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Study on Comprehensive Assessment of Environmental Impact of Air Pollution

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Abstract: Pollutants discharged from irrational energy consumption pose a serious threat to urban ecological security. The Western Taiwan Straits Economic Zone is an important part of China's coastal economy. With the rapid development of the economy in this area, the atmospheric environmental pollution problem, caused by energy consumption, has become increasingly serious. Therefore, the study of the environmental impact assessment of air pollution in the Western Taiwan Straits Economic Zone has reference value to prevent ecological risks. This paper constructed a regional-scale environmental impact assessment model that includes pollution sources, pollution stress, and evaluation results, and evaluated the environmental impact of SO_2, NO_2, CO, PM_{10}, and $PM_{2.5}$ from three perspectives: regional integration, different energy consumption sectors, and different cities. The results showed that the regional environmental impact level of the research area was high, and the main pollutants transformed from SO_2 to NO_2, PM_{10}, and $PM_{2.5}$ from 2008 to 2016. According to the results of different sectors, the transportation sector contributes the most to NO_2 and remains unchanged, and the industrial sector contributes the most to SO_2, PM_{10}, and $PM_{2.5}$. Combined with the research results of different cities, cities concentrated in the coastal areas contribute more pollution than other cities do.

Keywords: air pollution; ecological risk; Western Taiwan Straits Economic Zone; China's Multi-scale Emission Inventory Model (MEIC)

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1. Introduction

Energy is a national strategic resource and an important material basis for a country's economic growth and social development [1]. However, with the rapid growth of the Chinese economy, the demand for energy is increasing, the irrational energy consumption structure and the low energy utilization rate have made the contradiction of energy shortage more prominent. At the same time, environmental pollution, resource shortage, and natural disasters are also emerging, which pose a serious threat to the ecological environment [2–4]. Irrational energy consumption has become a key issue threatening regional ecological security. Studies showed that particles and gaseous pollutants generated by fossil fuel combustion are threatening the natural ecosystem [5,6]. For example, excessive nitrogen oxides in the atmosphere can affect the soil ecosystem, vegetation ecosystem, water ecosystem, etc. The impact can change the physical and chemical properties of the soil, inhibiting the activity of soil enzymes, some microorganisms, and animals [7]. The impact can also inhibit plant photosynthesis and lead to eutrophication when the pollution enters the water body [8], then resulting in algal bloom, fish kill, and lower biodiversity, etc. As an important trace gas, SO_2 plays an important role in the complex atmospheric processes such as haze and photochemical smog [9]. In addition, when there is water in the atmosphere, sulfur dioxide will lead to acid rain, which can destroy the forest ecosystem, unbalance the water environment acid, and corrode building materials [10,11]. Moreover,

when sulfur compounds oxidized to secondary sulfate and partialized (PM), those particles can cause climate change [12]. The increase of PM_{10} and $PM_{2.5}$ in the atmosphere will reduce atmosphere visibility, paralyze the traffic, worsen the ambient air quality, and damage the structure and function of the human respiratory system and also health [13,14]. The economic cost of air pollution is expected to be as high as one-third of the total environmental cost nation-wide [15]. These ecological and environmental problems can seriously affect life quality, restrict social and economic development [4], and become a severe challenge for China to move towards sustainable urbanization.

It is an urgent practical problem in energy planning and ecological management to conduct scientific assessments of air pollution emission and the environmental impact in the process of energy consumption because air pollution emission is one of the major elements of environmental pollution. It also has a strong practical significance to fundamentally solve the pollution problem caused by energy consumption, to guide China's energy consumption transformation, ecological environment protection, and formulate urban energy planning and environmental protection.

2. Overview

Air pollution caused by energy consumption poses a serious threat to the ecological environment. It is of great significance to study the emission sources to fundamentally improve the environmental problems. According to the nature of emission sources, they can be divided into mobile sources and fixed sources. Among them, mobile sources refer to the sources of air pollutants emitted by nonfixed emission equipment, which are composed of road mobile sources and nonroad mobile sources. Road mobile sources mainly include passenger cars, trucks, and motorcycles. Nonroad mobile sources are mainly divided into agricultural machinery, construction machinery, train and aircraft, ships, etc. [16]. Fixed source refers to the source of air pollutants discharged by fixed emission equipment. According to the industry classification, it mainly includes power plant, steel plant, cement plant, incineration plant, etc. [17]. At present, many mobile source emission models have been proposed. For example, the MOBILE model which was approved by the United States Environmental Protcction Agency is specially used to calculate the micro and macro average emission factors of motor cars. It is also one of the most widely used models in vehicle emission models, which is mainly used to estimate the emissions of Volatile Organic Compounds (VOC_S), Carbon Monoxide (CO), and Nitrogen Oxides (NO_x) [18]. Art model is used to simulate PM and SO_X emissions from mobile sources. The Emission Factor (EMFAC) model [19] and the Computer Programme to Calculate Emissions from Road Transport (COPERT) [18] model have strong advantages in simulating macro scale vehicle emissions. The International Vehicle Emission (IVE) [20] model is a vehicle emission model developed by the International Center for sustainable development and the University of California riverside, which is convenient for developing countries to localize. The existing research on mobile source emissions can be divided into a national scale and municipal scale. Among them, the study of the city scale is relatively more in depth. At the national scale, Ning [21] and Wei [22] have estimated and analyzed the emission amount, Emission Trend, and emission distribution intensity of major air pollutants (CO, NO_x, HC, $PM_{2.5}$, and VOC_s) from mobile sources in China. At the city scale, based on appropriate estimation methods and emission factors, Chinese scholars analyzed the mobile source emission inventories of Nanchang [23], Anyang [24], Lanzhou [25], Nanchong [26], Tianjin [27], and Changchun [28] in China. Foreign scholars studied the spatial variability and gradient of mobile source pollution emissions in Tehran (Iran) [29], Kansas (USA) [30], Tel Aviv (Israel) [31], Houston, Texas (USA) [32], Kansas (USA) [33], Denver (USA) [34], and other cities, and the contribution of mobile source pollution emissions to regional air pollution. In terms of fixed source research, Zhang [35], Wei [36], Tang [37] and others carried out relevant research on VOC, SO_2, and NO_2 emissions from fixed sources based on chromatography technology, thermal analyzer gas chromatography combined technology, the Differential Optical Absorption Spectrum (DAOS), and other technologies. Liu [38]

and Zhang [39] analyzed the main pollution emissions of fixed sources by collecting the monitoring data of fixed source pollution emissions and combining with relevant emission factors, respectively.

