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# A study of Environmental Kuznets Curve in China: regional panel analysis

Master's thesis

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I have written this Master Thesis independently. Any ideas or data taken from other authors or other sources have been fully referenced.

## Abstract

This paper selects China's provincial data from 2003 to 2021 to examine the relationship between water pollution, air pollution, solid waste pollution and economic growth in seven regions of China based on the Environmental Kuznets Curve (EKC) theory. The panel unit root tests indicate that all variables are integrated on the order of one, I(1). Cointegration test shows that there is long-run relationship in the panel data. Then DOLS (dynamic ordinary least squares) estimator indicates that the EKC hypothesis is valid at country level and all regions except southwest region. There is an increasing relationship between solid waste pollution and economic growth in southwest region. Furthermore, this article finds out that the economic growth contributes to the reduction of water pollution and air pollution, but increases solid waste pollution, governments need to pay more attention to solid waste pollution.

**Keywords**

Environmental Kuznets curve; Economic growth; Environmental pollution
China; Regional study

**JEL classification**

C23; C52; Q53; S180

# 1.Introduction

China's economy had developed rapidly since joining the WTO, according to China national Bureau of Statistic data, the GDP has reached 126.06 trillion Chinese Yuan(yuan) in 2023 which is 18 times as it was in 2001, China's GDP has maintained an average annual growth rate of 7.29 since the financial crisis. And this rapid growth has been at the expense of natural resources and the environment. In 2022, China's primary energy consumption ranked first in the world, accounting for 26.4% of the total consumption (British Petroleum, 2023), followed by excessive resource and energy consumption, environmental pollution growing increasingly serious. China's sulfur dioxide emissions reached the world's highest level in 2004, and that many Chinese cities are worse polluted than similarly sized foreign cities (Yi, Hao& Tang, 2007). Although China's sulfur dioxide emissions have shown a downward trend, sulfur dioxide itself and the resulting acid rain are a serious health hazard to the population, the government should raise the attention to sulfur dioxide pollution (Yaguchi, Sonobe & Otsuka). And the decline in forests and soil erosion have exacerbated China's water shortage (Groot, Withagen & zhou,2004). As China becomes the world's second-largest economy, the environment will be under greater pressure. The relationship between environmental degradation and economic development in China has become a hot topic (Zhang,2021).

The most influential theoretical argument regarding the relationship between economic growth and environmental pollution is the environmental Kuznets curve (EKC) hypothesis. In the early 1990s, the American environmental economists Grossman and Krueger, based on many data analysis and empirical tests, found that there is a relationship between environmental quality and economic growth. The relationship shows that with the increase of per capita income, the environment first deteriorates and then improves, thus resulting in an EKC curve. This theory is used to describe the changing trend of the relative relationship between the environmental quality and economic growth of a country or region. (Grossman & Krueger, 1991)

The environmental Kuznets curve has been validated in many studies (Panayotou, 1993; Deacon & Norman, 2006; Fosten et al.,2012; Sinha & Shahbaz, 2018; Dogan & Seker,2016; Amar,2021). Additionally, through empirical studies researchers also discovered

N-shaped, inverted N-shaped curve. Apergis (2016) selected carbine dioxide and GDP data from year 1960 to 2013 for 15 countries to examine the EKC hypothesis, however, the EKC theory was not been corroborated in Switzerland, Spain, Portugal. Onafowora and Owoye(2014) verified the EKC hypothesis for carbon dioxide in eight countries, results showed that in Japan and South Korea the inverted U-shaped curve is verified but for the other six countries, there existed N-shaped EKC curve. Moutinho, Varum and Madaleno (2017) analyzed the relationship between economic growth and environmental variables in Portugal and Spain, resulted showed that an inverted N–shaped relationship between the economic growth and emissions. No all study support the EKC hypothesis. Egli (2002) questioned the existence of EKC curves in individual countries by analyzing economic and environmental data for Germany. He argued that in the short run, income changes have a small impact on pollution emissions; in the long run, only some pollutant indicators and income show the typical "inverted U-shaped" EKC.

For developing nations, such as China, the existence of the EKC relationship takes on added significance, one obvious implication of such a relationship is that a lower income, developing (and polluted) nation can “grow” its way into a greener existence (Brajer, Mead & Xiao, 2008, p.675). The EKC hypothesis is also confirmed in China. Poon, Casas and He (2006) validated the EKC in China based on panel data of $SO_2$ and soot from the period 1998-2004, the result showed that there was an inverted U-shaped relationship between $SO_2$ emission and economic growth but U-shaped relationship for soot. Shen’s (2006) study yielded the opposite result, a U-shaped relationship for $SO_2$ emission and economic growth is validated. This research is based on the Chinese provincial data from 1993 to 2002 and in addition, an inverted U-shaped EKC relationship was found in COD discharge. Song, Zheng, and Tong (2008) extended the EKC research on solid waste in addition to waste gas emission and wastewater emission. They selected Chinese 29 provincial data from 1985-2005 and the inverted U-shaped EKC is verified in waste gas emission and solid waste produced had an inverse N-shaped relationship.

Because of the regional development disparity, moreover, China is among the upper-middle-income countries in the world. Research on country-level will ignore high-income areas (Li, Shi & Wu, 2020). Some scholars have also conducted regional studies on the relationship between environmental pollution and economic growth in China. A study of air pollution in high- and low-income regions of China showed that PM2.5 emissions and economic growth exhibited an inverted U-shaped EKC in both regions (Li, Shabaz, Jiang & Dong, 2021). Wang and Lv (2022) studied the relationship between agricultural carbon dioxide emissions and economic growth in Henan Province as an example, and the results showed that Henan is currently in the upward stage of the inverted U-shaped curve. Nie, Li, Wang and Zhang divide China into eastern, central and western regions, analyzed the relationship between $CO_2$ and GDP per capita. The U-shaped curve is observed in central and western regions, EKC is not supported in eastern region. Du (2011) similarly categorized China into eastern, central, and western regions, but the study focused on the relationship between industrial pollution and regional economic growth, EKC is supported in all regions, but the shape of EKC is different among regions. To, Lee and Lau (2021) selected Shenzhen city to test the EKC hypothesis between haze pollution and economic growth during the period 1990-2020. An inverted U-shaped EKC is verified and in addition, after year 2010, the haze pollution decrease as economic grows. Xiong, Yu, Jong, Wang, and Cheng (2017) focused on the Beijing-Tianjin -Hebei region and used panel data from 2004 to 2014 to test the relationship between economic growth and discharge volume of industrial wastewater, discharge volume of $SO_2$ and generated volume of industrial solid waste. The results showed that there is a U-shaped EKC of $SO_2$ emission and inverted N-shaped EKC of solid waste. The wastewater and economic growth have a wave-type relationship.

