ASSESSMENT OF ENVIRONMENTAL KUZNETS CURVES FOR INDUSTRIAL SOLID WASTE IN CHINA

A Thesis

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by

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ABSTRACT

Urbanization and industrialization have caused a sharp growth in solid waste generation and accumulation globally, which imposes a severe burden on the environment. Industrial Solid Waste (ISW), as an essential part of solid waste, has not gotten enough attention for a long time. The paper analyzes the driving forces of ISW generation in China using the Environmental Kuznets Curve (EKC) framework. Based on panel data of 140 cities in China from 2006 to 2015, the study examined the existence of an EKC relationship between per capita income and the generation of ISW. Our results show that the relationship between income level and ISW generation per capita, as the pollution indicator, presents an inverse U-shape, confirming the EKC hypothesis. Only a few cities in China have attained the turning point income level. Therefore, in most Chinese cities, the ISW generation is now increasing with the economic growth. After performing the heterogeneity analysis, we also found that the peak ISW pollution level of the cities would increase with the augment of the proportion of second industry to GDP industrial and the volume of freight of city.

BIOGRAPHICAL SKETCH

Zhongling Yu was born in December 1996 in China. He is a master student major in Applied Economics and Management in Cornell University. He finished his undergraduate study at Stony Brook University, which allows him to set up a quite individualized study plan in both mathematics and economics. The courses he took under mathematics program in undergraduate and graduate studies provide him the ability to complete abstract reasoning and improved his quantitative skills, these becomes his solid foundations for advanced study in economics. His research interests include environmental economics, demographic economics, urban and regional economics, and international trade. Besides being a graduate in economic, he is fond of playing piano, playing go (Weiqi), and marathon running. He is an outgoing person and a man of discipline. He has won the amateur top-level certificate of piano when he was 16 years old and be awarded with Summa Cum Laude in his graduation ceremony at Stony Brook University.

ACKNOWLEDGMENTS

This project would not have been possible without the support of many people. My sincere thanks go to Professor Nancy Chau for guiding this work. I have benefited greatly from your wealth of knowledge and meticulous editing. I am extremely grateful that you took me on as a student and continued to have faith in me over the years.

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1. Introduction

1.1 What is ISW pollution

ISW pollution is a global issue that poses threats to the environment and human society. Because of its complicated composition, ISW management requires high-level disposal technology (Zhou et al., 2017). A massive amount of useless and difficult recycling ISW has to be stored every year. The storage process of ISW releases a large amount of toxic and hazardous substances to the surrounding environment in a relatively slow way through leaching (Liu et al., 2016). In countries without enough financial and technical input, ISW needs to be openly dumped without any protection procedure (Ferronato & Torretta, 2019). The increasing ISW generation is a serious threat to the environment for both developed and developing countries.

1.2 Current ISW Situation in China

In China, the management burdens of ISW are particularly huge. After the reform and opening-up in 1978, the economy of China has experienced unprecedented growth. The industrialization and economic advancement of China also vigorously increased the volume of solid waste generation. As a crucial part of solid waste, ISW takes a majority percentage of total solid waste generated in China. According to *the report of the Ministry of Ecology and Environment of the People's Republic of China*, the total quantities of municipal solid waste (MSW), general industrial solid waste (ISW), and hazardous solid waste (HW) in 2019 were 242 million tons, 4.410 billion tons, and 81 million tons (Fig. 1).[1] With the rapid growth of the industrialization process, the quantity of ISW generated in 2019 has increased by 540% compared with 2000 (Fig. 2). This vast annual generation amount inevitably led to the unrecycled ISW accumulation problem. The total quantity of stored ISW reached 10 billion tons in 2012, and in 2006 alone, the accumulated ISW occupied and destroyed 2 million acres of land (Zhao et al., 2013). The long-term accumulated damage of ISW pollution to the environment has brought a daunting challenge to China. Because China has a long history of recording province-level and city-level ISW management data, it offers an opportunity to study ISW generation trends on a macro scale. For example, the important Industrial province of last century, Liaoning province, has recorded the detailed data of ISW generation and disposal of each city since the 1980s (Xu et al., 2019). Analyzing those ISW data with large region scale and time spans could help understand the solid waste management problem of China and provide policy implications for developing countries that go through rapid economic growth or industrial restructuring processes like China.

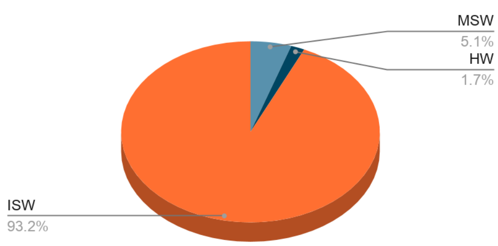
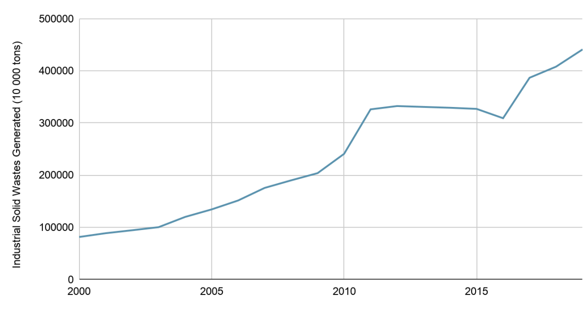


Fig. 1. Composition of solid waste in China (2019)

Fig. 2. Industrial Solid Wastes Generated in China between 2000 and 2019


Source: China Environment Statistical Yearbook

[1] Ecological Environment Statistics Annual Report_Ministry of Ecology and Environment of the People's Republic of China (n.d.). Retrieved March 22, 2021, from https://www.mee.gov.cn/hjzl/sthjzk/

According to *the Law of the People's Republic of China on the Prevention and Control of Environmental Pollution*, solid waste in China is classified into three types: industrial solid waste, municipal solid waste, and hazardous waste. Municipal solid waste (MSW) generally includes waste discharge from everyday life, and hazardous waste (HW) refers to solid waste that is identified to be dangerous according to the identification criteria of the nation or provinces. Industrial solid waste (ISW), also known as general industrial waste, refers to solid waste discharged in industrial production activities such as scrap metal, slag, and mine tailings.[2] Those three types of solid waste can all cause various environmental pollution, and health hazards, due to improper handling and transportation (Sn, 2017).

1.3 Global Scale of Solid Waste

The World Bank solid waste management group (2019) reported 2.01 billion tons of MSW generation globally, with at least 33 percent not treated in an environmentally safe manner. Globally, about 37 percent of waste is disposed of in the landfill.[3] Most developing countries do not have clean incineration technology, therefore facing a significant challenge in MSW recycling. The study shows that in lower-income countries, 93 percent of waste is treated by open dumping.[4] Since open dumping is the lowest cost option for low-income countries, HW is also open dumped in those developing countries. The improper handling of MSW and HW has

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[2] Law of the People's Republic of China on Prevention and Control of Environmental Pollution by Solid Waste -. (n.d.). Retrieved March 22, 2021, from http://english.mofcom.gov.cn/aarticle/policyrelease/internationalpolicy/200703/20070304471567.html

[3] The data was collected by World Bank solid waste experts serving as regional focal points along with support from consultants collecting and documenting information on solid waste management data and practices globally. The data covered 217 countries and economies and 367 cities. https://www.greengrowthknowledge.org/research/what-waste-20-global-snapshot-solid-waste-management-2050

[4] *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050.* (2019, January 7). Green Growth Knowledge Platform. https://www.greengrowthknowledge.org/research/what-waste-20-global-snapshot-solid-waste-management-2050

caused heavy metals pollution in the water, soil, and plants and poses severe risks to people living nearby (Alam & Ahmade, 2013).[5]

1.4 Impacts of ISW pollution in the World

The environmental pollution associated with ISW is also severe. According to The World Bank, for the countries with available ISW generation data, the ISW generation is almost 18 times greater than the municipal solid waste (MSW) (*What a Waste 2.0*, 2019). The management of the large volume of ISW could be costly for the governments. This storage process requires many human resources, material, and land space (Liu et al., 2016). In developing countries without special storage facilities and effective ISW collection systems, many ISW has to be openly dumped. It is reported that from 1960 to 1993, nearly 5000,000 tons of ISW have been dumped of Santo Amaro City of Brazil without any cover or precaution. The heavy metal of ISW persisted in the soil for at least 15 years until 2008 and caused severe soil contamination affecting people's health surrounding the dumping sites, particularly the children (Carvalho et al., 2018). Numerous studies from India, Lebanon, Tanzania, Italy, Greece, etc., have claimed that the poorly managed ISW contaminates groundwater, soil, and the atmosphere, which also poses threats to public health (Rao et al., 2011, El-Fadel et al., 2001, Mbuligwe & Kaseva, 2006, Tarantini et al., 2009, Damalas et al., 2008).

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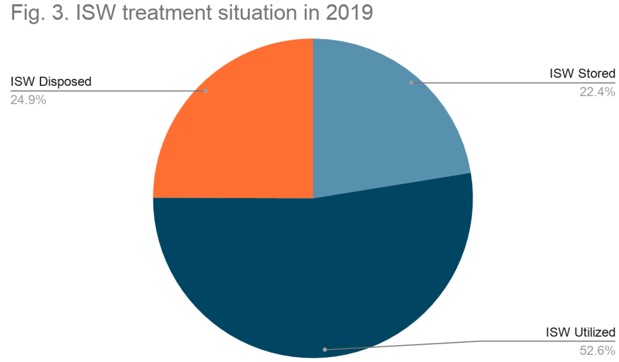
[5] The typical examples and references of various ISW pollution impacts are: water pollution in India (Rao et al., 2011), soil pollution in Brazil (Carvalho et al., 2018), air pollution in Greece (Damalas et al., 2008).