Most of the existing researches on pollution sources are carried out by mobile sources, and there are relatively many researches on the city scale. Environmental Impact Assessment (EIA) refers to the determination and assessment of the environmental impact of a project on the physical-chemical, biological, cultural, and socio-economic components [40]. As an important tool in the process of environmental management, the Environmental Impact Assessment aims to "conduct a comprehensive and fair discussion on major environmental impacts, and inform decision-makers and the public of reasonable alternatives to avoid or minimize adverse impacts or improve the quality of the human environment" [41]. The objective of the EIA is to provide decision support for environmental quality monitoring and ecological environment management [42]. Therefore, some governments have paid more and more attention to EIA. In 1970, the United States adopted the "National Environmental Protection Policy Act" and formally implemented environmental impact assessment as a law. This implementation had a positive effect on the environmental protection resource recycling and was soon accepted by the globe [43,44]. In 1983, Turkey also incorporated the EIA system into laws [45]. In 1979, China also began to implement Environmental Impact Assessment, and then passed the promulgation and implementation of the Environmental Impact Assessment Law of the People's Republic of China, making the legal status of the EIA clear [46]. So far, nearly 200 countries have formulated Environmental Impact Assessment regulations [47]. It can be seen that these governments attach great importance to environmental impact assessment. Based on this phenomenon, scholars have carried out Environmental Impact Assessment work in succession. Based on the energy consumption by departments, the existing research can be divided into four categories: industry, transportation, electricity, and housing.

The Environmental Impact Assessment studies on industrial sectors involve enterprises, including iron and steel plants and automobile manufactory. Sun et al. [48] used the total environmental impact score (TEIS) to evaluate the environmental impact of air pollutants produced in the main industrial processes of a steel plant in Northeast China. Jaehun and Jehean [49] used the life cycle method to evaluate the environmental impact of pollutants produced by Korean automobile manufacturers in the production and logistics processes. Abduaziz et al. [50] evaluated the impact of assembly plants and logistics in the automotive industry on the atmospheric environment; it was carried out to investigate the impact of strategic decisions and operations on production costs and environmental sustainability. There are only a few evaluation studies in the transportation sector. For example, based on the GREET (Green gases, Regulated Emissions, and Energy use in Transportation) model, Bicer and Dincer [51] selected several indicators, such as human toxicity, global warming, acidification, eutrophication, and terrestrial ecotoxicity, and carried out risk assessments on internal combustion engine vehicles with multiple fuels. The power sector conducts EIA research on pollution emissions from different power generation facilities and different types of energy. For example, Osamah and Ibrahim [52] took Ontario, Canada, as the research object, used the comprehensive life cycle assessment method to analyze, evaluate, and compare the environmental impact of pollutants such as carbon dioxide, methane, sulfur oxide, nitrogen oxide, and total particulate matter produced by various types of power generation facilities in the whole life cycle. Atilgan and Azapagic [53] used the full life cycle assessment method to assess the environmental impact of fossil fuels such as lignite, coal, and natural gas used in power plants. The Environmental Impact Assessment research of the construction sector can be divided into two types: the building as a whole and the building structure only. For the former, Jaehun and Jehean [54] analyzed seven types of air emissions in the life cycle of an apartment building in South Korea from the building materials production to the treatment and recycling, and evaluated the impact on the environment. Tae et al. [55] proposed a simple carbon emission assessment system to investigate the entire life cycle of an apartment building in South Korea from the per-

spective of carbon emissions. Poorang et al. [56] used the full life cycle assessment method to assess the impact of buildings' CO_2 emission in Pakistan. For research of the building structure, scholars have selected roof greening systems and alternative insulation materials to carry out EIA. Rasul and Arutla [57] used Simapro software (CML, Leiden University, Leiden, The Netherlands) to simulate the roof, and Life Cycle Assessment (LCA) was used to evaluate and analyze the environmental impact of building roof greening systems in Australia; Maja et al. [58] used LCA to evaluate the environmental performance of various building institutions of residential buildings, revealing the impact of different structural systems and alternative insulation materials on global warming and acidification potential.

To sum up, most of the existing air EIA studies are carried out in a single energy consumption department, while the comprehensive studies in multiple departments and the spatial analytical assessment studies of pollutants are few. Therefore, based on China's Multi-scale Emission Inventory Model (MEIC), this study obtained the data of pollution emission sources in the Western Taiwan Straits Economic Zone. By establishing the quantitative relationship between risk sources and receptors, this study selected the Western Taiwan Straits Economic Zone to build a more comprehensive and detailed framework and method system for the comprehensive assessment of regional air pollution environmental impact, to assess air pollution environmental impact of the overall area, different cities, and different industries in this area, and to obtain the comprehensive regional air pollution environmental impact status, to put forward corresponding policy suggestions to achieve the sustainability of the regional ecosystem, promote the progress of environmental impact assessment to quantitative development, and then promote the construction of ecological civilization in China [1].

3. The Study Area and Research Methods

3.1. The Study Area

The Western Taiwan Straits Economic Zone (referred to as "Haixi District") refers to the area on the west coast of the Taiwan Strait with Fujian province in China as the main body. It is connected with the Pearl River Delta and the Yangtze River Delta from the north to the south, Taiwan island from the east, and the vast hinterland of Jiangxi and Zhejiang province in China from the west. The geographical scope includes 20 prefecture-level and beyond cities in China, including the cities in Fujian Province, Shantou, Jieyang, Chaozhou and Meizhou city in Guangdong Province, and Wenzhou, Lishui, Quzhou and other cities in Zhejiang Province, covering a total area of 270,000 km^2. Haixi District, the area investigated in this study, has an area of 145,400 km^2 and is composed of 13 cities: 9 prefecture-level cities in Fujian Province, Shantou, Chaozhou and Jieyang in Guangdong Province, Wenzhou in Zhejiang Province, accounting for 1.51% of China's land area, as shown in Figure 1 [59]. The average annual temperature is 17.5–23.5 °C and the average annual precipitation is 1446.6–2624.4 mm.

Haixi District has strong advantages of geography, economy, and regarding to Taiwan Province. In terms of location, Haixi District is located between the Pearl River Delta and the Yangtze River Delta, which are two of the largest economic zones in China; in terms of Taiwan advantages, Haixi District is an important hub for cross-strait exchanges in China; moreover, as a regional economic complex with unique advantages that drive the national economy, Haixi District is one of the key areas for China's future development under the guidance of national regional development strategy. However, with the rapid development of the Haixi District, the air pollution caused by energy consumption has become more serious. Facing the pressure of soot pollution and vehicle exhaust pollution [60,61], the environmental impact is becoming more severe, which can negatively impact the district development as well. Therefore, this study selected Haixi District as the research area for the comprehensive assessment of the regional environmental impact of air pollution, because it can provide an important basis and guarantee for the sustainable development of the region, as well as an important demonstration role for the scientific development of other cities and regions.