Most regional studies of China are province-based, and large variations in results between provinces and municipalities, making it difficult to reflect national trends. Some studies have roughly categorized China into three regions, east, central and west, which can lead to high intra-regional heterogeneity, and the EKC curves may exhibit more mixed characteristics. And most studies focus on carbon dioxide and sulfur dioxide, with relatively few studies on water pollution and solid waste.

To fill in the research gap, firstly, in this paper, China is divided into seven regions not just based on the economic status but also considering the geographical factors and cultural differences. Secondly, three indicators-waste gas, waste water and solid waste are included in the study and data update to 2003-2021. Finally, for the robustness, regional results are compared with national trends.

This paper aims to investigate the relationship between economic growth and environmental pollution across different regions in China based on the Environmental Kuznets Curve theory. First, the study applied LLC (Levin, Lin and Chu) and IPS (Im, Pesaran and Shin,) panel unit root tests and Pedroni cointegration test to ensure the stationary and cointegration of panel data to avoid pseudo-regression. Then constructed the parameter estimation model and run DOLS (dynamic ordinary least squares) estimator to evaluate the relationship among the variables.

The rest of the paper is structured as follows. Section 2 reviews the previous literature on Environmental Kuznets Curve. Section3 provides a description of the data and the econometric method. Section 4 provides the empirical results and discussion. Section 5 provides the conclusion of this paper.

## 2. Literature Review

### 2.1. Existence and Significance of Environmental Kuznets Curve

With the increasingly serious impact of environmental problems on human life, the relationship between the environment and the economy has gradually become a key concern in the field of economics (Gill, Viswanathan & Hassan, 2018). EKC hypothesis provides a theoretical framework for understanding the complex relationship between economic growth and environmental pollution. Research on the Environmental Kuznets Curve began in the 1990s, and many scholars have analyzed the existence and significance of the Environmental Kuznets Curve.

Crossman and Krueger (1991) through an empirical study on the relationship between air quality and economic growth in a cross-section of urban areas in 42 countries and concluded that there is an inverted U-shape relationship between sulfur dioxide, soot, and the income curve. Shafik and Bandyoppadhyay (1992) selected a large amount of data to verify and analyze the relationship between environmental quality and economic development, they found that the emissions of sulfur dioxide, suspended particulate matter and solid waste would first increase and then improve with economic growth, presenting a typical inverted U-shape relationship, whereas water pollution does not satisfy the EKC hypothesis, which shows that the inverted U-shaped EKC curve is only one of the relationships between economic growth and environmental development.

As the research on EKC continues to deepen, scholars are trying to add factors that may have an impact on environmental quality, such as population density, economic structure, technological progress, and trade openness, to further analyze the relationship between environmental quality and economic growth. Judging from the verification results, the EKC curve is no longer only inverted U-shape. Studies on different countries and different indicators have also shown results such as positive U-shape and N-shape.

Mazzanti, Musolesi and Zoboli (2006) conducted a panel data study on 109 countries from 1995 to 2001 and believed that countries with a higher degree of industrialization will have inverted U-shape and inverted N-shape curves. Dkhili (2023) looked at the relationship between carbon dioxide and renewable energy, FDI, and trade in MENA countries, the results showed that there is a long-term declining relationship between renewable energy, economic growth, trade openness, and foreign direct investment (FDI). India's carbon dioxide emissions have N-type EKC regardless of whether there is an interaction term for $CO_2$ emissions, while the ecological footprint has no EKC (Hossain et al., 2023). Pata and Samour (2022) innovatively introduced the impact of nuclear energy on environmental indicators and tested French data from 1977 to 2017. However, the empirical analysis showed that there is no inverted U-shaped relationship between carbon dioxide emissions and income, but the load capacity factor fits the EKC hypothesis, which proves that the validity of the EKC hypothesis in France varies according to the dependent variable. A study of 56 middle- and high-income countries found that income inequality can affect the relationship between carbon emissions and economic growth, changing the EKC curve from an inverted U-shape to N-shape (Wang, Yang & li,2023). Research by Bibi and Jamil (2021) confirmed that between 2000 and 2018, in Latin America and the Caribbean, East Asia and the Pacific, Europe and Central Asia, South Asia, the Middle East and North Africa, and Sub-Saharan Africa all have inverted U-shape EKC between average air pollution and economic growth. Dogan and Lotz (2020) tested the EKC hypothesis for seven European countries from 1980-2014, an inverted U-shaped relationship confirmed for $CO_2$ emissions, but when industrial sector's value added, U-shaped relationship is observed.

From above, the EKC hypothesis is confirmed in many researches and different shape of curve is observed. Most studies have used GDP per capita as an indicator of economic development, and used air pollution and $CO_2$ emission measuring environmental quality.

### 2.2. The Environmental Kuznets Curve in China

The literature review of EKC in China is based on the research which have chosen to study the EKC hypothesis using air pollution, water pollution, and solid waste pollution as representatives of environmental degradation.

He (2009) used $SO_2$ emissions as a pollution indicator to investigate and validate the EKC for 26 provinces in China from 1991 to 2001. The turning point of EKC in China was 10,000 yuan per capita with significant negative impacts from economic growth. In addition, the Capital-Labor abundance ratio also has an indirect influence on the inter-provincial income level in China. Liao Dogan and Baek (2017) used panel cointegration method and dynamic ordinary least square method to test the panel data and $SO_2$ emissions were used as pollution indicator for emissions for 29 provinces from 1990 to 2012 to test the EKC hypothesis. The inverted U-shaped EKC is also confirmed. Song, Zhang, and Wang (2013) selected China's provincial panel data from 1993 to 2010 and used Graphical analyses to argue whether the relationship between industrial gas emissions and economic growth is consistent with the EKC hypothesis, and results showed that EKC does not exist for Liaoning, Anhui, Fujian, Hainan, and Qinghai provinces, while EKC of Shanghai, Guizhou, Tibet, Jilin, and Beijing have reached inflection point. Bonnefond Clement and Yan (2021) selected the panel data of 30 provinces in China from 2000 to 2012 and used semiparametric panel techniques to test the relationship between six pollution indicators including $CO_2$, $SO_2$, COD and waste water, and only $CO_2$ emission and per capita GDP showed a typical inverted U-shaped curve. Hao, Gao, Guo, Gai, and Wu (2021) applied Generalized Method of Moments method to panel data of 30 provinces in China during the period 2000–2017 to test the EKC hypothesis for sulfur dioxide, carbon dioxide, and nitrogen oxides, sewerage pollution, arguing for an inverted U-shaped curve for four indicator and economic growth, in addition, the inflection point of sulfur dioxide emission is 1790 USD in year 2005.