1.5 ISW Management Situation in China

The comprehensive utilization rates and the technique level of recycling of ISW in China are still low in China. Many of the major types of ISW are not widely recycled in China (Wen et al., 2014). In 2016 alone, 626 million tons of ISW were stored or dumped in China.[6] Recognizing the scale of the problem, the Chinese government has been giving increasing weight to the regulation of the level of ISW pollution since the beginning of the present century. Although laws and sustainable policies are being promulgated more frequently, the amount of ISW produced annually is still increasing. About 600 million tons of non-recyclable ISW still need to be stockpiled annually until 2019 (Xu et al., 2019). Figure 3 shows the ISW utilization and storage situation in 2019. The long-term accumulated damage of ISW pollution to the environment is a daunting challenge for China.

Fig. 3. ISW treatment situation in 2019



Source: China Statistical Yearbook of 2020

Many factors influence the generation of solid waste. The growths of urbanization and population were considered as two of the main types of social determinants that affect the generation of solid waste (Mazzanti et al., 2009, Shi et al., 2019, Gui et al., 2019). The rapid

[6] The current situation and anticipation of industry development trend of Industrial solid waste in China (2017). China Environmental Protection Industry. http://www.cnki.com.cn/Article/CJFDTotal-ZHBY201810004.htm

growth of the urban population causes a significant increase in consumption, human activities, which results in the continuous growth of solid wastes. Other social drivers like the increase of income level will also lead to higher demand for resources. As for the case of ISW, the regional industrial structure and the level of industrial development plays a vital role in the generation and discharge of ISW in this region. In China, ten industry sectors generated over 90% of total ISW.[7] ISW generation in provinces and cities was primarily determined by the source sectors and industry companies located in the regions (Huang et al., 2006, Zhai et al., 2020). For example, the Ling Feng City of Shanxi Province is a coal-producing region. The coal-related ISW like coal gangue, mining gauge, coal ash, iron blast-furnace slag, and boiler slag make up 91% of the total waste generated in the region in 2019.[8] With various primitive resources extracted from the natural world, cities have become the areas of concentrated resources and produce large litters simultaneously. According to *the 2019 Annual Report on Prevention and Control of Solid Waste in China*,[9] about 39.3% of ISW generated in 200 large and medium-sized cities cannot be recycled.

1.6 Regulation and Policies of ISW Controlling

Many countries have tried to formulate laws and regulations to curb solid waste generation in the legislation mains (*What a Waste 2.0*, 2019). In high-income countries, solid

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7 The ten industry sectors are: Production and distribution of electric power and heat power, Smelting and processing of ferrous metals, Smelting and processing of non-ferrous metals, Processing of petroleum, coking, processing of nuclear fuel, Mining and processing of ferrous metal ores, Mining and processing of non-ferrous metal ores, Mining and washing of coal, Manufacture of chemical raw materials and chemical products, Manuf. of non-metallic mineral products and Processing of food from agric. products. Source from *China Statistical Yearbook 2020*

8 The 2019 Annual Report on Prevention and Control of Solid Waste in Ling Feng City_Ministry of Ecology and Environment of Ling Feng City. http://sthjj.linfen.gov.cn/contents/2541/626061.html

9 The 2019 Annual Report on Prevention and Control of Solid Waste in China_Ministry of Ecology and Environment of the People's Republic of China. https://www.mee.gov.cn/hjzl/sthjzk/gtfwwrfz/.

waste management is often the responsibility of local governments, such as cities, prefectures, and states. Local agencies oversee the waste services, designing more specific local regulations, and allocating financial resources in waste-related activities. Those operations are often hard to follow in low-income and middle-income countries. Since the lack of laws, shortage of financial resources, solid waste services are challenging to achieve. The deployment efforts of waste policies were constantly challenged by the ambiguity of the policy's guidelines, limited financing, and low staff technical capacity.

China has encountered the same challenges in the ISW management sector. In China, the management and recycling of ISW are the responsibilities of the pollution industries. Local governments have power to supervise, punish and take regulatory actions to close the industries. Provincial governments are also responsible for the direct financial subsidies to encourage the development of local green industries and clean technology upgrading. The government of China has developed a series of national strategies that details the ISW management situation and promotes a green economy (Table 1). The environmental investment in ISW only accounted for 9.72% and 23.53% during the 11th Five Year Plan and 12th Five Year Plan (Price et al., 2011). Since provincial and municipal governments are the primary entities responsible for implementing the central government's macro policies, in cities located in the middle and western parts of China that are highly reliant on the energy economy, following environmental protection policies may also harm the growth rate of the local GDP (Zhao et al., 2014). Because of the lack of standardized pollution punishment systems and financial subsidies for the development of cleaner technology, the accurate performance of ISW regulation enforcement may vary from city to city (Liu et al., 2016). Therefore, to evaluate the overall solid waste regulation stringency and efficiency of the ISW guiding plan of the Chinese central government, instead of case studies, a cross region city-level study in China allowing for city-specific factors of ISW generation is needed.

Table 2
History of Industrial Solid Waste Management in China

Year	National Industrial Solid Waste Policies and Plans
1995	The Solid Waste Pollution Prevention and Control Law
2001	The 10th Five-Year Plan
2006	The 11th Five-Year Plan
2008	Circular Economy Promotion Law of the People's Republic of China
2011	The 12th Five-Year Plan
2012	The 12th Five-Year Plan for bulk Industrial Solid Waste
2015	The revised version of Solid Waste Pollution Prevention and Control Law
2016	Environmental Protection Tax Law of the People's Republic of China
2017	Plan for Prohibiting the Entry of Foreign Garbage and Advancing the Reform of the Solid Waste Import Administration System

Sources: Summarized by author

1.7 ISW and EKC

Unlike most previous studies of ISW issues focusing on accessing the efficiency of ISW treatment process or structure in the ecological or engineering field, the Environmental Kuznets Curve (EKC) approach is applied in this study because of its ability to determine the correlation between each social-economic driving factor and the generation of solid waste. By quantitatively analyzing ISW generation trend at a macro level, our study can provide a clear picture of the ISW generation situation and a feedback understanding about the efficiency of the central government regulation. Estimating the curve and its turning point (if any) could also provide policymakers a useful means to predict future pollution levels and help them make related regulatory policies (Kaika & Zervas, 2013a). Suppose the results show that the income level of many cities has not yet surpassed the turning point. In that case, the country might need to anticipate continuous solid waste growth in the following decades. Governments should implement a more stringent regulation or promote more environmentally friendly technology in the related industries to avoid severe economic and ecological loss accompanied by solid waste accumulation.

2. Literature Review

The literature review will consist of three parts: a summary of the EKC development history, model specifications; a review of papers investigating the EKC on solid waste; a review of case studies exploring the EKC in China using ISW as environmental indicators.

2.1 General EKC Literature

Environmental Kuznets Curve (EKC) was considered one of the empirical hypotheses describing the relationship between the measured levels of environmental indicators and income per capita. It was first proposed by Grossman and Krueger (1991). The hypothesis clarifies that both per capita GDP and pollution would increase during the early stage of economic development, but after per capita GDP reaches a certain level (called turning point), pollution emissions will decrease. This means that the relationship between economic growth and the indicator of environmental degradation will represent an inverted U shape. The reasons that the quality of the environment will be improved after the turning point might be the increase of public environmental awareness, improvements in energy efficiency, or technology. What is worth noting is that economic growth does not automatically improve the environment in the EKC hypothesis. Sound environmental policies may be needed to create better environmental quality in the financial development period. Following this pioneering study, many studies focused on economic development and ecological pollutant nexus have been conducted to examine the EKC hypothesis. Mixed results are produced for the existence of an inverted U-shaped relationship between the pollution indicator and economic index, and the validity of the EKC hypothesis is still controversial. Several reviews cover theoretical developments and empirical studies of the EKC hypothesis (Dinda, 2004; Stern, 2004; Kaika & Zervas, 2013a).

2.2 The WKC Literature

Air quality indicators such as carbon dioxide (CO2) emission (Shafik & Bandyopadhyay, 1992; York et al., 2003; Galeotti et al., 2006; and so forth), sulfur dioxide and nitrous oxide (SO2, NO2) emissions (List & Gallet, 1999, Flores et al., 2009; Cho et al., 2014; and so forth) are most frequently utilized as environmental degradation variables to examine the EKC hypothesis. The ecological degradation indicators of the EKC hypothesis could also be specific types of solid waste; studies that test the nexus between waste generation and income level could be included in the so-called WKC (Waste Kuznets Curve) hypothesis literature. Cole et al. (1997) tested the EKC hypothesis using cross-country panel data of 13 OECD countries from 1975 to 1990, with solid waste generation as one of the environmental indicators, including solid waste generation. The author found no evidence that confirms the WKC hypothesis. Mazzanti and Zoboli (2009) tested the MSW and package waste generation in European countries, using fixed and random effect regressions on the data set of MSW generation of Italian provinces. The study finds that the evidence does not support an inverted U-shape Kuznets curve. Baalbaki & Marrouch (2020) did not find evidence confirming the inverted-U-shaped relationship for MSW using the data of 33 OECD countries between 1995 and 2012. On the other hand, many studies favor the WKC hypothesis (Jaligot & Chenal, 2018, Madden et al., 2019, Cheng et al., 2020, etc.). The results of the WKC literature are mixed. MSW, hazardous waste, aggregated direct material flows and waste electrical and electronic equipment (WEEE) all have been used to indicate environmental degradation in the EKC framework (Boubellouta & Kusch-Brandt, 2021, Seppälä et al., 2001, Mazzanti et al., 2009, etc.). However, few studies have explored the ISW generation and socio-economic development nexus. Our research using the ISW data in China will provide more evidence for the WKC literature.