Figure 1. The administrative division of The Western Taiwan Straits Economic Zone.

3.2. Research Methods

Based on Tang's [62] research of the urban ecological risk assessment framework, this study constructs a comprehensive assessment model of regional air pollution environmental impact, which can be used for a more systematic environmental impact assessment on a regional scale, as shown in Figure 2. The model consists of four parts: Pollution Source, Pollution Stress, Evaluation End Point, and Evaluation Result. Among them, the Pollution Source refers to energy consumption, which includes the total energy consumption of the Haixi District, energy consumption of different industries (industry, power, transportation, agriculture, and housing) and different cities; the Pollution Stress refers to the five main categories of air pollution emissions, which include SO_2, NO_2, PM_{10}, $PM_{2.5}$, and CO. The Assessment End Point refers to the environmental impact value of five main air pollutants discharged by Pollution Sources. The Assessment Result refers to the Environmental Impact Level of main air pollutants corresponding to the Assessment End Point and the control measures proposed. Specifically, the environmental impact value in the Assessment End Point is determined based on the ratio of the two indicators of pollutant emission and atmospheric environmental carrying capacity determined by the Box model in the Haixi District; the Assessment Result is determined based on the environmental impact assessment standard determined by the Delphi method, where the higher impact level, the higher the corresponding impact, and vice versa. The highest environmental impact level in the pollution stress of the whole Haixi District and different industries are selected as the corresponding impact level of the two pollution sources, and the corresponding pollutants are the primary pollutants.

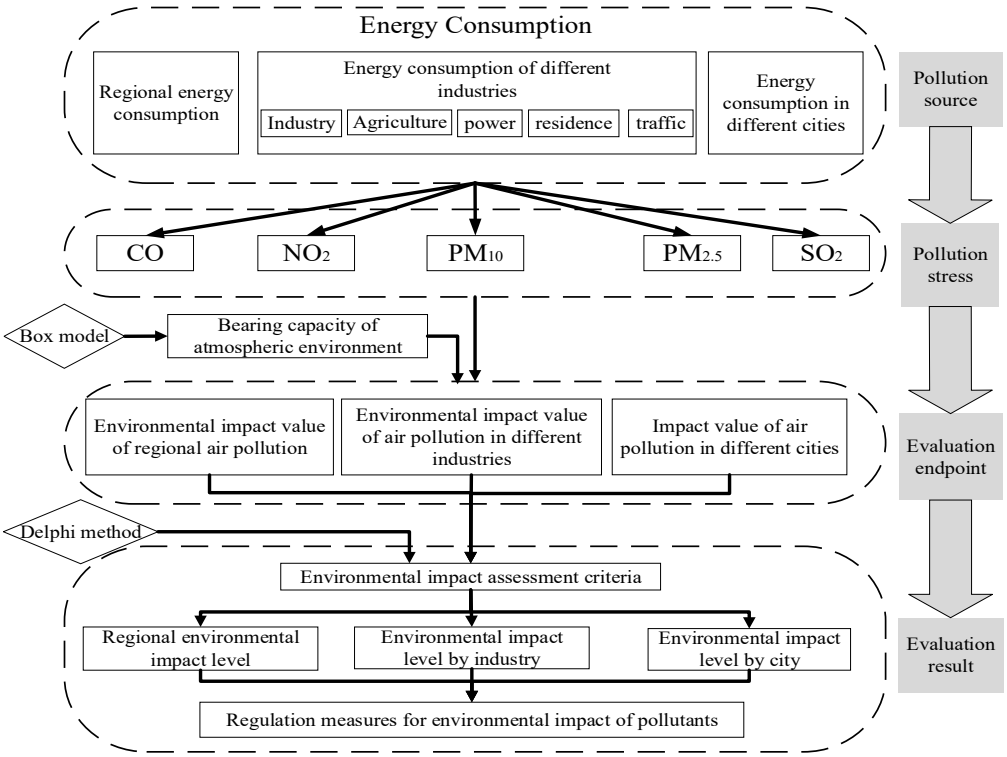

Figure 2. Comprehensive assessment model of regional environmental impact.

3.2.1. The Pollution Sources and The Pollution Stress

Haixi District, as an economic complex that drives the national economy, is economically integrated with industry, agriculture, and commerce. Moreover, the Haixi District has a large area and geographical advantages. In this context, while studying the risk of energy consumption pollution in the Haixi District, it is important to evaluate the risk of pollutants in different industries and cities to realize the sustainable development and protect the ecological environment of the Haixi District. Therefore, this study divides pollution sources into regional comprehensive energy consumption, the energy consumption of different industries (industry, agriculture, electricity, transportation, and housing) and different cities.

Pollution Stress refers to the emissions of different types of pollutants from varied sources. The data used comes from MEIC (Multi-resolution Emission Inventory for China). MEIC is a list of emission sources developed by the Tsinghua University; this list has a high expressiveness in China (http://www.meicmodel.org/dataset-meic.html): it includes provincial emission and grid emission data. Emission data includes grid emission inventory data with a spatial resolution of 0.25, 0.5, and 1.0 in five sectors, including power, industry, civil, transportation, and agriculture. At present, MEIC is widely used by relevant scholars to study the temporal and spatial emission characteristics of pollutants [63,64].

Therefore, in this study, the grid emission inventory data of China air pollutants with a resolution of 0.25 degrees from 2008 to 2016 was obtained from MEIC, and ArcGIS 10.0 (ESRI, RedLands, CA, USA) was used to process the data. Multiple cities, industries, and comprehensive air pollutant emissions in the Haixi District were selected as the Pollution Stress. Among them, the pollution emission in the agricultural sector is zero. Therefore, different industries are divided into industry, electricity, transportation, and housing. The pollutants obtained by MEIC are CO, SO_2, $PM_{2.5}$, PM_{coarse}, and NO_x (PM_{10} and NO_2 are not included). Based on "the Guidelines for Atmospheric Environmental Impact Assessment (HJ2.2-2008)," it is pointed out that for general combustion equipment, the conversion of NO_x should be considered in the calculation of NO_2 concentration. When calculating the average concentration, NO_2 / NO_x is 0.8, which can be assumed to calculate

NO_2 concentration. The NO_2 emission was calculated according to the empirical value (NO_2/NO_x = 0.8) [65]. The PM_{10} emission was obtained by the sum of $PM_{2.5}$ and PM_{coarse}.