Jayanthakumaran and Liu (2012) developed simultaneous equations model using panel data from China to investigate the EKC hypothesis between economic growth and $SO_2$ and COD discharge. This study confirms the inverted U-shaped EKC relationship between

$SO_2$ and COD discharge and economic growth in China over the period 1990-2007. And that the inflection of COD discharge and $SO_2$ emission is 6859 yuan per capita and 15138 yuan per capita separately. Zhang and Gangopadhyay (2015) investigated the EKC from a regional perspective, the research used only Yangtze River Delta region data to test the l relationship between $SO_2$ emission, industrial dust emission, sewage emission and economic growth in China. The study demonstrated the inverted U-shaped environmental Kuznets curve hypothesis for the relationship between $SO_2$ emissions and economic growth, a monotonic positive relationship for industrial dust emission and wave-line relationship for industrial sewage emission. Hu Paudel and Tan (2022) used data of 240 cities from 2000 to 2011 tested the relationship between $SO_2$ emission, wastewater emission and economic growth in China based on nonparametric IV model and a synthetic control method, the inverted U-shaped EKC is supported by both $SO_2$ and wastewater emissions. Fang, Huang, and Yang (2020) selected panel data from 261 cities during 2004-2013, and used Fully Modified Ordinary Least Squares method to verify the relationship between industrial waste pollution, $SO_2$ emission and economic growth. The inverted U-shaped EKC is verified both industrial waste pollution and $SO_2$ emission, and the inflection point of industrial waste pollution is 42991–4828 yuan per capita, the inflection point of $SO_2$ is 9588–10663 yuan per capita.

Du (2011) analyzed the relationship between industrial pollution and economic growth in China from a regional perspective. The research divided China into eastern, middle, and western region based on their economic situation. Simulation method is applied to test the panel data from 1991 to 2005. The results showed that there are reverse N, N and reverse U EKC for industrial effluent of eastern, middle and western region with infection points 36821.91 yuan per capita,7630.179 yuan per capita and 4694.86 yuan per capita separately, and there were inverted N, U and N EKC for industrial sulfur dioxide of eastern, middle and western region with infection points 7784.42 yuan per capita,1352.468 yuan per capita and 4067.68 yuan per capita. Taguchi and Murofushi (2010) carried out fixed effect model to investigate the relationship between wastewater, waste gas, solid waste, and economic growth. The study is based on panel data of 29 provinces during 1988-2007 and found an inverted U-shaped EKC for all pollutions and the infection points is around 30000 yuan per capita. Zhao, Zhao and Zhang (2021) did EKC verification of the $SO_2$, solid waste,

waste water pollution in China using Spatial Durbin Model, the study used data of 30 provinces from 1999 to 2017. The inverted-N shaped EKC is confirmed for both $SO_2$ emission and solid waste but the EKC for waste water is not supported. Wu and Zhang (2022) used the same model to test EKC hypothesis by using the same pollution indicator, $SO_2$, solid waste and waste water pollution, but this study was based on data from 265 cities during 2006 – 2018 and no EKC relationship is supported. Yang He and Chen (2015) used panel data of 29 provinces from 1995 to 2015 of China and constructed a spatial model to test the EKC relationship between $CO_2$ emission, $SO_2$ emission, industrial dust, industrial waste gas, industrial smoke, industrial $SO_2$, industrial wastewater and economic growth, but no EKC relationship is confirmed. A summary of the literature about Environmental Kuznets Curve in China is shown in Table 1.

Table 1

*summary of the literature about Environmental Kuznets Curve in China*

| Author (s) | Period | Area | Methodology | Pollution Proxy | Results |
|---|---|---|---|---|---|
| He (2009) | 1991–2001 | 26 provinces | Regression | $SO_2$ | inverted U, inflection point: 10000 yuan |
| Liao Dogan and Baek (2017) | 1990–2012 | 29 provinces | Panel cointegration | $SO_2$ | inverted U |
| Song,Zhang and Wang(2013) | 1993–2010 | 30 provinces | Graphical analyses | Industrial waste gas emission | EKC does not exist for Liaoning, Anhui, Fujian, Hainan, and Qinghai, while EKC of Shanghai, Guizhou, Tibet, Jilin, and Beijing have reached inflection point. |
| Bonnefond Clement and Yan (2021) | 2000–2012 | 30 provinces | Semiparametric rich panel techniques | $CO_2$, $SO_2$, soot, AN, COD, waste water | inverted U for $CO_2$ |
| Hao Gao Guo Gai Wu (2021) | 2000–2017 | 30 provinces | GMM | $SO_2$, $CO_2$, and $NO_x$, sewerage | inverted-U for $SO_2$, inflection point: 15138 yuan at 2005 |
| Jayanthakumaran and Liu (2012) | 1990–2007 | 30 provinces | Simultaneous equations | $SO_2$ and COD | Both inverted U, inflection point: 6859 yuan for COD and 15138 yuan for $SO_2$ |
| Zhang and Gangopadhyay (2015) | 2003–2009 | Yangtze River Delta, China | FE | $SO_2$, industrial dust emission and sewage emission | inverted-U for $SO_2$, a monotonic positive relationship for industrial dust，wave-line for industrial sewage emission |
| Hu Paudel and Tan (2022) | 2000–2011 | 240 cities | nonparametric IV model | $SO_2$, wastewater emissions | inverted U-shaped for both $SO_2$, wastewater emissions |
| Fang Huang Yang (2020) | 2004–2013 | 261 cities | Fully Modified Ordinary Least Squares, panel cointegration | Industrial waste pollution, $SO_2$ | inverted U, inflection point: 42991–48828 yuan for industrial waste, 9588–10663 yuan for $SO_2$ |