2.3 Case Studies of ISW in China

Relatively few studies have estimated the EKC hypothesis using Industrial Solid Waste (ISW) as the pollution indicator. Several regional case studies have been conducted in China. Applying the per ISW data of Henan province from 1993 to 2008, Yanrong et al.(2011) analyzed the quantitative relationship between per capita GDP and generation of ISW using the EKC model. They concluded that the increasing ISW was primarily associated with the rapid development of industrial enterprises in Henan province. Based on the time series data of Yulin City from 1996 to 2017, Zhai et al. (2020) conducted a city-level study that explores the nexus between socioeconomic development and industrial "three wastes" emissions (solid waste, wastewater, waste gas). The per capita GDP exhibited an inverted U-shaped nexus with per capita industrial solid waste production, which supported the EKC hypothesis. The authors also calculated that the turning point would be in 2021 according to the GDP growth rate of Yuling City. Instead of analyzing the ISW, Shi et al. (2019) tested the EKC hypothesis using municipal solid waste (MSW) as a pollution indicator. Based on 258 prefecture-level cities' panel data, they found no evidence supporting an inverted U-shape curve between MSW generation and economic growth at the national level. According to our best knowledge, a national-level study analyzing the ISW generation within the EKC framework has never been conducted in China. We will fill this gap in the present literature.

3. Empirical Methodologies

The classic EKC hypothesis holds that the relationship between environmental quality deteriorates, and economic growth represents an inverted U-shaped curve, which means that pollution will increase with the economic development and then reverse. In subsequent studies, scholars have observed that the relationship might be an N-shaped, inverted N-shaped, or U-shaped when using a cubic model (Grossman & Krueger, 1995; Bednar-Friedl & Getzner, 2003; Lorente & Álvarez-Herranz, 2016).

A panel data set will be used instead of cross-sectional data in those models since panel data doesn't assume that a typical structure exists across all countries at a certain period (Wooldridge, 2010). Because no clear evidence of the advantages of logarithmic specification models, as Mazzanti et al. (2009) has noted, the traditional EKC functional form was utilized in the study.

A simple quadratic model tests the EKC hypothesis by specifying a reduced form:

$$ISW_{it} = \alpha + \beta_1 (GDPPC_{it}) + \beta_2 (GDPPC_{it})^2 + \sum_{j=1}^{k} \delta (X_{jt}) + \epsilon_{it} \quad (1)$$

Following Cheng et al. (2020), analyzing the EKC hypothesis of MSW in China. The cubic regression in our model is as follows:

$$ISW_{it} = \alpha + \beta_1 (GDPPC_{it}) + \beta_2(GDPPC_{it})^2 + \beta_3(GDPPC_{it})^3 + \sum_{j=1}^{k} \delta \, (X_{jt}) + \epsilon_{it} \qquad (2)$$

Where ISW refers to Industrial Solid Waste generation, GDPPC refers to the gross domestic product per capita; Delta is a vector of variables that contain other variables that might affect ISW generation. The details of those control variables in the study are shown in Section 5.1. i is the city, t is the year, and ϵ is the error term.

We will examine whether β_1 and β_2 are positive and negative, respectively, and whether they are statistically significant in the regression if β_1 is positive and statistically significant. At the same time, simultaneously, β_2 is negative and statistically significant. There is an inverted-U-shaped curve that confirms the EKC hypothesis.

The turning point τ, where ISW generation will no longer increase with GDP growth, is calculated as follows: $\tau = \beta_1 / (-2\beta_2)$ in the simple quadratic model (1)

The relationship between environmental degradation and economic growth may take several forms.

1. If $\beta_1>0$ and $\beta_2<0$ and $\beta_3=0$, there will be a classical inverted U-shaped EKC.
2. If $\beta_1<0$ and $\beta_2>0$ and $\beta_3=0$, there will be a U-shaped relationship between environmental degradation and economic development.
3. If $\beta_1<0$ and $\beta_2<0$ and $\beta_3>0$, there will be an N-shaped relationship, which suggests that environmental degradation will rise again beyond a certain income level.
4. If $\beta_1<0$ and $\beta_2>0$ and $\beta_3<0$, there will be an inverted N-shaped relationship, which suggests that the environmental quality will improve again beyond a certain income level.

According to Diao et al. (2009) and Lorente & Alvarez (2016), in the cubic model, the following form could be used to estimate the turning points:

$$\tau_{\mathrm{j}} = \frac{-\beta_2 \pm \sqrt{{\beta_2}^2 - 3\beta_1\beta_2}}{3\beta_3}, \ \forall j = 1,2$$

Where τ_1 represents the first turning point and τ_2 is the second. If none of the three β are equal to zero. We would have to calculate two turning points.

If $\beta_1=0$ and $\beta_2=0$ and $\beta_3=0$, there is no relationship between ISW and GDPPC.

If $\beta_1>0$ and $\beta_2=0$ and $\beta_3=0$ or $\beta_1<0$ and $\beta_2=0$ and $\beta_3=0$, there would be a monotonic increasing or decreasing relationship between ISW and GDPPC.

If $\beta_1>0$ and $\beta_2<0$ and $\beta_3=0$ or $\beta_1<0$ and $\beta_2>0$ and $\beta_3=0$, we can obtain the turning points at $\tau = \beta_1 / (-2\beta_2)$ by setting the derivatives of model (2) equal to zero. This is the case in the results of our study.

4. Data

The data source of our study is Chinese province-level Statistical Yearbooks (2005-2016) and China City Statistical Yearbooks (2005-2016). The data are reported by local administrative departments of provinces, autonomous regions, and municipalities directly under the central government. Details of the explanation of variables, measures, and data sources in the data can be found in Tables 2 and 3. After merging the data sets by city names, a panel of 140 cities (including province-level municipalities) covering 2005-2016 was built. The sample consists of cities from different regions of China with diverse economic development levels. The volume of ISW generated by those cities accounts for about 45% of the total ISW generation in China. We have selected this period from 2005-2016 as reference years for our study because this is the most recent data set that can be collected with the maximum number of cities. Other period options will have much fewer observations.[10]

The cities are classified by provinces and the Chinese city tier system.[11] The Chinese city tier system is a hierarchical classification that ranks 338 Chinese cities on six tiers: tier 1, new tier 1, tier 2, tier 3, tier 4, and tier 5. This system measures a city's development level and potential. The system is introduced to the analysis since it may indicate that high-class cities would be more likely to be developed beyond the turning point of the EKC hypothesis.

Table 2
Variables, Measures, and Data Sources

Symbol	**Variables**	**Measures**	**Predicted Relationship**	**Data sources**
ISW	ISW	The volume of Industrial Solid Waste Produced (10000tons)	Dependent variable	China Province Statistical Yearbooks 2005-2016
ISWPC	ISW per capita	The volume of Industrial Solid Waste Produced per capita (ton)	Dependent variable	China Province Statistical Yearbooks 2005-2016
GDP	GDP per capita	Gross Domestic Product per capita (yuan)	Independent variable	China City Statistical Yearbooks 2005-2016
SIP	Secondary Industry as Percentage to GDP	Secondary Industry as Percentage to GDP (%)	Control variables	China City Statistical Yearbooks 2005-2016
IOV	Gross Industrial Output Value per capita	Gross Industrial Output Value per capita (yuan)	Control variables	China City Statistical Yearbooks 2005-2016
WW	Industrial Waste Water discharged per capita	The volume of Industrial WasteWater Discharged per capita (ton)	Independent variable	China City Statistical Yearbooks 2005-2016
DUS	Industrial Soot (Dust) discharged per capita	The volume of Industrial Soot (Dust) emissions per capita (100g)	Independent variable	China City Statistical Yearbooks 2005-2016

[10] China has a long history in recording the city level ISW data in the Province Statistical Yearbooks, the earliest data could be traced back to 1980s in Liaoning Province, However, there are still many provinces that don't report the data to the public until now, most of the available data were reported after 2005. Appendix 1 shows the data availability between 1988 to 2018.

[11] Hernández, M. China city tiers. *South China Morning Post* http://multimedia.scmp.com/2016/cities/img/cover.jpg.

SO2	Industrial Sulfur Dioxide discharged per capita	The volume of Industrial Sulfur Dioxide Discharged per capita (100g)	Independent variable	China City Statistical Yearbooks 2005-2016
GCA	Green Coverage Area of Complete Region per capita	Green Coverage Area of built-up area (m^2)	Control variables	China City Statistical Yearbooks 2005-2016
RGCA	Green Covered Area as % of Completed Area	Green Covered Area as % of Completed Area (%)	Control variables	China City Statistical Yearbooks 2005-2016
RISW	Comprehensively Utilized Rate of General Industrial Solid Wastes	Comprehensively Utilized Rate of General Industrial Solid Wastes (%)	Control variables	China City Statistical Yearbooks 2005-2016
FDI	Amount of Foreign Capital Utilized per capita	Amount of Foreign Capital Utilized (USD)	Control variables	China City Statistical Yearbooks 2005-2016
IOVF	Gross Industrial Output Value by Foreign Funded Enterprise per capita	Gross Industrial Output Value by Foreign Funded Enterprise (yuan)	Control variables	China City Statistical Yearbooks 2005-2016
TFT	Total Freight Traffic per capita	Total Freight Traffic per capita (ton)	Indicator variables	China City Statistical Yearbooks 2005-2014

Table 3
Detail Explanation of Main Statistical Indicators

Variable description	Detail variable explanation
The volume of Industrial Solid Waste Produced	The total volume of solid, semi-solid, or high concentration liquid residuals produced by industrial enterprises in their production process, including residuals from melting, slag, powdered coal ash, gangue, chemical residues, tailings, radioactive residues, and other residues.
Gross Regional Product (GRP) or Regional "GDP"	All resident units in a region produce the final products at market prices during a certain period.
Secondary Industry as Percentage to GDP	The secondary industry refers to mining and quarrying (not including support activities for mining), manufacturing (not including repair service of metal products, machinery, and equipment), production and supply of electricity, heat, gas, water, and construction.
Gross Industrial Output Value	The final industrial products and services produced by industrial enterprises in a region during a certain period.
The volume of Industrial Wastewater Discharged	the aggregate of wastewater discharged to outsides through all factory drains by industrial enterprises. Included are released wastewater of production and factory sanitary drainage, direct cooling water, and the poisonous and harmful mine groundwater

	released by mining areas. Excluded are the indirect cooling water discharged to the outsides.
The volume of Industrial Sulfur Dioxide Discharged	The aggregate of sulfur dioxide emission to the air during the production and fuel combustion at the factory
The volume of Industrial Soot (Dust) emissions	The aggregate of industrial soot(dust) emission to the air during the production and fuel combustion at the factory
Comprehensively Utilized Rate of General Industrial Solid Wastes	The percentage ratio of General industrial solid waste comprehensively utilized to the sum of production amount of general solid waste and the previous storage capacity
Green Coverage Area of built-up area	the vertical projection area of trees, shrubs, lawns, and other vegetation in construction land area, including public green space, residential area, green land attached to institutions, green protection land, green production land, and scenic forest land, according to the Urban Greening Regulations.
Amount of Foreign Capital Utilized	The foreign capital utilized approved contracts, which are the actual payment amount by foreign investors according to the regulations of approved contracts, and one part of the total amount of enterprise investment loans from foreign investors' funds overseas.
Total Freight Traffic per capita	The weight of freight transported with various means with a specific period. Freight transport is calculated in terms of the actual weight of the goods and takes no account of the type of freight and distance of travel.