3.2.2. The Evaluation End Point

The Evaluation End Point refers to the impact value corresponding to the impact of stress. The impact value is used to evaluate the environmental impact level and is obtained by the pollution load defined by the ratio of discharge quantity of air pollutant (*DQAP*) and atmospheric environmental capacity (*AEC*) [65]. The formula is as follows:

$$V = DQAP \ / \ AEC \quad (1)$$

where *DQAP* is the emission of air pollutants (tons), which is obtained based on MEIC; *AEC* is the bearing capacity of air environment (tons); *V* is the environmental impact value, which can be used to evaluate the environmental impact of air pollutants in combination with the environmental impact rating standard of air pollutants (Table 1) based on the Delphi method [66].

Table 1. Environmental Impact Assessment Criteria.

Ratio	Impact Level	Significance
$V < 1$	Low	Air pollution emissions would not pose a threat to the atmosphere of the study area
$1 \leq V < 2$	Moderate	The air pollution emissions can threaten the air environment of the study area, but it is not significant
$V \geq 2$	High	Air pollution emissions pose a high threat to the atmosphere of the study area

AEC refers to the maximum permissible level of pollutants that can be tolerated by a unit of the atmosphere within a certain period and under a certain environmental standard. In this study, AEC for some pollutants in 13 cities of the Haixi District was estimated by the box model. The formula is as follows:

$$AEC = (C_{si} - C_{bi}) \times S \times H \times T \quad (2)$$

where *AEC* is the bearing capacity of urban atmospheric environment (ton/year); C_{si} is the daily average limit concentration value of pollutant *i*, taking "Ambient air quality standards (GB3095-2012)," wherein the daily average values of SO_2, NO_2, CO, PM_{10}, and $PM_{2.5}$ are 50 μg/m^3, 80 μg/m^3, 4000 μg/m^3, 50 μg/m^3, and 35 μg/m^3, respectively; C_{bi} is the background concentration value of pollutant *i*, based on the historical minimum concentration of pollutants in different cities obtained by The China Air Quality Online Analysis Platform (https://www.aqistudy.cn/historydata/about.php), as shown in Table 2; *S* is the administrative area of the study area; *H* is the maximum height of the atmospheric environmental quality detection station (20 m); *T* is the time, i.e., 365 days/year.

Table 2. Background concentrations (C_{bi}) of different urban pollutants within the Haixi District ($\mu g/m^3$).

	$PM_{2.5}$	PM_{10}	SO_2	CO	NO_2
Wenzhou	5	14	2	500	8
Nanping	5	10	4	600	7
Ningde	5	13	2	700	6
Sanming	4	12	5	600	10
Fuzhou	4	10	3	400	11
Quanzhou	4	11	3	500	10
Putian	6	13	5	400	4
Longyan	7	14	6	600	8
Zhangzhou	6	14	4	500	8
Xiamen	5	12	4	200	7
Chaozhou	3	10	7	600	4
Jieyang	7	13	5	500	6
Shantou	7	8	6	500	7
Haixi District	5	12	4	508	7

According to Formula (2), the AEC of 13 cities in the study area can be obtained, as shown in Table 3.

Table 3. Atmospheric environmental capacity (AEC) of different cities in Haixi District (ton/year).

	$PM_{2.5}$	PM_{10}	SO_2	CO	NO_2
Wenzhou	2552.49	3062.98	4083.98	297,790.03	6125.97
Nanping	6198.899	8265.19	9504.97	702,541.39	15,083.98
Ningde	2734.81	3372.93	4375.69	300,828.71	6745.86
Sanming	5275.14	6466.30	7657.46	578,563.50	11,911.60
Fuzhou	3014.36	3889.50	4570.17	350,055.22	6709.39
Quanzhou	2449.17	3081.22	3713.26	276,519.32	5530.39
Putian	881.25	1124.31	1367.40	109,392.26	2309.39
Longyan	3913.81	5032.04	6150.28	475,248.59	10,064.09
Zhangzhou	2996.13	3719.37	4752.49	361,602.18	7438.67
Xiamen	372.17	471.41	570.66	47,141.08	905.60
Chaozhou	777.90	972.38	1045.30	82,651.93	1847.51
Jieyang	1191.16	1574.03	1914.36	148,895.01	3148.07
Shantou	340.33	510.50	534.81	42,541.43	887.29

4. Results

4.1. Environmental Impact Assessment Results of the Haixi District

By applying the Haixi District emission results of five major pollutants, which was obtained by MEIC, into Formula (1), the environmental impact value of different pollutants in the Haixi District (2008–2016) are calculated and plotted through Origin software (OriginLab, Northampton, MA, USA), as shown in Figure 3. The curve fitting for each pollutant in Figure 3 has a reliable degree of fit ($R^2 \geq 0.5$); therefore, the curve fitting reflects the impact value trend. The environmental impact value trend of air pollutants discharged from the Haixi District from 2008 to 2016 was decreasing. By applying the threshold value of Environmental Impact Assessment (Table 1), it can be concluded that the risk value of CO in the Haixi District is continuously smaller than 1, which means the environmental impact level of CO was at a low level; however, the risk values of SO_2, NO_2, PM_{10}, and $PM_{2.5}$ were greater than 2, which means environmental impact levels of those pollutants were high. To sum up, although the environmental impact value caused by air pollutant emission in the Haixi District was decreasing from 2008 to 2016, the highest environmental impact level was constantly high, and was difficult to reverse in a short term; the primary pollutants were transformed from SO_2 to NO_2, $PM_{2.5}$, and PM_{10}.

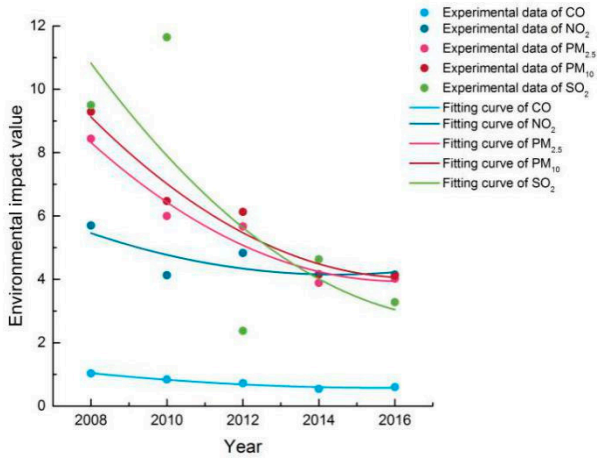

Figure 3. Environmental impact value (V) of pollution discharged in the Haixi District. (Note: $R^2_{co} = 0.96$; $R^2_{NO2} = 0.62$; $R^2_{PM2.5} = 0.95$; $R^2_{PM10} = 0.95$; $R^2_{SO2} = 0.60$).