| Author (s) | Period | Area | Methodology | Pollution Proxy | Results |
|---|---|---|---|---|---|
| Du (2011) | 1991–2005 | Eastern, Middle, and Western China | Simulation method | industrial sulfur dioxide, industrial effluent | industrial $SO_2$: inverted-N, U and N shape EKC of eastern, middle, and western region inflection points: 7784.42,1352.468,4067.68<br>industrial effluent: inverted-N, N and inverted U EKC of eastern, middle, and western region, inflection points: 36821.9, 7630.179, 4694.86 |
| Taguchi and Murofushi (2010) | 1988–2007 | 29 provinces | FE | Wastewater, waste gas, solid waste | Inverted U EKC, inflection points around 30000 yuan |
| Zhao Zhao Zhang (2021) | 1999–2017 | 30 provinces | SDM | $SO_2$, solid waste, waste water | inverted N for $SO_2$ and solid waste |
| Wu and Zhang (2022) | 2006–2018 | 265 cities | SDM Spatial Durbin Model | $SO_2$, solid waste, water pollution | No EKC confirmed |
| Yang He and Chen (2015) | 1995–2010 | 29 provinces | Spatial models, sensitivity analyses | $CO_2$, $SO_2$, industrial dust, industrial waste gas, industrial smoke, industrial $SO_2$, industrial wastewater | No EKC confirmed |

Source: author’s generation

## 3. Data and methodology

### 3.1. Data Source

GDP (gross domestic product) is a very common proxy for economic growth, in this paper, in this research, the annal real GDP per capita in yuan is used as the economic growth indicator, the GDP data were converted into a constant price (2000 prices).

$SO_2$ emission per capita, Chemical Oxygen Demand (COD) discharge per capita and solid waste per capita are generated as the pollution proxy for air pollution, water pollution and solid pollution. Because $SO_2$ emission is the major source of air pollution in China, 90% of sulfur dioxide comes from coal combustion, and China consumes 50% of the world's coal consumption (Liao, Dogan & Baek,2017). Water pollution brings unavoidable health hazards to the population, COD discharge is the main pollutant in wastewater (Lu et al., 2015). Based on the availability of data, this paper generated industry and domestic COD discharge to calculated the COD discharge per capita proxy. China's rate of harmless treatment of domestic waste reached 99.9% in 2021, of which 25 provinces and municipalities reached 100% harmless treatment, see Appendix. So in this research, industry solid waste is selected for solid pollution proxy. The unit of real GDP per capita is yuan, the unit of $SO_2$ emission per capita, COD discharge per capita and solid waste per capita is ton per person.

The period under examination in this paper is 2003–2021, this time period is chosen by availability of the data for all the variables. In the empirical analysis, panel data of 31 provinces and municipalities (Hong Kong, Macao and Taiwan are not included) in mainland China are collected to construct a panel data regression econometric model. The GDP data, and solid wastes data are obtained from China Statistical Yearbook, the $SO_2$ emission data, COD discharge data are obtained from the China Environment Yearbook.

### 3.2. Variable Description

Current research on China's EKC mainly focuses on the division by provinces, or uses the relatively coarse regional division method of eastern, central, and western regions, ignoring the possible North-South geographic variability, and coastal and inland geographic diversity, etc. Therefore, to obtain more accurate results of the regional differentiation analysis and consider the geographical differences and cultural differences this article divides the country into seven major economic regions to further examine the differences in regional distribution characteristics of the EKC: northeast China, north China, east China, central China, south China, northwest China, southwest China. Table 2 shows the division for seven regions and provinces and municipalities included in each region of China.

Table 2

*Seven Regions of China*

| region | Province/ Municipalities |
|---|---|
| north | Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia |
| northeast | Liaoning, Jilin, Heilongjiang |
| east | Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong |
| central | Henan, Hubei, Hunan |
| south | Guangdong, Guangxi, Hainan |
| northwest | Chongqing, Sichuan, Guizhou, Yunnan, Tibet |
| southwest | Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang |

Source: author's division

The province panel data are divided into the seven regions for further investigation, in the paragraphs below, real GDP per capita is represented by RG, COD discharge per capita is represented by COD, $SO_2$ emissions per capita is represented by SE, solid wastes per capita produced is represented by SOD.

Table 3 lists the observations, mean, minimum, maximum, and standard deviation of the dataset for all seven regions. The differences between the variables are relatively significant, indicating that the sample was selected to cover a wide range of areas. The standard deviation is used to measure the degree of dispersion of the data set. The fact that the standard deviation of each variable is smaller than the mean indicates that the sample observations for each variable are within the normal range and that the presence of extreme anomalous data is less likely.

Table 3

*Descriptive statistical analysis of variables*

| region | Variable | Obs | Mean | Std | Min | Max |
|---|---|---|---|---|---|---|
| north | RG | 95 | 36769.600 | 23440.500 | 6900.834 | 114697.900 |
| | COD | 95 | 0.007 | 0.004 | 0.001 | 0.014 |
| | SE | 95 | 0.021 | 0.018 | 0.000 | 0.064 |
| | SOD | 95 | 7.455 | 9.766 | 0.089 | 37.050 |
| northeast | RG | 57 | 33087.880 | 15477.590 | 8883.098 | 62732.980 |
| | COD | 57 | 0.010 | 0.004 | 0.003 | 0.015 |
| | SE | 57 | 0.013 | 0.007 | 0.003 | 0.029 |
| | SOD | 57 | 2.680 | 1.847 | 0.642 | 7.402 |
| east | RG | 133 | 39595.060 | 22954.900 | 6360.680 | 108547.800 |
| | COD | 133 | 0.008 | 0.003 | 0.002 | 0.019 |
| | SE | 133 | 0.010 | 0.006 | 0.000 | 0.027 |
| | SOD | 133 | 1.440 | 0.671 | 0.407 | 3.179 |
| central | RG | 57 | 24785.470 | 12638.090 | 7028.459 | 55172.080 |
| | COD | 57 | 0.008 | 0.003 | 0.002 | 0.015 |
| | SE | 57 | 0.009 | 0.005 | 0.001 | 0.017 |
| | SOD | 57 | 1.139 | 0.485 | 0.413 | 2.521 |
| south | RG | 57 | 24580.990 | 12595.590 | 5561.431 | 54342.200 |
| | COD | 57 | 0.011 | 0.005 | 0.005 | 0.024 |
| | SE | 57 | 0.007 | 0.006 | 0.000 | 0.022 |
| | SOD | 57 | 0.751 | 0.529 | 0.112 | 2.063 |
| northwest | RG | 95 | 17833.860 | 10297.660 | 3355.143 | 46498.130 |
| | COD | 95 | 0.007 | 0.002 | 0.002 | 0.012 |
| | SE | 95 | 0.013 | 0.011 | 0.000 | 0.040 |
| | SOD | 95 | 1.764 | 1.483 | 0.017 | 8.970 |
| southwest | RG | 95 | 17828.980 | 8282.779 | 5135.401 | 34337.350 |
| | COD | 95 | 0.010 | 0.005 | 0.002 | 0.024 |
| | SE | 95 | 0.024 | 0.016 | 0.002 | 0.064 |
| | SOD | 95 | 5.136 | 7.046 | 0.562 | 26.520 |
| country | RG | 589 | 28602.92 | 19175.79 | 3355.143 | 114697.9 |
| | COD | 589 | 0.008549 | 0.004031 | 0.001426 | 0.023993 |
| | SE | 589 | 0.014641 | 0.012898 | 0.000064 | 0.064472 |
| | SOD | 589 | 3.082803 | 5.438517 | 0.017301 | 37.05042 |