Variables

The **ISWPC** is the dependent variable, and it is calculated by dividing the total ISW by the number of inhabitants in the city. Following the previous studies that analyzing the MSW, ISW, E-waste (Boubellouta & Kusch-Brandt, 2021, Tang et al., 2020, Mazzanti et al., 2009), we use the weight of solid waste to measure its pollution level.

In the study, gross domestic product per capita, measured with the current nominal value of RMB, is used as a proxy for the per capita income of each city. A set of control variables that could influence ISW generation are included. Most of them are the first introduced in the ISW literature. We control the industry composition of cities by using *Secondary Industry as a Percentage of GDP* and the *Gross Industrial Output Value per capita* as a proxy. To measure the environmental protection stringency of the cities, we use *Per Capita Industrial Wastewater, Soot (Dust), and Sulfur Dioxide Discharged* as the indicators. We would also expect a positive relationship between those three pollutants and ISW since industrial solid waste is likely produced together with other industrial pollutants. We also control for the *Green Coverage Area of Complete Region per capita, Green Covered Area as % of Completed Area,* and *Comprehensively Utilized Rate of General Industrial Solid Wastes*. These three variables could represent the government's ability to protect the city's environment. Accordingly, we would expect a negative relationship between the two proxies and the ISW generation: *Per capita Amount of Foreign Capital Utilized and Gross Industrial Output Value by Foreign Funded Enterprise* controls different technologies. The signs of their coefficients would indicate the relationship between the introduction of foreign capital and ISW generation.

Table 4
Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ISW per capita	1220	2.946	7.818	.009	218.411
GDP per capita	1220	41941.047	31270.676	3761.414	467749
Secondary Industry as Percentage to GDP	1220	49.564	9.437	18.57	82.28
Gross Industrial Output Value per capita	1220	78041.24	96836.26	1337.152	762626.04
Gross Industrial Output Value by Foreign Funded Enterprise per capita	1220	10633.183	25005.824	3.042	265522.67
Amount of Foreign Capital Utilized per capita	1220	200.159	310.49	.074	2727.973
Industrial Waste Water discharged per capita	1220	19.914	20.138	.738	181.144
Industrial Sulfur Dioxide discharged per capita	1220	168.99	184.092	.573	2128.198
Industrial Soot (Dust) discharged per capita	1220	87.102	117.592	.58	1204.664
Comprehensively Utilized Rate of General Industrial Solid Wastes	1220	82.161	20.958	.82	100
Green Coverage Area of Complete Region per capita	1220	16.111	20.127	.121	226.965
Green Covered Area as % of Completed Area	1220	39.656	12.66	.39	376.58

Table 5
Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) iswpc	1.000											
(2) gdp	0.074	1.000										
	(0.009)											
(3) sip	0.199	0.152	1.000									
	(0.000)	(0.000)										
(4) iov	0.045	0.796	0.252	1.000								
	(0.114)	(0.000)	(0.000)									
(5) iovf	-0.052	0.662	0.015	0.796	1.000							
	(0.069)	(0.000)	(0.609)	(0.000)								
(6) fdi	0.001	0.643	0.060	0.669	0.748	1.000						
	(0.964)	(0.000)	(0.036)	(0.000)	(0.000)							
(7) ww	0.085	0.372	0.278	0.480	0.473	0.454	1.000					
	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)						
(8) so2	0.283	0.077	0.411	0.117	0.007	0.025	0.323	1.000				
	(0.000)	(0.007)	(0.000)	(0.000)	(0.819)	(0.374)	(0.000)					
(9) dus	0.383	0.105	0.218	0.057	-0.065	-0.013	0.094	0.601	1.000			
	(0.000)	(0.000)	(0.000)	(0.047)	(0.022)	(0.652)	(0.001)	(0.000)				
(10) risw	-0.268	0.090	0.004	0.117	0.130	0.088	0.028	-0.258	-0.227	1.000		
	(0.000)	(0.002)	(0.885)	(0.000)	(0.000)	(0.002)	(0.326)	(0.000)	(0.000)			
(11) gca	0.095	0.497	0.061	0.614	0.647	0.614	0.467	0.311	0.182	-0.006	1.000	
	(0.001)	(0.000)	(0.034)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.838)		
(12) rgca	0.045	0.173	0.143	0.270	0.274	0.279	0.297	0.096	0.024	0.056	0.371	1.000
	(0.117)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.394)	(0.049)	(0.000)	

The descriptive statistics and the pairwise correlation of variables are shown in Table 4 and Table 5. ISW generation per capita has a significant positive correlation with Per Capita Industrial Soot (Dust), Sulfur Dioxide Discharged, and Secondary Industry as Percentage to GDP. In contrast, the correlation of ISW generation per capita with the Comprehensively Utilized Rate of ISW is strong but negative. Because Gross Industrial Output Value per capita is highly correlated with GDP per capita and Gross Industrial Output Value by Foreign Funded Enterprise per capita, it is not included in the model.

5. Empirical findings

5.1 WKC analysis

We begin the analysis by examining the relationship between ISW and GDP with the cubic model (2).

$$ISW_{it} = \alpha + \beta_1 (GDPPC_{it}) + \beta_2(GDPPC_{it})^2 + \beta_3(GDPPC_{it})^3 + \sum_{j=1}^{k} \delta (X_{jt}) + \epsilon_{it} \quad (2)$$

X_{it} includes other control variables for the city i at time t; nine control variables are included. The nine control variables included in the model are: Secondary Industry as Percentage to GDP, Gross Industrial Output Value by Foreign, Funded Enterprise per capita, Foreign Capital Utilized per capita, Industrial Wastewater Discharged per capita, Industrial Sulfur Dioxide Discharged per capita, Industrial Soot (Dust) emissions per capita, Comprehensively Utilized Rate of General Industrial Solid Wastes, Green Coverage Area per capita and Green Covered Area as % of Completed Area. Under the EKC hypothesis, the coefficient β_1 is expected to be positive, and β_2 is expected to be negative.

One of the estimation issue concerns is to choose between fixed and random effects estimation methods for panel data. We have employed the Hausman specification test to determine the estimation method. The results reject all the assumptions of the random-effects model; therefore, the fixed-effects method is selected for the panel data. We also tested the for time-fixed effects, the result is that: Prob>F is 0.8483 > 0.05, so we fail to reject the null that the coefficients for all years are jointly equal to zero, therefore time fixed effects are not needed in this case.

After decided the estimation method used, we first estimate the basic model without any control variables then add all control to the model. The results are shown in Table 6. The results of the two models both indicate that $\beta_1>0$ and $\beta_2<0$ and $\beta_3=0$. The estimated values of β_1 (coefficient of GDP per cap) and β_2 (coefficient of GDP.cap square) are positive and negative respectively and statistically significant, confirming the classical EKC hypothesis that there is an inverted U-shape between pollution and economic growth.

Our results provide supporting evidence for the EKC hypothesis, which is in line with other previous studies that use solid waste as environmental degradation indicators, such as Mazzanti et al. (2008) for Italy, Jaligot and Chenal (2018) for Switzerland, and Boubellouta & Kusch-Brandt (2020) for 30 European countries.

Table 6
Estimated Results of WKC analysis

VARIABLES	(1) basic model	(2) the model with control variables
Per capita GDP	0.000146***	0.000154**
	(4.59e-05)	(6.49e-05)
Square of per capita GDP	-8.12e-10***	-8.69e-10**
	(2.86e-10)	(4.10e-10)
Cubic of per capita GDP	0***	0**
	(0)	(0)
Secondary Industry as Percentage to GDP		-0.0407
		(0.0724)
Gross Industrial Output Value by Foreign Funded Enterprise per capita		-1.43e-05
		(1.57e-05)
Foreign Capital Utilized per capita		-0.000532
		(0.000863)
Industrial Wastewater Discharged per capita		0.00437
		(0.0181)
Industrial Sulfur Dioxide Discharged per capita		0.00618
		(0.00633)
Industrial Soot (Dust) emissions per capita		0.0116**
		(0.00447)
Comprehensively Utilized Rate of General Industrial Solid Wastes		-0.0235
		(0.0208)
Green Coverage Area per capita		-0.00715

		(0.0144)
Green Covered Area as % of Completed Area		-0.0156
		(0.0144)
Constant	-1.324	1.292
	(1.293)	(2.976)
Observations	1,220	1,220
R-squared	0.028	0.053
Number of cities	140	140
City FE	YES	YES
Year FE	NO	NO
Turning point (US dollars)	**13581.7*****	**13329.7****

The turning point is calculated as $\tau = \beta_1 / (-2\beta_2)$ by setting the derivatives of model (2) equal to zero, when $\beta_1>0$ and $\beta_2<0$ and $\beta_3=0$.
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The turning point is calculated between 13329.7 US dollars and 13581.7 US dollars.[12] The EKC hypothesis implies that the pollution level will decrease when the regional income level increases until reaching this turning point. In 2016, seventeen cities of 115 observations were above the threshold (Table 7). In 2008, there was only one city of 91 observations above this point.