4.2. Results of the Environmental Impact Assessment on Different Energy Consumption Departments

The results of the Environmental Impact Assessment on energy-generated pollutants from different sectors, such as power, industry, transportation, and housing in the Haixi District are shown in Figure 4. Since the curve fitting of energy-generated pollutants from different departments has a high degree of fit ($R^2 \geq 0.5$), the curve fitting can represent the impact value trend. The level of environmental impact caused by different pollutants from varied departments can be obtained through the impact value of pollutant emissions and in combination with Environmental Impact Assessment standards (Table 1).

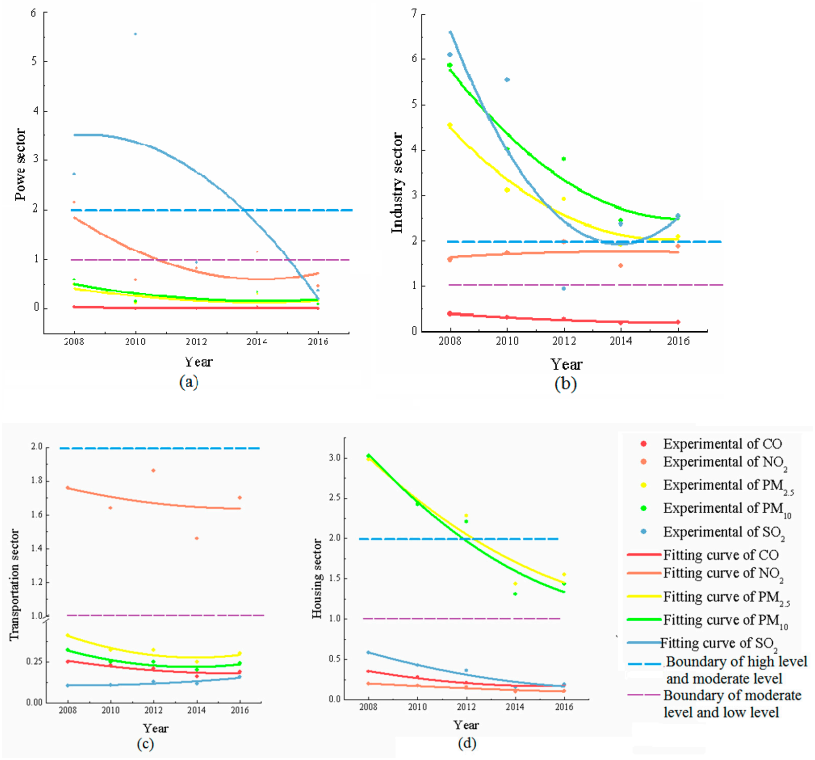

Figure 4. Environmental impact value (V) of pollution discharged in different departments of the Haixi District. (Note: (**a**): Environmental impact value (V) of pollution discharged by the power sector; (**b**): Environmental impact value (V) of pollution discharged by the industrial sector; (**c**): Environmental impact value (V) of pollution discharged by the transportation department; (**d**): Environmental impact value (V) of pollution discharged by the residential sector.)

This research shows: from 2008 to 2016, the environmental impact value trend (Figure 4a) caused by the power sector pollutants was decreasing. Among them, the impact value of PM_{10}, $PM_{2.5}$, and CO was continuously smaller than 1, that is, the environmental impact levels of these pollutants were low; from 2010, the risk value of SO_2 and NO_2 was decreased from greater than 2 to smaller than 1, that is, the environmental impact levels of these two pollutants changed from high to low. It can be seen that in 2010, an important turning point of "the 11th five-year plan in China," the power structure of the Haixi District was optimized and adjusted. A large number of desulfurization and denitrification facilities were put into use [67], and a series of effective related measures were conducted [68].

The environmental impact value of PM_{10}, $PM_{2.5}$, and SO_2 discharged by the industrial sector (Figure 4b) was at a high level. The environmental impact levels corresponding to NO_2 and CO were in the medium and low level respectively and the environmental impact value of the high-level state pollutants was reducing. It showed that from 2008 to 2016, the implementation of energy-saving engineering projects in key areas, such as industrial boiler transformation, residual heat and pressure utilization, and energy system energy saving in the Haixi District had some achievements, but they need to be further promoted. The energy-saving technology transformation and contract energy management policies also needed to be further implemented [69].

The environmental impact value of NO_2 produced by the transportation department (Figure 4c) was decreasing, continually staying at a medium level: between 1 and 2. The environmental impact value of CO, SO_2, PM_{10}, and $PM_{2.5}$ was low, which means the primary pollutant produced by the transportation department was NO_2, and the ownership of motor vehicles, waterway, and air transportation in the Haixi District was increasing exponentially from 2008 to 2016. However, the environmental impact value of NO_2 was decreasing. This phenomenon showed that the construction of green airports, the application of electric motor car, and the law enforcement and inspection were all effective in the study area [69,70]. Those effective practices needed to be further strengthened in the future.

The pollutants generated by the residential sector during the energy consumption process (Figure 4d) were decreasing; the environmental impact value corresponding to SO_2, NO_2, and CO was continued at a low level, and the environmental impact levels corresponding to PM_{10} and $PM_{2.5}$ were dropped from high to the middle. One reason is that the use of natural gas and clean energy was increasing in domestic fuel, and used as an alternative to liquefied petroleum gas [71].

Combined with the definition of fixed source and mobile source in the section "Overview," it can be seen that the three major energy consumption sectors of industrial power and housing are the fixed source of pollution emissions, and the transportation sector is the mobile source of pollution emissions. To sum up, by 2016, for the fixed sources of pollution discharge in Haixi District, among the pollutants discharged by different departments in the Haixi District, the environmental impact level of the power sector was low; the environmental impact level of the industrial sector was high, and the corresponding pollutants were PM_{10}, $PM_{2.5}$, and SO_2; though the corresponding pollutants were PM_{10} and $PM_{2.5}$. Mobile source is the transportation sector, and being the highest environmental impact level sector, the sector was in the moderate.

4.3. Environmental Impact Assessment Results of Different Cities

By applying the Haixi District emission results of five major pollutants, which were obtained by MEIC, into Formula (1), the environmental impact value of different pollutants in the Haixi District (2008–2016) are calculated and plotted through Origin software (OriginLab, Northampton, MA, USA), as shown in Figures 5–8. Then, based on the impact value and combined with the Environmental Impact Assessment criteria (Table 1), this research carried out the Environmental Impact Assessment of different types of pollutants in different cities.