*Notes.* RG -real GDP per capita, COD -COD discharge per capita,

SE - $SO_2$ emissions per capita, SOD-solid wastes per capita

The units: RG yuan per capita; COD, SE and SOD: ton per capita.

Source: author’s calculations

### 3.3. Methodology

First, when conducting macro econometric studies, it is common to consider whether there is a unit root problem in panel data. If a regression analysis is performed on a non-stationary series, pseudo-regression often occurs and the results of its regression are meaningless. To avoid pseudo-regression and ensure the validity of the results, the data need to be tested for stationarity (Du, Liu, Lei &Huang). By testing the stationarity of the data, we can better understand the patterns and trends of the data, and provide a more accurate and reliable basis for further data analysis and prediction. LLC test assumed that the sample individuals are homogeneous. Consider that the seven regions have different economic characteristics, IPS panel unit root tests are also applied to test the integrality and smoothness of all variables (Nie, Li, Wang &Zhang, 2019).

Levin, Lin and Chu (2002) proposed the LLC unit root test, which is mainly used to test whether data with serial correlation have unit root. This test is based on the ADF unit root test, which solves the problem of insufficient statistical performance that may occur when serial correlation is strong by the correction of the ADF test. The LLC test formula:

$$\Delta x_{i,t} = \rho_i x_{i,t-1} + \sum_{j=1}^{pi} \beta_{ij} \Delta x_{i,t-j} + \alpha_{mi} d_{mt} + \varepsilon_{i,t} \qquad (1)$$

where

$i$ – region

$t$ – time

$x_{i,t}$ – the dataset for province i over time t

$d_{mt}$ – vector of deterministic variables

$\alpha_{mi}$ – vector of coefficients

$pi$ – lag order

$\varepsilon_{i,t}$ – error term

Hypothesis of the LLC test, $H_0$: $\rho_i = 0$ (unit root exists); $H_1$: $\rho_i < 0$.

The IPS test is an improvement on the traditional ADF (Augmented Dickey-Fuller) test and is specifically designed to deal with the unit root test problem for panel data. (Im, Pesaran & Shin, 2003).

The main idea of the IPS test is to consider individual heterogeneity (cross-section dependence) and serial correlation in panel data, and to construct a unit root test statistic for panel data accordingly. Compared with the traditional ADF test, the IPS test is more suitable for panel data because it considers the special structure of panel data. The IPS test formula:

$$\Delta y_{i,t} = \rho_i y_{i,t-1} + \sum_{j=1}^{pi} \beta_{ij} \Delta y_{i,t-j} + \alpha_{mi} d_{mt} + \varepsilon_{i,t} \qquad (2)$$

where

$y_{i,t}$ – the dataset for province i over time t

$d_{mt}$ – vector of deterministic variables

$\alpha_{mi}$ – vector of coefficients

$pi$ – lag order

$\varepsilon_{i,t}$ – error term

Second, in this paper, the Pedroni cointegration test is used to determine the existence of cointegration. The test was proposed by Pedroni (2004). The core idea of the Pedroni test is to determine whether there is a long-run equilibrium relationship between multiple variables by testing the smoothness and cointegration of panel data. It considers the individual and time dimensions of the panel data and allows for a more comprehensive analysis of the relationship between multiple variables which improves the accuracy and reliability of the test and is therefore widely used in research in economics and other social science field (Chen, Zhao, Lai, Wang & Xia,2019) (Bozkurt, Akan & Okumus, 2016).

Pedroni Panel co-integration tests are based on the residuals of following formula:

$$Y_{it} = \beta_i + \beta_{1i} l\, n(X_{it}) + \beta_{2i}[ln(X_{it})]^2 + \beta_{2i}[ln(X_{it})]^3 + \rho_i t + \varepsilon_t \qquad (3)$$

where

$Y_{it}$ – pollution indicator of region i over time t, for our cases, $Y$ is logarithmic COD discharge per capita , logarithmic $SO_2$ emission per capita and logarithmic solid waste per capita

$X_{it}$ – real GDP per capita

$\rho_i$ – deterministic trend specific to each region

$\varepsilon_t$ – residual term

The null hypothesis is that there is no co-integration, whereas the alternative hypothesis is that co-integration exists among variables.