Table 7
List of cities above the turning point income level

City	province	city class	sip	risw
Dongying	Shandong	Tier 3	62.170	93.740
Foshan	Guangdong	Tier 2	59.630	86.200
Nanjing	Jiangsu	New Tier 1	39.200	85.800
Xiamen	fujian	Tier 2	40.820	84.440
Huhehaote	Neimenggu	Tier 3	27.870	43.780
Dalian	Liaoning	New Tier 1	41.850	95.310
Weihai	Shandong	Tier 3	45.560	95
Guangzhou	Guangdong	Tier 1	29.420	96.480
Hangzhou	Zhejiang	New Tier 1	36.420	85.120
Wuhan	Hubei	New Tier 1	43.880	97.450
Jinan	Shandong	Tier 2	36.240	99.130
Zibo	Shandong	Tier 3	52.480	95.790
Shenzhen	Guangdong	Tier 1	39.910	40.850
Yantai	Shandong	Tier 2	49.980	82.920
Zhuhai	Guangdong	Tier 2	48.500	93.640
Changsha	Hunan	New Tier 1	48.230	94
Qingdao	Shandong	New Tier 1	41.560	93.760

[12] The Currency unit of the turning points income level is converted from the RMB to US dollars using the average exchange rate for the year of 2016. https://www.exchangerates.org.uk/CNY-USD-spot-exchange-rates-history-2016.html

The coefficient signs of *Amount of Foreign Capital Utilized, Green Coverage Area of Complete Region, Green Covered Area as % of Completed Area, Comprehensively Utilized Rate of General Industrial Solid Wastes* and *Gross Industrial Output Value by Foreign Funded Enterprise* are negative as expected. The coefficient signs of *Industrial Soot (Dust), Industrial Wastewater, and Sulfur Dioxide Discharged* are positive as expected. Once these variables are introduced, the EKC coefficients are still significant.

5.2 Heterogeneity WKC analysis

The previous WKC studies rarely involve heterogeneity analysis, and the regional differences that may affect the WKC results are often ignored. Since China is a country with vast territory and various city types, there are significant gaps in social factors and economic levels in different Chinese cities and regions. It is possible that those differences between cities could influence the WKC relationship and the resulting turning points. In this section, we selected five social and political characteristics: industrial manufacturing levels, ability to monitor pollution levels, legal regulations, the volume of freight, and exposure to foreign direct investments. The cities in the panel data are graded to high, medium, and low levels by those characteristics.[13] We performed the WKC analysis in each subsection and compared the results.

[13] The cities' Freight level are graded according to the data of China City Statistical Yearbook 2015, the other four city characteristics are graded by the data collected from China City Statistical Yearbook 2017. Cities in the first 25% in ranking are classified as high level; cities in between 25% and 75% in ranking would be classified as medium level; and cities in the lowest 25% are classified as low level.

5.2.1 Industrial manufacturing ability

Table 8
Estimated results of Heterogeneity WKC analysis (a)

VARIABLES	Cities in different Industrial manufacturing levels		
	(1) high level	(2) medium level	(3) low level
Per capita GDP	0.000379	0.000114**	0.000101***
	(0.000310)	(4.48e-05)	(3.16e-05)
Square of per capita GDP	-3.18e-09	-5.89e-10**	-8.87e-10**
	(3.64e-09)	(2.35e-10)	(3.67e-10)
Cubic of per capita GDP	0	0**	0*
	(0)	(0)	(0)
Constant	-6.304	-0.712	0.109
	(6.897)	(1.349)	(0.631)
Observations	287	597	336
R-squared	0.030	0.090	0.144
Number of cities	36	68	36
Turning point (US dollars)	8964.6	**14602.8****	**8546.4****

The turning point is calculated as $\tau = \beta_1 / (-2\beta_2)$ by setting the derivatives of model (2) equal to zero, when $\beta_1>0$ and $\beta_2<0$ and $\beta_3=0$.
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

It is often considered in the previous literature that the city's industrial manufacturing level could be the key factor affecting the cities' ISW generation situation. Li et al. (2016) conducted the Hierarchical Clustering analysis to study the ISW generation and treatment situation in the major cities of China. Their clustering results show that the cities with high industrial manufacturing ability and the high proportion of Secondary Industry to GDP, such as Chongqing and Kunming, would have higher ISW emission amounts. The study concluded that the ISW generation mainly corresponds with the industrial structure of the cities, which consisted of other ISW literature (Huang et al., 2006, Zhai et al., 2020). In the cities where GDP highly relies upon the second industry, the municipal governments have to make the local decision between lower GDP and lower ISW pollution volume (Xu et al., 2019). The central government's environmental policies may be weakened in those cities, and the relationship between ISW and GDP could be different.

We used the Secondary Industry as Percentage to GDP as the indicator of cities' industrial manufacturing level. After grading the cities in our panel data to high, medium, and low levels and performing the WKC regression at each level, the results show that the turning point in the cities with low industrial manufacturing levels is much lower than the medium-level cities. The results are shown in Table 8. As the economy grows, the cities with lower industrial composition have a lower turning point of income level than cities with higher industrial composition. The results indicate that cities concentrated with primitive source sectors and industry companies are harder to reach the pollution peak point than other cities.

5.2.2 Environmental Regulation Stringency and Pollution Management Ability

Table 9
Estimated Results of Heterogeneity WKC analysis (b)

VARIABLES	Cities in different levels of environmental regulation stringency			Cities in different levels of pollution management ability		
	(1) high level	(2) medium level	(3) low level	(1) high level	(2) medium level	(3) low level
Per capita GDP	0.000179**	0.000176	4.11e-05	3.44e-05	0.000106***	0.000328*
	(7.03e-05)	(0.000135)	(4.69e-05)	(3.01e-05)	(2.83e-05)	(0.000166)
Square of per capita GDP	-1.01e-09**	-1.18e-09	7.75e-10	-2.01e-10	-6.96e-10***	-1.57e-09
	(4.28e-10)	(1.59e-09)	(2.75e-09)	(3.29e-10)	(2.13e-10)	(1.36e-09)
Cubic of per capita GDP	0**	0	-0	0	0***	0
	(0)	(0)	(0)	(0)	(0)	(0)
Constant	-2.496	-1.785	0.358	0.572	-0.755	-3.768
	(2.613)	(2.915)	(0.299)	(0.655)	(0.886)	(3.966)
Observations	330	543	247	245	539	336
R-squared	0.134	0.017	0.165	0.100	0.154	0.046
Number of cities	31	62	32	30	58	37
Turning point	**13350.4***	11236.6	3990.6	12876.6	**11452.8*****	**15726.4***

(US dollars)

The turning point is calculated as $\tau = \beta_1 / (-2\beta_2)$ by setting the derivatives of model (2) equal to zero, when $\beta_1>0$ and $\beta_2<0$ and $\beta_3=0$.
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 10
Summary statistic of cities in different levels of pollution management ability

	High level				Medium level				Low level			
VARIABLES	N	mean	min	max	N	mean	min	max	N	mean	min	max
gdp	245	39,050	5,093	185,338	539	47,991	3,761	290,477	336	36,149	4,853	467,749
risw	245	95.56	30.90	100	539	86.95	14.86	100	336	66.45	0.820	100
iswpc	245	1.518	0.0351	14.56	539	2.430	0.00885	24.19	336	5.186	0.00874	218.4
Number of cities	30	30	30	30	58	58	58	58	37	37	37	37

The difference in legal regulation and pollution management ability are also considered as important factors that could influence the WKC relationship and turning points in the previous literature (Cheng et al., 2020, Kaika & Zervas, 2013a). The cities or provinces are considered to have more support and ability to curb the ISW emission if they have a stricter environmental regulation or more power to manage and monitor the pollution level. Although all the provincial and municipal governments in China had to follow the national environmental protection plan and resource use policies, there is still no unified and adequate national standard ISW management system (Liu et al., 2016). Local governments have to make their own waste control regulation. Therefore, the intensity of punishment and monitor for ISW pollution varies from city to city. Following the study of Zhou et al. (2017), we utilized the green covered area per capita as a proxy to measure the stringency of environmental regulation and the comprehensive utilization rate of ISW as indicators to measure the cities' waste monitor and management ability levels. From Table 9, we could see from the results that the turning points do not vary much from the previous results. Since the coefficients of the WKC for several levels of environmental regulation stringency and waste management ability are not statistically significant. However, the summary statistic (Table 10) shows that the ISW pollution generated per capita decrease with the comprehensive utilization rate of ISW level of cities. The cities with a high level of waste utilization rate could also be the cities with fewer concentrated industrial factories.

