacQueen, J. (1967). Some methods for classification and analysis of multivariate observations. *Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability, 1967*, 281–297.

Ministry of Ecology and Environmental of People's Republic of China (MEEPRC), (2017). Bulletin on China's Ecological Environment 2017. Available online at: http://www.mee.gov.cn/hjzl/sthjzk/zghjzkgb/201805/P020180531534645032372.pdf. (Accessed 19 May 2019).

National Bureau of Statistics of China (NBSC). (2017). *China city statistical yearbook 2017*. . China: China Statistics Press.

Parchomenko, A., & Borsky, S. (2018). Identifying phosphorus hot spots: A spatial analysis of the phosphorus balance as a result of manure application. *Journal of Environmental Management., 214*, 137–148. https://doi.org/10.1016/j.jenvman.2018.01.082.

Schikuta, E., & Erhart, M. (1997). The BANG-clustering system: Grid-based data analysis. In International Symposium on Intelligent Data Analysis. Springer, Berlin, Heidelberg https://doi.org/10.1007/bfb0052867
Shunze, W., et al. (2014). The fourth comprehensive analysis report of national environmental protection related industries. *China Environmental Protection Industry., 8*, 4–17 (in Chinese).
Tianyancha. (2018). Available online at: www.tianyancha.com. (Accessed 19 May 2018).
Williams, S. (1996). Pearson's correlation coefficient. The New Zealand medical journal, 109(1015), 38. https://doi.org/https://doi.org/10.32388/y3qecy
Wu, Y., Sheng, J., & Huang, F. (2015). China's future investments in environmental protection and control of manufacturing industry: lessons from developed countries. *Natural Hazards, 77*(3), 1889–1901. https://doi.org/10.1007/s11069-015-1681-2.
Xepapadeas, A., & de Zeeuw, A. (1999). Environmental policy and competitiveness: The Porter hypothesis and the composition of capital. *Journal of Environmental Economics and Management, 37*(2), 165–182. https://doi.org/10.1006/jeem.
Xu, X., & Zhang, T. (2020). Spatial-temporal variability of PM2. 5 air quality in Beijing, China during 2013–2018. Journal of Environmental Management, 262, 110263 https://doi.org/10.1016/j.jenvman.2020.110263
Yunze, M. A. (2011). Problems and solutions facing environmental protection industry in China. *Energy Procedia, 5*, 275–279. https://doi.org/10.1016/j.egypro.2011.03.049.
Zeng, D., Chang, W., & Chen, H. (2004). A comparative study of spatio-temporal hotspot analysis techniques in security informatics. In Proceedings. The 7th International IEEE Conference on Intelligent Transportation Systems (IEEE Cat. No. 04TH8749) (pp. 106–111). IEEE https://doi.org/10.1109/itsc.2004.1398880
Zhang, C., Weng, S., & Bao, J. (2020). The changes in the geographical patterns of China's tourism in 1978–2018: Characteristics and underlying factors. *Journal of Geographical Sciences, 30*(3), 487–507.
Zhang, J., & Shang, J. (2010). Research on developing environmental protection industry based on TRIZ theory. *Procedia Environmental Sciences, 2*, 1326–1334. https://doi.org/10.1016/j.proenv.2010.10.143.
Zhang, Q., Jiang, X., Tong, D., Davis, S. J., Zhao, H., Geng, G., & Ni, R. (2017). Transboundary health impacts of transported global air pollution and international trade. *Nature, 543*(7647), 705–709. https://doi.org/10.1038/nature21712.
Zhao, J., Zhao, X., Ren, Y., & Wang, M. (2020). The Impact of Environmental Finance Development on the Growth of Environmental Protection Industry. In 2020 International Conference on Social Science, Economics and Education Research (SSEER 2020) (pp. 257–262). Atlantis Press.

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