Third, follow the ground-breaking report on the EKC of Grossman and Krueger (1995), in this paper, I first consider the standard EKC regression model (Stern,2004), all the variables are in natural logarithm to reduce volatility and the possible influence of heteroscedasticity.

$$ln(E_{it}) = \beta_0 + \beta_1 ln(GDP_{it}) + \beta_2 ln\left(GDP_{it}\right)^2 + \epsilon_{it} \qquad (4)$$

Where

$E_{it}$ – the pollutant emission

$GDP$ – real GDP per capita

$\varepsilon_t$ – the random error

This simplified equation illustrates directly the effect of income on pollution. Considering the possibility of "N"-shaped curves, and the cubed term for GDP per capita allows for a more flexible shape of the pollution-economy relationship (Hao, Liu, Weng & Gao, 2016), based on the significance and sign of $\beta$, the shape of EKC can be determined. Equation (4) can be rewrite as:

$$ln(E_{it}) = \beta_0 + \beta_1 ln(RG_{it}) + \beta_2 ln\left(RG_{it}\right)^2 + \beta_3 ln\left(RG_{it}\right)^3 + \epsilon_{it} \qquad (5)$$

Where

$E_{it}$ – the pollutant emission level in the year t for the region i, for our cases, $E$ is COD discharge per capita, $SO_2$ emission per capita and solid waste per capita

$RG$ – real GDP per capita

$\varepsilon_t$ – the random disturbance item following independent and identical distribution (i.i.d)

This paper uses a two-step test procedure (Du et al., 2018). A unit root test and cointegration tests were conducted for the sequence of variables, to avoid spurious regression or pseudo regression of the model.

As the EKC may have multiple functional forms, thus requiring a predetermined logit model. DOLS estimator will be run on the panel data for cubic equations first, if coefficient of [ln(RG)]$^3$ is not statistical significant, will then run for the quadric equation.

## 4. Empirical results and analysis

### 4.1. Unit root test

The unit root tests of LLC for the same root case and PS(Im,Pesaran,Shin) for the different root case are also adopted to examine the environmental pollution variables and economic growth variable of each region in China. The results of both panel unit root tests for all variables are shown in Table 4 and Table 5 respectively.

Table 4

*Panel unit root tests:LLC*

| | LLC Statistic | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Var/Region | north | northeast | east | central | south | northwest | southwest | country |
| ln(RG) | -0.82 | -0.49 | -2.74* | -1.53 | -1.73* | -0.46 | 0.20 | -3.78* |
| [ln(RG)]$^2$ | -0.18 | -0.50 | -2.19* | -1.20 | -2.25* | -0.42 | -0.04 | -3.57* |
| [ln(RG)]$^3$ | -0.36 | -0.57 | -1.65 | -0.96 | -2.72* | -0.44 | 0.05 | -3.38* |
| ln(COD) | -2.86* | -0.85 | -2.24* | -0.62 | -2.07* | -2.19* | 0.01 | -3.98* |
| ln(SE) | -1.8* | -1.89* | -2.72* | -1.44 | 0.77 | -3.60* | -2.33* | -4.77* |
| ln(SOD) | -1.31 | -2.76* | -1.69 | -2.08 | -5.78* | -3.09* | -0.73 | -6.16* |
| Δln(RG) | -6.19* | -4.52* | -4.88* | -4.64* | -4.21* | -6.15* | -5.78* | -11.67* |
| Δ [ln(RG)]$^2$ | -6.34* | -4.53* | -5.02* | -4.70* | -4.06* | -5.23* | -5.79* | -11.7* |
| Δ [ln(RG)]$^3$ | -6.31* | -4.52* | -5.17* | -4.78* | -3.93* | -4.91* | -5.24* | -11.68* |
| Δln(COD) | -6.38* | -6.08* | -8.89* | -2.71* | -7.82* | -6.29* | -9.19* | -17.1* |
| Δln(SE) | -7.09* | -12.96* | -6.66* | -6.16* | -3.77* | -8.08* | -7.76* | -17.9* |
| Δln(SOD) | -3.95* | -5.74* | -7.49* | -6.60* | -5.76* | -6.89* | -7.17* | -15.4* |

*Notes*. Δ represents first order difference, RG - real GDP per capita, COD- COD discharge per capita, SE -SO2 emission per capita, SOD – solid waste per capita. Ln() indicate the logarithmic transformation. *Indicates statistical significance at least 5% level.

Source: author's calculations

For LLC tests, the null hypothesis is that panels contain unit roots and the alternative hypothesis is that panels are stationary. As shown in table 4, for LLC test, the null hypothesis of nonstationary cannot be rejected because there is unit root for at least one variable in every region. The results show that there are heterogeneous unit roots among these panels, first-order differencing is required.

The results of the first-order difference tests for all variables are at least at 5% level of significance and the explanatory and interpretive variables are integrated of order one.

For IPS tests, the original data likewise cannot reject the null hypothesis but the results of the first-order difference tests for all variables are at the 5% level of significance and the explanatory and interpretive variables are integrated of order one.

Table 5

*Panel unit root tests:LPS*

| | LPS Statistic | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Var/Region | north | northeast | east | central | south | northwest | southwest | country |
| ln(RG) | 0.05 | 1.52 | 0.13 | -0.07 | -0.25 | 2.39 | 1.42 | 1.11 |
| $[\ln(RG)]^2$ | 0.65 | 1.04 | 0.67 | 0.29 | -1.02 | 2.12 | 1.09 | 1.14 |
| $[\ln(RG)]^3$ | 1.05 | 1.29 | 1.34 | 0.55 | -1.60 | 1.76 | 1.07 | 1.38 |
| ln(COD) | -1.12 | -0.29 | -1.29 | -1.20 | -1.00 | -0.78 | 1.23 | -1.5 |
| ln(SE) | 0.93 | -1.35 | -1.02 | 0.89 | 0.42 | -2.43* | -1.88* | -1.47 |
| ln(SOD) | -0.44 | -0.85 | -0.10 | -0.15 | -4.29* | -1.29 | 0.52 | -2.24 |
| $\Delta\ln(RG)$ | -5.17* | -3.18* | -3.98* | -3.65* | -3.11* | -4.45* | -3.99* | -7.83* |
| $\Delta\ [\ln(RG)]^2$ | -5.4* | -3.19* | -3.20* | -3.81* | -2.94* | -3.67* | -3.97* | -7.85* |
| $\Delta\ [\ln(RG)]^3$ | -5.45* | -3.18* | -3.34* | -3.99* | -2.83* | -3.35* | -3.69* | -7.97* |
| $\Delta\ln(COD)$ | -5.83* | -5.01* | -3.48* | -4.18* | -6.41* | -4.55* | -7.30* | -14.24* |
| $\Delta\ln(SE)$ | -5.5* | -10.73* | -7.84* | -5.26* | -1.80* | -7.40* | -6.15* | -14.85* |
| $\Delta\ln(SOD)$ | -2.92* | -4.88* | -5.25* | -5.21* | -5.84* | -5.12* | -6.10* | -13.18* |

*Notes*. Δ represents first order difference, RG - real GDP per capita, COD- COD discharge per capita, SE -SO2 emission per capita, SOD – solid waste per capita. *Indicates statistical significance at least 5% level.