5.2.3 FDI and Total Freight

Table 11
Estimated Results of Heterogeneity WKC analysis (c)

VARIABLES	Cities in different levels of foreign direct investment			Cities in different levels of the total volume of freight		
	(1) high level	(2) medium level	(3) low level	(1) high level	(2) medium level	(3) low level
Per capita GDP	6.92e-05**	0.000191	9.31e-05	0.000191***	0.000240*	0.000175**
	(3.05e-05)	(0.000167)	(7.67e-05)	(6.41e-05)	(0.000135)	(7.87e-05)
Square of per capita GDP	-3.82e-10**	-3.24e-10	-6.18e-10	-9.48e-10***	-2.48e-09*	-3.30e-09**
	(1.83e-10)	(2.19e-09)	(2.37e-09)	(3.32e-10)	(1.45e-09)	(1.49e-09)
Cubic of per capita GDP	0*	-0	0	0***	0*	0**
	(0)	(0)	(0)	(0)	(0)	(0)
Constant	-0.359	-2.505	0.389	-2.010	-2.632	-1.348
	(1.125)	(3.480)	(0.790)	(2.125)	(2.978)	(1.160)
Observations	297	522	301	364	623	224
R-squared	0.148	0.034	0.250	0.166	0.015	0.204
Number of cities	31	63	31	36	68	34
Turning point (US dollars)	**13631.8****	44235.0	11340.4	**15154.2*****	**7279.9***	**3997.4****

The turning point is calculated as $\tau = \beta_1 / (-2\beta_2)$ by setting the derivatives of model (2) equal to zero, when $\beta_1>0$ and $\beta_2<0$ and $\beta_3=0$.
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Foreign investment and international trade are often considered factors other than income level, leading to an EKC pattern in pollution. The pollution haven hypothesis was first formally postulated by Copeland and Taylor (1994) in the context of North-South trade, which indicates that trade liberation would open the floodgates for migration of pollution-intensive industries to nations with lax environmental standards (generally assumed as developing countries). This movement could reduce the pollution level in developed countries and increase pollution emission in developing countries. Because of the profit generated through the trade of goods and foreign direct investment (FDI), the industrial composition of those developing countries would change and become specialized in pollution-intensive sectors, which lead to environmental deterioration in those areas. FDI might be the shift of ecological responsibility of dirty foreign industries and often considered as the cause of pollution in the host country (He 2006, Becker & Henderson 2000, López et al. 2013, etc.). However, the linkage between FDI and pollution is controversial. Many studies have found that the FDI inflows may bring better technology to the host country, which will lead to positive outcomes in the long run (Porter & van der Linde, 1995, Cole, 2004, Harrison & Eskeland, 1997). The technology transfer from the industries of countries with strict environmental regulation, an increase of the GDP, and change of the industrial composition of the host countries bring by trade liberalization all might provide an alleviating effect on pollution emission (Chao et al. 2007, Atici, C. 2012, Ren et al. 2014, etc.). Therefore, we chose the FDI used in the cities as a proxy and graded the cities into three levels. There is no significant effect of the FDI on the WKC relationship are shown (Table 11). The turning point in the robust results of high-level FDI cities also didn't change much compared to the models in the section 5.1. Therefore, no conclusive results could be made about the FDI effect on the WKC relationship based on current results.

The total volume of freight in the cities is considered relating to the ISW generation and utilization rate. Zhou et al. (2017) have indicated that freight could bring a large amount of solid waste. Industrial packaging materials and waste are the major sources of solid waste, especially in port areas. After performing the WKC regression in cities of different freight levels, we found that as the total volume of freight increases, the turning point of the ISW pollution level becomes harder to reach (Table 11). This result confirms the idea that the freight volume would have a positive effect on the ISW generation. In cities with large values of trade, the ISW pollution level would not be likely to decrease in the short run.

6. Discussion

Due to the data limitation, our study didn't cover all the provinces and cities in China. Future research with more comprehensive data coverage should consider conducting clustering and spatial analysis about the ISW generation in areas with a high concentration of heavy industries or primitive resources. Since the city with a high economic level or developed industrialization system would likely influence the surrounding cities. The potential spillover effect has been examined in the MSW generation context. The paper of Gui et al.(2019) shows that cities with a large amount of MSW generation in China could export the solid waste to nearby cities through consumption, transportation, and economic exchanges. Whether the mutual influence between cities also existed in the ISW was also an exciting topic to study. In addition, many studies have found that the middle and west region of China has appeared an increasing trend in the ISW generation (Xu et al., 2019, Zhou et al., 2017). However, those inland regions of China are also considered less developed and have backward technology, which makes them incapable of managing the ISW pollution (Zhao et al., 2013). Regional-level study of the ISW generation and treatment situation in those areas is needed.

The previous solid waste researchers often viewed the tertiary industry proportion as an essential factor that affected the generation of MSW (Mateu-Sbert et al., 2013, Gui et al., 2019). Since the growth of the tertiary industry, especially tourism, will generate a significant amount of consumption packages and catering food waste, contributing to a large proportion of MSW. Industrial solid waste (ISW), unlike the MSW, mostly comes from Industrial activity. Therefore, in theory, the ISW should be related mainly to the share of secondary industry, which includes the mining and quarrying, manufacturing, production, and supply of electricity, heat, gas, water, and construction activity. Interestingly, we didn't find a significant relationship between the proportion of the second industry to GDP and ISW generation share in the WKC regression in the 5.1 section. Future studies that focus on the relationship between the second industrial and ISW generation could provide meaningful policy implications for cities or countries going through a rapid industrial restructuring process.

By utilizing the regular panel OLS or within estimator (random or fixed effects) models, the problems of unobserved heterogeneity, potential endogeneity of regressors, and serial correlation are common phenomena in panel data analysis (Berk et al., 2020) could occur. Future research could adopt the dynamic panel model, particularly the System Generalized Method of Moments (GMM) estimator, proposed by Arellano and Bover (1995) and Blundell and Bond (1998) to estimate the ISW data. Compared to the OLS levels and Within Groups estimators, the GMM estimator eliminates country effects by first-differencing and controls for possible endogeneity of explanatory variables (Amirnejad et al., 2021). As the GMM estimators in the dynamic model could capture the short-run contemporaneous effects of variables on the ISW generation, the cointegration techniques could also investigate the long-run EKC relationship between ISW and GDP among the time series. The Autoregressive Distributed-lagged (ARDL) Model found by Pesaean et al. (2001) is frequently used in the previous analysis of the EKC hypothesis because it could solve the non-stationary problem related to the time series data (Islam et al., 2013, Bölük & Mert, 2015, Al-Mulali, 2015, Al-Mulali et al., 2016; and so forth).

Future research or case studies that analyze the ISW generation in a long period or with a small sample of data could apply the ARDL approach to determine a long-run relationship. Moreover, a wide range of methodologies, including linear versus nonlinear model specifications, single countries, or cross-country analysis, could be applied to study the ISW generation. Our study could be viewed as the first step for future research in this field.

7. Conclusion and policy implications

While the impact of municipal solid waste (MSW) has attracted extensive attention to the increase of global population and consumption, as a crucial type of solid waste, the pollution prevention and treatment of industrial solid waste (ISW) has not received enough attention from the public. About 36 billion tons of ISW are generated annually globally, which is almost 18 times greater than municipal solid waste (MSW). In addition to its large scale, the ISW is also hard to recycle. The mismanagement situation of ISW is common in both developed and developing countries(Carvalho et al., 2018, Rao et al., 2011, Tarantini et al., 2009, and so forth). Because of its hazardous characteristics, those poorly treated ISW will seriously pollute the groundwater, soil, and atmosphere, which poses severe threats to human safety.

Due to the lagged waste treatment technology and the huge, China has to meet increasingly severe ISW management problems in recent decades. Although the Chinese government has adopted various national policies and guidelines to curb the ISW generation trend, the amount of ISW generated in China is still huge and increases continually every year. The regional performance of ISW management and environmental regulation executive ability also vary from city to city. Much previous literature has analyzed the Chinese ISW pollution issues, focusing on the efficiency of the ISW treatment process and utilization structure. Few papers have explored the relationship between ISW pollution and economic growth. How various social and political factors affect the ISW generation at the city level remains an open question.

The study attempts to investigate the nexus between economic and social driving forces and ISW generation in China. By utilizing a panel comprising 140 cities of China over 2005-2016, the relationship between economic growth and ISW generation was examined based on the EKC approach. (1) The results show that the ISW generation per capita, as the pollution indicator, is inverse U-shaped, confirming the EKC hypothesis. The ISW will continue to increase and then decrease until it reaches the turning point (90183.873 Chinese yuan). Only a few cities have attained this level; therefore, the ISW generation will not start to decrease with the economic growth in the short run for most Chinese cities. (2) The volume of Industrial Soot (Dust) emissions has a positive and statistically effect on the generation of ISW. In heterogeneity WKC analysis, we find that: (3) The turning point would increase with the proportion of Secondary Industry as Percentage to GDP of city. Therefore, the cities concentrated with manufacturing companies or mining and quarrying sectors would likely have a high ISW pollution peak level than other cities. (4) Cities with a high volume of freight also would have high ISW pollution turning points than other cities. The trade level has a positive impact on the city's ISW generation. (5) The summary statistic obtained in the data indicates that cities with a high waste management ability would tend to have lower ISW generation amounts. This result is consistent with the study of Xu et al. (2019) that the regional development of comprehensive utilization of ISW in China is imbalanced.

What is worth noting is that the EKC pattern obtained in the study is merely a description of data; the economic growth would not automatically solve the ISW pollution issues. The study attempts to introduce the ISW to the literature exploring the economic and pollution nexus and provide new insight into the existing ISW literature.

Finally, several political suggestions regarding China's ISW pollution control and management issues are offered based on the above discussion and findings.

The turning point of ISW generation in the study is calculated at a very high level. Thus, most Chinese cities are still expected to witness a further increase in ISW growth if the pattern does not change by the effective pollution control measures. Economic restructuring, such as reducing the proportion of mining and quarrying industries of the city, could be a possible means for local governments to control ISW pollution.

The recycling rate of many types of ISW is still low. Since the waste treatment level would positively decrease the generation and pollution level of cities. Government should continue to increase waste disposal technological upgrading, especially in the mid and west regions of China where ISW generation is massive, but solid waste utilization technologies continue to lag behind.

The central government of China should enhance the legal regulations of the ISW pollution control and treatment. There is still no standard system that supervises and reinforces the national environmental plan, and the legal liability of ISW pollution in China is also ambiguous. The enforcement level of local governments for the policies and regulations varies considerably. A standardized legal and law system from generation to disposal of ISW needs to be constructed. The ISW data collection and consolidation system across cities are also in need.