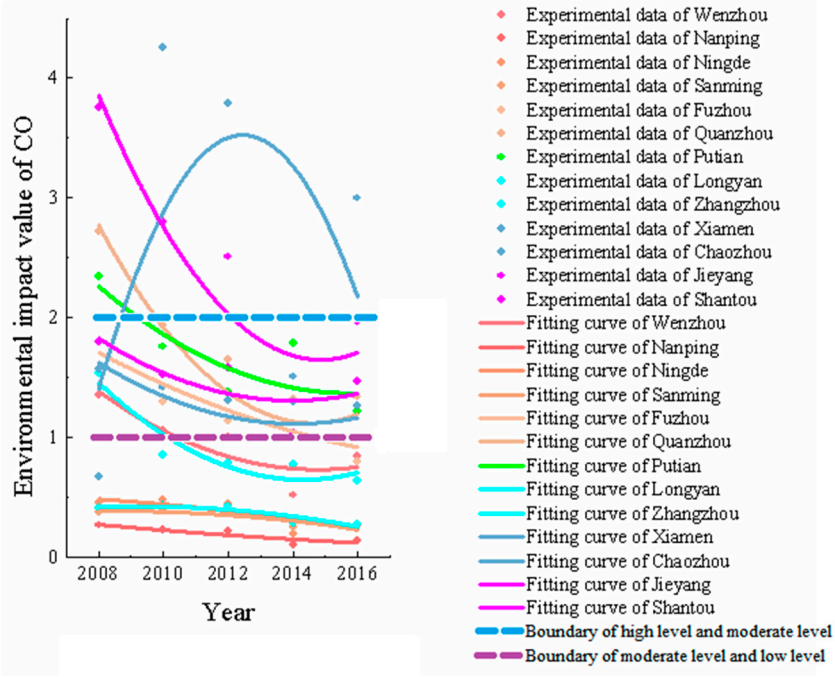

Figure 5. Environmental impact value (V) of CO in different cities. (Note: $R^2_{Wenzhou}$=0.78; $R^2_{Nanping}$ = 0.82; R^2_{Ningde} = 0.66; $R^2_{Sanming}$ = 0.76; R^2_{Fuzhou} = 0.76; $R^2_{Quanzhou}$ = 0.89; R^2_{Putian} = 0.71; $R^2_{Longyan}$ = 0.81; $R^2_{Zhangzhou}$ = 0.89; R^2_{Xiamen} = 0.32; $R^2_{Chaozhou}$ = 0.99; $R^2_{Jieyang}$ = 0.58; $R^2_{Shantou}$ = 0.98).

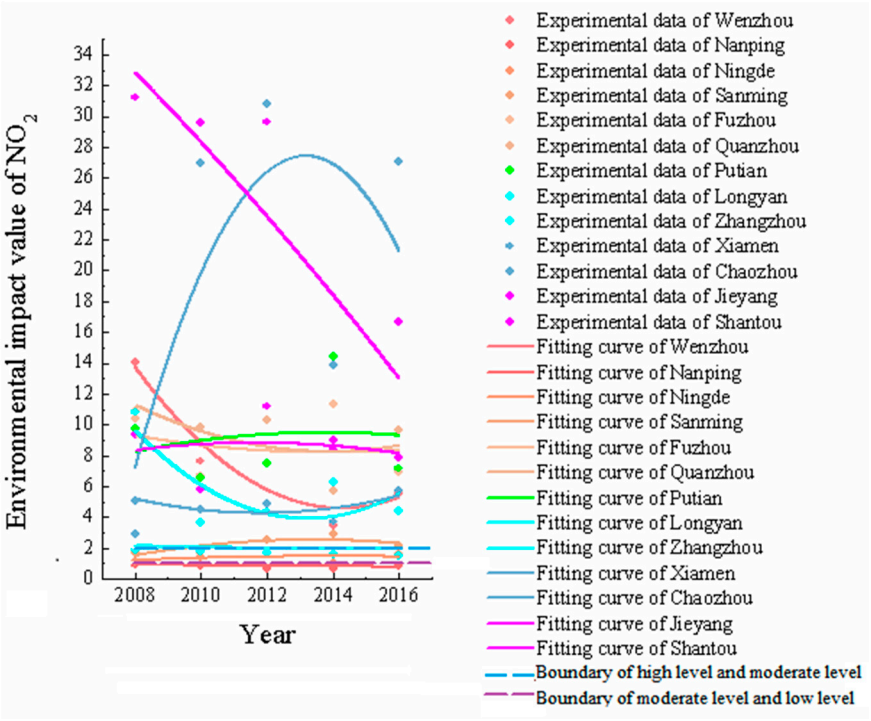

Figure 6. Environmental impact value (V) of NO_2 in different cities. (Note: $R^2_{Wenzhou}$ = 0.91; $R^2_{Nanping}$ = 0.15; R^2_{Ningde} = 0.73; $R^2_{Sanming}$ = 0.65; R^2_{Fuzhou} = 0.04; $R^2_{Quanzhou}$ = 0.36; R^2_{Putian} = 0.0: $R^2_{Longyan}$ = 0.03; $R^2_{Zhangzhou}$ = 0.61; R^2_{Xiamen} = 0.46; $R^2_{Chaozhou}$ = 0.43; $R^2_{Jieyang}$ = 0.02; $R^2_{Shantou}$ = 0.63).