Source: author’s calculations

## 4.2. Panel co-integration tests

To ensure that the variables have a stable relationship in the long run, we continue the panel co-integration tests with Pedroni test. The results of Pedroni test are shown in Table 6.

Table 6

*Panel cointegration test*

| | | ln(COD) Statistic | ln(SE) Statistic | ln(SOD) Statistic |
|---|---|---|---|---|
| north | Modified Phillips–Perron t | 2.439*** | 1.816** | 1.674** |
| | Phillips–Perron t | -1.138 | 0.111 | 0.689 |
| | Augmented Dickey–Fuller t | 0.059 | 0.471 | -1.856 |
| northeast | Modified Phillips–Perron t | 1.533* | 2.165** | 1.195 |
| | Phillips–Perron t | -0.275 | 1.453 | -8.263*** |
| | Augmented Dickey–Fuller t | -0.183 | 1.281 | -3.895*** |
| east | Modified Phillips–Perron t | 3.209*** | 2.831*** | 1.533 |
| | Phillips–Perron t | 2.537*** | 1.210 | -3.661*** |
| | Augmented Dickey–Fuller t | 2.34*** | 0.243 | -4.29*** |
| central | Modified Phillips–Perron t | 1.936* | 1.796** | 1.254 |
| | Phillips–Perron t | 1.361 | 1.210 | -1.830** |
| | Augmented Dickey–Fuller t | 1.331 | 0.243 | -1.436 |
| south | Modified Phillips–Perron t | 1.747** | 1.779** | 1.754** |
| | Phillips–Perron t | 0.731 | 0.858 | -1.160** |
| | Augmented Dickey–Fuller t | 0.754 | 1.094 | -1.456* |
| northwest | Modified Phillips–Perron t | 2.635*** | 1.101 | 1.454* |
| | Phillips–Perron t | 2.021 | -3.466*** | -4.942*** |
| | Augmented Dickey–Fuller t | 1.916 | -3.042*** | -3.353*** |
| south | Modified Phillips–Perron t | 2.474*** | 1.719** | 2.307** |
| | Phillips–Perron t | 1.455* | -0.935 | -3.072*** |
| | Augmented Dickey–Fuller t | 1.171 | -0.808 | -1.078 |
| country | Modified Phillips–Perron t | 5.707*** | 4.494*** | 3.71*** |
| | Phillips–Perron t | 2.175** | -0.460 | -5.335*** |
| | Augmented Dickey–Fuller t | 2.965*** | -0.455 | -6.677*** |

*Notes*. COD- COD discharge per capita, SE -SO2 emission per capita, SOD – solid waste per capita. *** indicates statistical significance at the 1% level. ** indicates statistical significance at the 5% level. * Indicates statistical significance at the 10% level

Source: author’s calculations

From table 6, we can conclude that he null hypothesis of no co-integration can be rejected at the 10% significance level for COD discharge per capita, null hypothesis can be rejected at the 5% significance level for solid waste per capita and null hypothesis can be rejected at the 5% significance level at Modified Phillips–Perron test for SO2 emission per capita.

Thus, the Pedroni co-integration test provides evidence of the existence of a long-term equilibrium relationship between real GDP per capita and COD discharge per capita, solid waste per capita and $SO_2$ emission per capita.

### 4.3. Validation of regional EKC in China

Given the evidence from the unit root and cointegration tests, the panel data are unitary to the first order but there is long-run cointegration, this research proceed to estimate the EKC with the DOLS (dynamic OLS) estimator. Dynamic Ordinary Least Square was introduced by Stock and Watson (1993). Kao and Chiang (2001) compared commonly used regression models, ordinary least squares (OLS), fully modified OLS(FMOLS) and dynamic OLS(DOLS), and DOLS was found to be superior to the other two models as it showed minimal bias in small samples. DOLS includes leads and lags of the differenced explanatory variables in the regression equation. This helps to correct for autocorrelation and heteroskedasticity in the error term, effectively mitigating endogeneity bias (Ibrahiem & Hanafy, 2020). The equations of the DOLS shows as follows:

$$\hat{\beta} = [N^{-1} \sum_{t=1}^{N} (\sum_{t=1}^{N} Z_{it} Z_{it}^{'})^{-1} (\sum_{t=1}^{T} Z_{it}\, \hat{Y}_{it})\, ] \tag{6}$$

Where

$\hat{Y}_{it}$ – is the dependent variables

$Z$ – vector of repressors

Regressions were conducted using the dynamic ordinary least squares (DOLS) method for each of the regional panel data and 30 provinces panel data. The data is executed in cubic polynomial model first, and if coefficients are not significant at 5% level, data will then execute in quadratic polynomial model.

The results of COD discharge per capita cointegration estimation is presented in table 7, all coefficients are significant at 5% level in the cubic polynomial model in the south region. In other regions and at country level, all coefficients are significant at 5% level in the quadratic polynomial model. EKC relationship between COD per capita and economic growth is validated in all regions and at country level.

Table 7

*DOLS Regression for COD discharge*

| ln(COD) | ln(RG) | $[\ln(RG)]^2$ | $[\ln(RG)]^3$ | Inflection point |
|---|---|---|---|---|
| country | 24.89 | -1.28 | | 16697.26 |
| north | 39.25 | -1.9 | | 30607.49 |
| northeast | 17.24 | -0.90 | | 14443.5 |
| east | 10.10 | -0.49 | | 29911.55 |
| central | 48.22 | -2.39 | | 24052.64 |
| south | -27.52 | 5.37 | -0.27 | 17818.63 |
| northwest | 10.53 | -0.59 | | 7510.07 |
| southwest | 20.46 | -1.22 | | 4380.859 |

*Notes*. COD- COD discharge per capita, RG -real GDP per capita,

Source: author’s calculations

Based on the regression results, the EKC is confirmed in all regions and at the country level, which is contrary to Bonnefond Clement and Yan’s (2021) findings of EKC not present in COD discharge per capita. And the inflection point of the inverted U-shaped COD discharge EKC is at 16697.26 yuan real GDP per capita, indicating that the COD discharge per capita would increase when the per capita GDP is less than 16697.26 yuan, and after per capita GDP surpassed the inflection point, COD discharge per capita would decline with increase of per capita GDP. All regions and country level have reached the right descent phase of COD discharge per capita EKC, indicating that that the growth of economic development contributes to the reduction of COD discharge.