Appendix

Appendix 1

References

Alam, P., & Ahmade, K. (2013). Impact of Solid Waste on Health and The Environment. *International Journal of Sustainable Development and Green Economics (IJSDGE)*, *2*, 165–168.

Al-Mulali, U. (2015). Investigating the environmental Kuznets curve hypothesis in Vietnam. *Energy Policy*, 9.

Al-Mulali, U., Solarin, S. A., & Ozturk, I. (2016). Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: An autoregressive distributed lag (ARDL) approach. *Natural Hazards*, *80*(3), 1729–1747. https://doi.org/10.1007/s11069-015-2050-x

Amirnejad, H., Mehrjo, A., & Satari Yuzbashkandi, S. (2021). Economic growth and air quality influences on energy sources depletion, forest sources and health in MENA. *Environmental Challenges*, *2*, 100011. https://doi.org/10.1016/j.envc.2020.100011

Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics*, *68*(1), 29–51. https://doi.org/10.1016/0304-4076(94)01642-D

Atici, C. (2012). Carbon emissions, trade liberalization, and the Japan–ASEAN interaction: A group-wise examination. Journal of the Japanese and International Economies, 26(1), 167–178. https://doi.org/10.1016/j.jjie.2011.07.006

Becker, R., & Henderson, V. (2000). Effects of Air Quality Regulations on Polluting Industries. Journal of Political Economy, 108(2), 379–421. JSTOR. https://doi.org/10.1086/262123

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, *87*(1), 115–143. https://doi.org/10.1016/S0304-4076(98)00009-8

Baalbaki, R., & Marrouch, W. (2020). Is there a garbage Kuznets curve? Evidence from OECD countries. *Economics Bulletin*, *40*(2), 1049–1055.

Bednar-Friedl, B., & Getzner, M. (2003). Determinants of CO2 emissions in a small open economy. *Ecological Economics*, *45*(1), 133–148.

Berk, I., Kasman, A., & Kılınç, D. (2020). Towards a common renewable future: The System-GMM approach to assess the convergence in renewable energy consumption of EU countries. *Energy Economics*, *87*, 103922. https://doi.org/10.1016/j.eneco.2018.02.013

Bölük, G., & Mert, M. (2015). The renewable energy, growth and environmental Kuznets curve in Turkey: An ARDL approach. *Renewable and Sustainable Energy Reviews*, *52*, 587–595. https://doi.org/10.1016/j.rser.2015.07.138

Borghesi, S. (1999). *The Environmental Kuznets Curve: A Survey of the Literature* (SSRN Scholarly Paper ID 200556). Social Science Research Network. https://doi.org/10.2139/ssrn.200556

Boubellouta, B., & Kusch-Brandt, S. (2020). Testing the environmental Kuznets Curve hypothesis for E-waste in the EU28+2 countries. *Journal of Cleaner Production*, *277*, 123371. https://doi.org/10.1016/j.jclepro.2020.123371

Boubellouta, B., & Kusch-Brandt, S. (2021). Cross-country evidence on Environmental Kuznets Curve in Waste Electrical and Electronic Equipment for 174 Countries. *Sustainable Production and Consumption*, *25*, 136–151. https://doi.org/10.1016/j.spc.2020.08.006

Bruyn, S. M. de. (2000). *Economic Growth and the Environment: An Empirical Analysis*. Springer Netherlands. https://doi.org/10.1007/978-94-011-4068-3

Carvalho, F. M., Tavares, T. M., & Lins, L. (2018). Soil Contamination by a Lead Smelter in Brazil in the View of the Local Residents. *International Journal of Environmental Research and Public Health*, *15*(10), 2166. https://doi.org/10.3390/ijerph15102166

Chao, C.-C., & Yu, E. S. H. (2007). Trade liberalization, foreign ownership, and the environment in a small open economy. International Review of Economics & Finance, 16(4), 471–477. https://doi.org/10.1016/j.iref.2005.12.001

Cheng, J., Shi, F., Yi, J., & Fu, H. (2020). Analysis of the factors that affect the production of municipal solid waste in China. *Journal of Cleaner Production*, *259*, 120808. https://doi.org/10.1016/j.jclepro.2020.120808

China: National Plan on Banning "Foreign Garbage" and Reducing Solid Waste Imports. (n.d.). [Web page]. Library of Congress, Washington, D.C. 20540 USA. Retrieved July 12, 2021, from https://www.loc.gov/item/global-legal-monitor/2017-08-08/china-national-plan-on-banning-foreign-garbage-and-reducing-solid-waste-imports/

China: Revised Law on the Prevention and Control of Environmental Pollution by Solid Wastes. (n.d.). Retrieved July 12, 2021, from https://www.skuld.com/topics/environment/garbage/china-revised-law-on-the-prevention-and-control-of-environmental-pollution-by-solid-wastes/

Cho, C.-H., Chu, Y.-P., & Yang, H.-Y. (2014). An Environment Kuznets Curve for GHG Emissions: A Panel Cointegration Analysis. *Energy Sources, Part B: Economics, Planning, and Policy*, *9*(2), 120–129. https://doi.org/10.1080/15567241003773192

COLE, M. A., RAYNER, A. J., & BATES, J. M. (1997). The environmental Kuznets curve: An empirical analysis. *Environment and Development Economics*, *2*(4), 401–416.

Cole, M. (2004). Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages. *Ecological Economics*, *48*(1), 71–81.

Copeland, B. R., & Taylor, M. S. (1994). North-South Trade and the Environment. *The Quarterly Journal of Economics*, *109*(3), 755–787. https://doi.org/10.2307/2118421

Damalas, C. A., Telidis, G. K., & Thanos, S. D. (2008). Assessing farmers' practices on disposal of pesticide waste after use. *Science of The Total Environment*, *390*(2), 341–345. https://doi.org/10.1016/j.scitotenv.2007.10.028

Diao, X. D., Zeng, S. X., Tam, C. M., & Tam, V. W. Y. (2009). EKC analysis for studying economic growth and environmental quality: A case study in China. *Journal of Cleaner Production*, *17*(5), 541–548. https://doi.org/10.1016/j.jclepro.2008.09.007

Dinda, S. (2004). Environmental Kuznets Curve Hypothesis: A Survey. *Ecological Economics*, *49*(4), 431–455. https://doi.org/10.1016/j.ecolecon.2004.02.011

Du, L., Wei, C., & Cai, S. (2012). Economic development and carbon dioxide emissions in China: Provincial panel data analysis. *China Economic Review*, *23*(2), 371–384. https://doi.org/10.1016/j.chieco.2012.02.004

El-Fadel, M., Zeinati, M., El-Jisr, K., & Jamali, D. (2001). Industrial-waste management in developing countries: The case of Lebanon. *Journal of Environmental Management*, *61*(4), 281–300. https://doi.org/10.1006/jema.2000.0413

ENVIRONMENTAL PROTECTION LAW OF THE PEOPLE'S REPUBLIC OF CHINA. (n.d.). Retrieved July 12, 2021, from http://www.asianlii.org/cn/legis/cen/laws/eplotproc564/

Ferronato, N., & Torretta, V. (2019). Waste Mismanagement in Developing Countries: A Review of Global Issues. *International Journal of Environmental Research and Public Health*, *16*(6), 1060. https://doi.org/10.3390/ijerph16061060

Flores, C., Flores-Lagunes, A., & Kapetanakis, D. (2009). Lessons From Quantile Panel Estimation of the Environmental Kuznets Curve. *Econometric Reviews*, *33*. https://doi.org/10.2139/ssrn.1469791

Galeotti, M., Lanza, A., & Pauli, F. (2006). Reassessing the environmental Kuznets curve for CO2 emissions: A robustness exercise. *Ecological Economics*, *57*(1), 152–163.

Grossman, G., & Krueger, A. (1991). *Environmental Impacts of a North American Free Trade Agreement* (NBER Working Paper No. 3914). National Bureau of Economic Research, Inc. https://econpapers.repec.org/paper/nbrnberwo/3914.htm

Grossman, G. M., & Krueger, A. (1995). Economic Growth and the Environment. *The Quarterly Journal of Economics*, *110*(2), 353–377.

Gui, S., Zhao, L., & Zhang, Z. (2019). Does municipal solid waste generation in China support the Environmental Kuznets Curve? New evidence from spatial linkage analysis. *Waste Management*, *84*, 310–319. https://doi.org/10.1016/j.wasman.2018.12.006

Harrison, A. E., & Eskeland, G. (1997). *Moving to Greener Pastures? Multinationals and the Pollution-haven Hypothesis*. The World Bank. https://doi.org/10.1596/1813-9450-1744

He, J. (2006). Pollution haven hypothesis and environmental impacts of foreign direct investment: The case of industrial emission of sulfur dioxide (SO2) in Chinese provinces. Ecological Economics, 60(1), 228–245. https://doi.org/10.1016/j.ecolecon.2005.12.008

Huang, Q., Wang, Q., Dong, L., Xi, B., & Zhou, B. (2006). The current situation of solid waste management in China. *Journal of Material Cycles and Waste Management*, *8*(1), 63–69. https://doi.org/10.1007/s10163-005-0137-2

Islam, F., Shahbaz, M., & BUTT, M. S. (2013). Is There an Environmental Kuznets Curve for Bangladesh? Evidence from ARDL Bounds Testing Approach. *The Bangladesh Development Studies*, *36*(4), 1–23.

Jaligot, R., & Chenal, J. (2018). Decoupling municipal solid waste generation and economic growth in the canton of Vaud, Switzerland. *Resources, Conservation and Recycling*, *130*, 260–266. https://doi.org/10.1016/j.resconrec.2017.12.014

Kaika, D., & Zervas, E. (2013a). The Environmental Kuznets Curve (EKC) theory—Part A: Concept, causes and the CO2 emissions case. *Energy Policy*, *62*(C), 1392–1402.