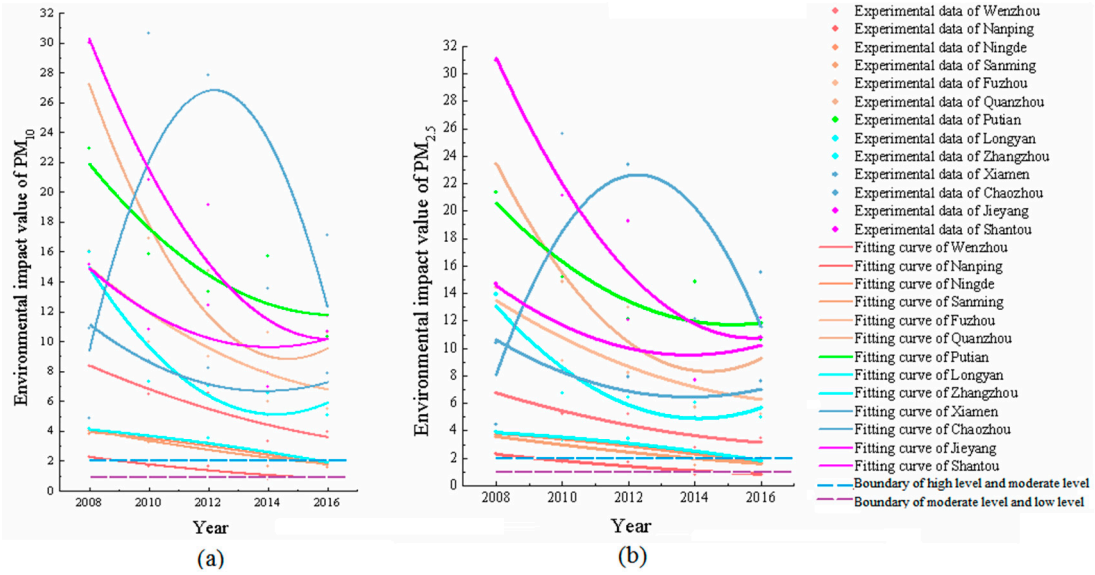

Figure 7. Environmental impact value (V) of PM_{10} (**a**) and $PM_{2.5}$ (**b**) in different cities. (Note: $R^2_{WenzhouPM2.5} = 0.84$; $R^2_{NanpingPM2.5} = 0.87$; $R^2_{NingdePM2.5} = 0.73$; $R^2_{SanmingPM2.5} = 0.83$; $R^2_{FuzhouPM2.5} = 0.76$; $R^2_{QuanzhouPM2.5} = 0.91$; $R^2_{PutianPM2.5} = 0.80$; $R^2_{LongyanPM2.5} = 0.92$; $R^2_{ZhangzhouPM2.5} = 0.88$; $R^2_{XiamenPM2.5} = 0.51$; $R^2_{ChaozhouPM2.5} = 0.75$; $R^2_{JieyangPM2.5} = 0.66$; $R^2_{ShantouPM2.5} = 0.89$; $R^2_{WenzhouPM10} = 0.85$; $R^2_{NanpingPM10} = 0.89$; $R^2_{NingdePM10} = 0.85$; $R^2_{SanmingPM10} = 0.85$; $R^2_{FuzhouPM10} = 0.75$; $R^2_{QuanzhouPM10} = 0.92$; $R^2_{PutianPM10} = 0.80$; $R^2_{LongyanPM10} = 0.93$; $R^2_{ZhangzhouPM10} = 0.87$; $R^2_{XiamenPM10} = 0.51$; $R^2_{ChaozhouPM10} = 0.76$; $R^2_{JieyangPM10} = 0.66$; $R^2_{ShantouPM10} = 0.88$).

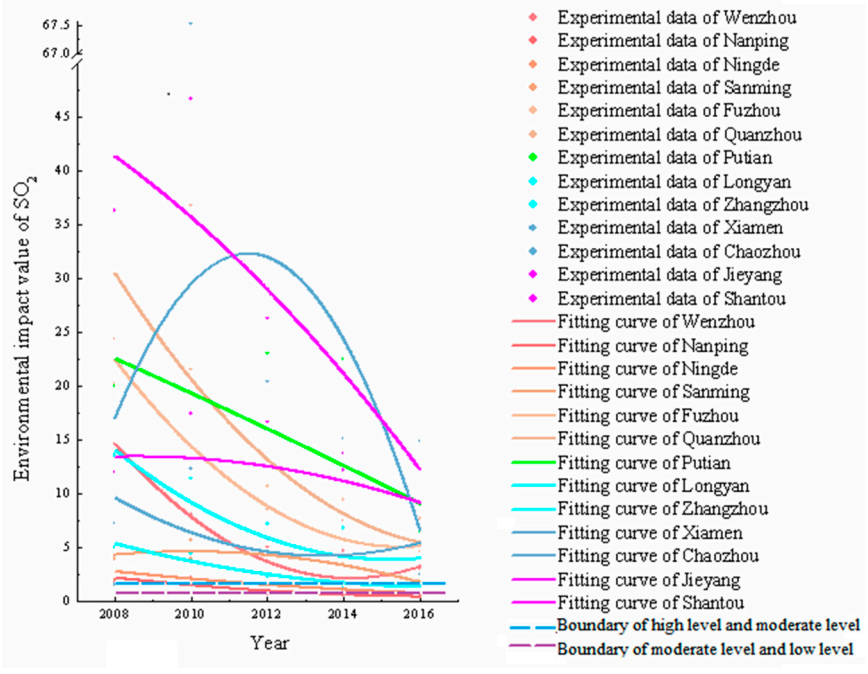

Figure 8. Environmental impact value (V) of SO_2 in different cities. (Note; $R^2_{Wenzhou} = 0.97$; $R^2_{Nanping} = 0.74$; $R^2_{Ningde} = 0.50$; $R^2_{Sanming} = 0.78$; $R^2_{Fuzhou} = 0.88$; $R^2_{Quanzhou} = 0.57$; $R^2_{Putian} = 0.91$; $R^2_{Longyan} = 0.92$; $R^2_{Zhangzhou} = 0.96$; $R^2_{Xiamen} = 0.25$; $R^2_{Chaozhou} = 0.63$; $R^2_{Jieyang} = 0.87$; $R^2_{Shantou} = 0.78$).

The environmental impact value of CO emitted by different cities in the Haixi District is shown in Figure 5. From 2008 to 2016, except the trend of the environmental impact value of pollutants in Xiamen city cannot be determined ($R^2 < 0.5$), the environmental impact value of other urban pollutants showed a downward trend ($R^2 \geq 0.5$). From the perspective of Environmental Impact Assessment, the environmental impact levels of the three inland

cities (Nanping, Sanming, and Longyan) and Ningde city, located in the northeast of the Haixi District, remained at a low level; the environmental impact levels of Chaozhou and Jieyang city, located in Guangdong province, were moderate; the environmental impact level of Xiamen city was low since 2010; while the impact levels of other cities were reduced by one level from 2008 to 2016. It can be seen that from 2008 to 2016, cities with a low level of CO environmental impact were concentrated in inland areas; by 2016, Xiamen city had the highest level of CO environmental impact in the Haixi District.

The Environmental impact value (V) lead by NO_2 in different cities of the Haixi District is shown in Figure 6. It shows that the environmental impact value of Wenzhou, Ningde, Sanming, Zhangzhou, and Shantou city was decreasing 2008 to 2016 ($R^2 \geq 0.5$), while the trend of impact value of other cities could not be determined ($R^2 < 0.5$). However, whether the trend of impact value can or cannot be determined, the environmental impact levels of different urban pollutants remained unchanged. Among them, the environmental impact level of NO_2 in Nanping city was continued at a low level, and that of Ningde and Longyan city was continued at a medium level, while other cities continued to be high. To sum up, from 2008 to 2016, the environmental impact level of NO_2 emitted by different cities in the Haixi District remained unchanged, and the cities with the highest environmental impact levels were concentrated in coastal areas.