Law of the People's Republic of China on Prevention and Control of Environmental Pollution by Solid Waste -. (n.d.). Retrieved March 22, 2021, from http://english.mofcom.gov.cn/aarticle/policyrelease/internationalpolicy/200703/20070304471567.html

Li, J., Li, F., Xi, S., & Jin, R. (2016). *Descriptive Study of 2014 industrial solid waste treatment situation in major cities of China*. Undefined. /paper/Descriptive-Study-of-2014-industrial-solid-waste-in-Li-Li/058289e9342254ce133d986c396365a313005224

Li, X., Zhang, C., Li, Y., & Zhi, Q. (2016). The Status of Municipal Solid Waste Incineration (MSWI) in China and its Clean Development. *Energy Procedia*, *104*, 498–503. https://doi.org/10.1016/j.egypro.2016.12.084

List, J., & Gallet, C. A. (1999). The environmental Kuznets curve: Does one size fit all? *Ecological Economics*, *31*(3), 409–423.

Liu, Y., Guo, D., Dong, L., Xu, Y., & Liu, J. (2016). Pollution Status and Environmental Sound Management (ESM) Trends on Typical General Industrial Solid Waste. *Procedia Environmental Sciences*, *31*, 615–620. https://doi.org/10.1016/j.proenv.2016.02.111

Lorente, D., & Alvarez, A. (2016). An Approach to the Effect of Energy Innovation on Environmental Kuznets Curve: An Introduction to Inflection Point. *Bulletin of Energy Economics*, *4 (3),* 224–234.

Lorente, D. B., & Álvarez-Herranz, A. (2016). Economic growth and energy regulation in the environmental Kuznets curve. *Environmental Science and Pollution Research International*, *23*(16), 16478–16494. https://doi.org/10.1007/s11356-016-6773-3

López, L. A., Arce, G., & Zafrilla, J. E. (2013). Parcelling virtual carbon in the pollution haven hypothesis. Energy Economics, 39, 177–186. https://doi.org/10.1016/j.eneco.2013.05.006

Madden, B., Florin, N., Mohr, S., & Giurco, D. (2019). Using the waste Kuznet's curve to explore regional variation in the decoupling of waste generation and socioeconomic indicators. *Resources, Conservation and Recycling*, *149*, 674–686. https://doi.org/10.1016/j.resconrec.2019.06.025

Mazzanti, M., Montini, A., & Zoboli, R. (2008). Municipal Waste Generation and Socioeconomic Drivers: Evidence From Comparing Northern and Southern Italy. *The Journal of Environment & Development*, *17*(1), 51–69. https://doi.org/10.1177/1070496507312575

Mazzanti, M., Montini, A., & Zoboli, R. (2009). Municipal waste generation and the EKC hypothesis new evidence exploiting province-based panel data. *Applied Economics Letters*, *16*(7), 719–725. https://doi.org/10.1080/13504850701221824

Mbuligwe, S. E., & Kaseva, M. E. (2006). Assessment of industrial solid waste management and resource recovery practices in Tanzania. *Resources, Conservation and Recycling*, *47*(3), 260–276. https://doi.org/10.1016/j.resconrec.2005.11.002

Mateu-Sbert, J., Ricci-Cabello, I., Villalonga-Olives, E., & Cabeza-Irigoyen, E. (2013). The impact of tourism on municipal solid waste generation: The case of Menorca Island (Spain). *Waste Management (New York, N.Y.)*, *33*. https://doi.org/10.1016/j.wasman.2013.08.007

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, *16*(3), 289–326. https://doi.org/10.1002/jae.616

Price, L., Levine, M. D., Zhou, N., Fridley, D., Aden, N., Lu, H., McNeil, M., Zheng, N., Qin, Y., & Yowargana, P. (2011). Assessment of China's energy-saving and emission-reduction accomplishments and opportunities during the 11th Five Year Plan. *Energy Policy*, *39*(4), 2165–2178. https://doi.org/10.1016/j.enpol.2011.02.006

Rao, G. T., Rao, V. V. S. G., Ranganathan, K., Surinaidu, L., Mahesh, J., & Ramesh, G. (2011). Assessment of groundwater contamination from a hazardous dump site in Ranipet, Tamil Nadu, India. *Hydrogeology Journal*, *19*(8), 1587–1598. https://doi.org/10.1007/s10040-011-0771-9

Ren, S., Yuan, B., Ma, X., & Chen, X. (2014). International trade, FDI (foreign direct investment) and embodied CO2 emissions: A case study of Chinas industrial sectors. China Economic Review, 28, 123–134. https://doi.org/10.1016/j.chieco.2014.01.003

Seppälä, T., Haukioja, T., & Kaivo-oja, J. (2001). The EKC Hypothesis Does Not Hold for Direct Material Flows: Environmental Kuznets Curve Hypothesis Tests for Direct Material Flows in Five Industrial Countries. *Population and Environment*, *23*, 217–238. https://doi.org/10.1023/A:1012831804794

Shafik, N., & Bandyopadhyay, S. (1992a). Economic growth and environmental quality: Time series and cross-country evidence. In *Policy Research Working Paper Series* (No. 904; Policy Research Working Paper Series). The World Bank. https://ideas.repec.org/p/wbk/wbrwps/904.html

Shi, F., Yi, J., & Fu, H. (2019). *Analysis of the Factors that Affect the Production of Municipal Solid Waste in China*. https://doi.org/10.13140/RG.2.2.11901.61926

Sn, C. (2017). Solid Waste Pollution: A Hazard to Environment. *Recent Advances in Petrochemical Science*, *2*(3). https://doi.org/10.19080/RAPSCI.2017.02.555586

Stern, D. I. (2004). The Rise and Fall of the Environmental Kuznets Curve. *World Development*, *32*(8), 1419–1439. https://doi.org/10.1016/j.worlddev.2004.03.004

PUBLIC-PRIVATE-PARTNERSHIP LEGAL RESOURCE CENTER. (n.d.). PUBLIC-PRIVATE-PARTNERSHIP LEGAL RESOURCE CENTER. Retrieved July 12, 2021, from https://ppp.worldbank.org/public-private-partnership/library/china-circular-economy-promotion-law

Porter, M. E., & van der Linde, C. (1995). Toward a New Conception of the Environment-Competitiveness Relationship. Journal of Economic Perspectives, 9(4), 97–118. https://doi.org/10.1257/jep.9.4.97

Tang, J., Wang, Q., & Choi, G. (2020). Efficiency assessment of industrial solid waste generation and treatment processes with carry-over in China. *Science of The Total Environment*, *726*, 138274. https://doi.org/10.1016/j.scitotenv.2020.138274

Tarantini, M., Loprieno, A. D., Cucchi, E., & Frenquellucci, F. (2009). Life Cycle Assessment of waste management systems in Italian industrial areas: Case study of 1st Macrolotto of Prato. *Energy*, *34*(5), 613–622. https://doi.org/10.1016/j.energy.2008.12.004

Wen, X., Luo, Q., Hu, H., Wang, N., Chen, Y., Jin, J., Hao, Y., Xu, G., Li, F., & Fang, W. (2014). Comparison research on waste classification between China and the EU, Japan, and the USA. *Journal of Material Cycles and Waste Management*, *16*. https://doi.org/10.1007/s10163-013-0190-1

What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. (2019, January 7). Green Growth Knowledge Platform. https://www.greengrowthknowledge.org/research/what-waste-20-global-snapshot-solid-waste-management-2050

Wooldridge, J. (2010). *Econometric Analysis of Cross Section and Panel Data* [MIT Press Books]. The MIT Press. https://econpapers.repec.org/bookchap/mtptitles/0262232588.htm

Xu, S., Chen, Y., Hu, J., Xue, N. (2019). Generation, Treatment and Supervision countermeasures and Suggestions for General Industrial Solid Waste in China. *Solid waste and Chemical Management Center, Ministry of Environmental Protection, Beijing 100029*, 2019 https://r.cnki.net/kcms/detail/detail.aspx?filename=HJKP201808003011&dbcode=CRJT_CPFD&dbname=CPFDLAST2019&v=MjI1NjhEN3VRS3JpZlplZHZGQ2puVXJmTkoxMFJMU2ZBZnJHNEg5bk1wNDlGWitzT0RSTkl5QlVTNnpkNVBuMlVxbUJB

Yanrong, W., Cuili, W., & Han, W. (2011). Research on the Quantitative Relationship between the Generation of Industrial Solid Waste and Per Capita GDP of Henan Province. *Energy Procedia*, *5*, 593–597. https://doi.org/10.1016/j.egypro.2011.03.104

Yu, Y. (2015). Ex-post assessment of China's industrial energy efficiency policies during the 11th Five-Year Plan. *Energy Policy*, 14.

York, R., Rosa, E., & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics*, *46*, 351–365. https://doi.org/10.1016/S0921-8009(03)00188-5

Zhai, X., Cheng, Z., Ai, K., & Shang, B. (2020). Research on Environmental Sustainability of Coal Cities: A Case Study of Yulin, China. *Energies*, *13*, 2470. https://doi.org/10.3390/en13102470

Zhao, L., Yao, Z., Wu, X., & Ren, C. (2013).Generation Characteristics and control countermeasures of industrial solid waste in China. *Energy Policy*, *2013*. https://www.cnki.com.cn/Article/CJFDTotal-HJGC2013S1132.htm

Zhao, X., Li, H., Wu, L., & Qi, Y. (2014). Implementation of energy-saving policies in China: How local governments assisted industrial enterprises in achieving energy-saving targets. *Energy Policy*, *66*, 170–184. https://doi.org/10.1016/j.enpol.2013.10.063

Zhou, B., Sun, C., & Yi, H. (2017). Solid Waste Disposal in Chinese Cities: An Evaluation of Local Performance. *Sustainability*, *9*, 2234. https://doi.org/10.3390/su9122234

12th Five-Year Plan (2011-2015) for National Economic and Social Development | ESCAP Policy Documents Managment. (n.d.). Retrieved March 16, 2021, from https://policy.asiapacificenergy.org/node/37