The Environmental impact assessment (V) of $PM_{2.5}$ and PM_{10} in different cities in the Haixi district are shown in Figure 7. From 2008 to 2016, the trend of environmental impact value corresponding to the emissions of the 13 cities in the study area is obvious ($R^2 \geq 0.5$). Among them, the environmental impact value of Xiamen city showed an inverted "U" trend, while the environmental impact value of the other 12 cities showed a decreased trend. And the results of the Environmental Impact Assessment show that the environmental impact level of Nanping city was decreased from high to low, the levels of Longyan, Ningde, and Sanming city were reduced from high to moderate, while other cities remained at a high level. In conclusion, from 2008 to 2016, the cities with reduced environmental impact levels were concentrated in inland areas, and the environmental impact level of cities in coastal areas was high.

The Environmental impact assessment (V) of SO_2 in different cities of the Haixi District are shown in Figure 8. From 2008 to 2016, except for the uncertain trend of the Xiamen city's environmental impact value ($R^2 < 0.5$), the environmental impact value of the other 12 cities was decreasing ($R^2 \geq 0.5$). The assessment results showed that the environmental impact levels of Nanping and Ningde City, an inland city, has been decreased from high to low; the environmental impact levels of Longyan and Sanming city had been decreased from high to moderate; although the environmental impact value of other cities was changed, the impact level was continued at a high level. It can be seen that from 2008 to 2016, cities with reduced environmental impact levels were concentrated in internal areas, while cities with high environmental impact levels were concentrated in coastal areas.

4.4. Summary

In general, from 2008 to 2016, the environmental impact level in the Haixi District was high, and the primary pollutants were transformed from SO_2 to $PM_{2.5}$, PM_{10}, and NO_2. The assessment results of different departments in the Haixi District show that from 2008 to 2016, the industrial sector was continued at a high level of environmental impact, and the primary pollutants were PM_{10}, $PM_{2.5}$, and SO_2; the environmental impact of the power and residential sectors gradually decreased from a high level to a medium or low level, and the primary pollutant in the high level of the power sector was SO_2, while the primary pollutant in the residential sector was PM_{10} and $PM_{2.5}$; the environmental impact level of transportation department is moderate, with NO_2 as the primary pollutant. According to the risk assessment results of different urban pollutants in the Haixi District, the environmental impact value of most urban pollutants in the Haixi District was decreasing, while the cities with lower environmental impact levels were concentrated in inland areas, and the cities with higher environmental impact levels were concentrated in coastal areas.

5. Discussion

From 2008 to 2016, the air pollution in the Haixi District was at a high-level state, and the high emission areas were mainly concentrated in the coastal areas. This result was consistent with the research results of Shi and Yang [72] and Lu [73]. The development of key emission sources should be limited, and the development model of low energy consumption and low pollution should be promoted. In the pollution research of multiple sectors, the housing and transportation sectors also have a great impact on the environment, but the existing emission reduction plans were mainly concentrated in the power and industrial sectors. However, housing and transportation also need relevant emission reduction policies [74,75].

At present, there are still some deficiencies in the calculation process of this study. First, although some experts and scholars' research results were referred to in the classification of the environmental impact rating standard, the method adopted was the Delphi method, which has certain subjective randomness and needs to be further improved by combining it with the opinions of multiple departments. Moreover, the data of MEIC is not verified when it is used, and NO_2 was estimated based on the experience value in Shi [76]. In future research, it is necessary to collect relevant data and calibrate them in combination with the actual monitoring data. Due to the difficulty of data acquisition, this study only has 5 years of data, and future research can be based on more years of data. This study did not select a specific function, but tried different functions according to the data. Based on $R^2 > 0.5$ [77], it was considered that there was a trend. In the future, the function can be further studied. In the research process, only five primary pollutants in the ambient air quality standard GB3095-2012 were selected, and the research on secondary pollution (such as O_3) was lacking, so the environmental impact caused by secondary pollutants can be further studied; due to the setting of MEIC data volume, this study can only obtain data from 2008 to 2016, a long-term research can be conducted in combination with the collection of other databases in the future study.

6. Conclusions

By sorting out the previous studies, it is found that, mainly air pollution research was focused on a single sector. Based on the overall assessment of regional pollution, this study carried out Environmental Impact Assessment research from multiple sectors such as agriculture, transportation, industry, electricity, and housing, as well as from different urban perspectives, and constructed a more comprehensive Environmental Impact Assessment model.

Based on the research of the overall Environmental Impact Assessment of Haixi District, it can be seen that from 2008 to 2016, the regional environmental impact level of the Haixi District was high, and the primary pollutants transformed from SO_2 to NO_2, PM_{10}, and $PM_{2.5}$; while the environmental impact level of CO was low, so it can be seen that the prevention measures for CO emission in the Haixi District were in place.

The Environmental Impact Assessment of different energy consumption departments shows that from 2008 to 2016, the environmental impact led by the traffic pollution was moderate, with NO_2 as the primary pollutant; the environmental impact of industrial pollution was high, with SO_2, PM_{10}, and $PM_{2.5}$ as the primary pollutants; the environmental impact caused by residential buildings was decreased from high to low, with $PM_{2.5}$ and PM_{10} as the primary pollutants; the pollution impact of power sector was decreased to a low level. It can be seen that at present, the power sector has used the clean energy big data operation platform, built a variety of power supply joint optimization scheduling model, and continuously increased the proportion of clean power in energy consumption [78]. The transportation sector needs to require local governments to rationally control the number of fuel vehicles and promote new energy vehicles, build corresponding charging stations (piles), gas stations, and other infrastructures. The local government should also encourage industries such as public transport, airports, taxis, environmental health, postal services, express delivery to adopt clean energy, strengthen the construction of urban

pedestrian and bicycle transportation systems, and guide the public to live a low-carbon life. Moreover, it is important to strengthen the supervision of motor vehicles and ships in use and non-road mobile machinery [79]; the industrial sector also needs to implement performance improvement and technical transformation, to gradually improve the low nitrogen combustion transformation, to standardize the operation and management of denitration facilities, to fully implement the coal to gas project, and to further expand and eliminate small coal-fired boilers in enterprises [80]. The residential sector still needs to accelerate the construction of natural gas pipeline network, to increase the supply and use of natural gas, and to increase the proportion of clean energy [81].

From the perspective of different cities to carry out the research of Ecological Risk Assessment, it can be seen that from 2008 to 2016, the cities with higher environmental impact grades in the Haixi District were concentrated in coastal areas, while the environmental impact value of most urban pollutants was decreasing. It can be seen that while developing the economy in the coastal areas, environmental protection and renewable utilization of resources must be taken into account. Effective administrative measures can be taken to strengthen air pollution control in coastal areas and improve air environment quality in the Haixi District [82].

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