The north, east and central region have higher inflection points because that these regions entered a fast-paced phase of economic growth before other regions, but the economic growth during this period is at the cost of high consumption of energy and resource (Du, 2011), thus the COD discharge is possibly higher in these regions.

Industrialization started late in the northwest and southwest regions, and have initially low levels of pollution. With the gradual development of the economy, pollution increases rapidly, but from a small base, so it reaches the turning point earlier.

The results of $SO_2$ emission per capita cointegration estimation is presented in table 8, all coefficients are significant at 5% level in the cubic polynomial model in the north and southwest region, indicating an inverted N-shaped EKC curse. In other regions and at country level, all coefficients are significant at 5% level in the quadratic polynomial model, indicating an inverted U-shaped EKC curve.

Table 8

*DOLS Regression for $SO_2$ emission*

| ln(SE) | ln(RG) | $[\ln(RG)]^2$ | $[\ln(RG)]^3$ | Turning point |
|---|---|---|---|---|
| country | 28.98 | -1.51 | | 14705.84 |
| north | -49.61 | 9.70 | -0.48 | 23860.99 |
| northeast | 24.47 | -1.29 | | 13147.67 |
| east | 12.86 | -0.72 | | 7562.824 |
| central | 7.33 | -0.44 | | 4146.418 |
| south | 24.95 | -1.32 | | 12720.88 |
| northwest | 7.96 | -0.45 | | 6932.668 |
| southwest | -10.51 | 2.90 | -0.17 | 9054.345 |

*Notes*. SE- $SO_2$ emission per capita, RG -real GDP per capita,

Source: author's calculations

The inverted U-shaped EKC curve for $SO_2$ emission per capita has been verified in other studies (He,2009;Liao, Dogan & Baek ,2017;Wang, Zhang, Wang&Zhang,2020). And the inflection point of the inverted U-shaped $SO_2$ emission per capita EKC is at 14705.84 yuan real GDP per capita which is similar to Jayanthakumaran and Liu's(2012) finding and Hao, Gao, Guo, Gai and Wu's(2021) finding of inflection points at 15138 yuan and 13425 yuan respectively , indicating that the $SO_2$ emission per capita would increase when the per capita GDP is less than 14705.84 yuan, and after per capita GDP surpassed the inflection point, $SO_2$ emission per capita would decline with increase of per capita GDP. All regions and country level have reached the right descent phase of $SO_2$ emission per capita EKC, indicating that that the growth of economic development contributes to the reduction of $SO_2$ emission.

The northeast region is China's industrial base, with a concentration of high energyconsuming and high-pollution industries such as steel, coal, and electricity. These industries contribute significantly to economic growth. But they are also accompanied by large amounts of pollution emissions (Liu, Li &Zhong,2021). The presence of highly polluting industries delays the arrival of pollution peaks, leading to higher GDP levels at the turning point.

Moreover, the north region has high population density and rapid urbanization. Energy demand and pollution emissions from urban expansion and infrastructure construction will also delay the EKC turning point (Xiong, Yu, Jong, Wang& Cheng, 2017).

International trade has a positive impact on reducing SO2 emissions. Prosperous export trade in the east region improves environmental quality through the upgrading of advanced technologies (He, 2010).

The results of solid waste per capita cointegration estimation is presented in table 9, all coefficients are significant at 5% level in the cubic polynomial model in south region, indicating an inverted N-shaped EKC curve. The EKC is not validated in southwest region, there is a long-term increasing relationship between solid waste per capita and GDP per capita. In other regions and at country level, all coefficients are significant at 5% level in the quadratic polynomial model, indicating an inverted U-shaped EKC.

Table 9

*DOLS Regression for Solid Waste*

| ln(SOD) | ln(RG) | $[\ln(RG)]^2$ | $[\ln(RG)]^3$ | Turning point |
|---|---|---|---|---|
| country | 12.29 | -0.55 | | 71182.34 |
| north | 6.64 | -0.31 | | 44801.64 |
| northeast | 4.85 | -0.22 | | 61267.21 |
| east | 31.91 | -1.46 | | 55714.74 |
| central | 6.01 | -0.30 | | 22404.12 |
| south | -16.19 | 3.09 | -0.15 | 27146.41 |
| northwest | 4.61 | -0.21 | | 58454.27 |
| southwest | - | - | - | |

*Notes*. SOD-solid waste per capita, RG -real GDP per capita

Source: author’s calculations

From the long-term estimates, there is an inverted U-shaped EKC between solid waste per capita and GDP per capita at the national level, this is contrary to the inverted N-shaped

EKC tested by Zhao, Zhao and Zhang (2021) and Song, Zheng and Tong (2008), but consistent with the conclusion of Boubellouta, Kusch-Brandt (2021). And the inflection point of the inverted U-shaped solid waste per capita EKC is at 71182.34 yuan real GDP per capita, indicating that the solid waste per capita would increase when the per capita GDP is less than 71182.34 yuan, and after per capita GDP surpassed the inflection point, solid waste per capita would decline with increase of per capita GDP. Yu (2021) also verified the inverted U-shaped curve, but argued that the inflection point was in 90183.87 yuan.

In terms of regional results, 16 provinces and municipalities have reached the inflection point, indicating that the solid waste per capita decrease when GDP per capita increase. But the EKC hypothesis is not supported in southwest region.

### 4.4. Policy Implicaion

Water pollution in China has shown a downward trend with economic growth. For the more economically developed northern, eastern, and central regions, the government should promote cleaner production processes, support enterprises to carry out technological upgrading, to improve the efficiency of wastewater disposal, and to reduce COD emissions. For the late start of industrialization in the western region, the government should improve the wastewater treatment infrastructure, increase capital investment.

In 2006, China's 11th Five-Year Plan clearly put forward energy saving as the goal, and $SO_2$ as a key target for emission reduction, this policy makes the s $SO_2$ emissions in various regions have been controlled, and began to reduce after the 11th Five-Year Plan (Liu & Wang,2017). And all regions are in the right declining part of the observed curves, indicating that economic growth promoted reduction of $SO_2$ emissions, government should take measures to maintain this trend. For the developing regions like southwest, northwest, and central China, the Government needs to adopt effective clean energy policies to promote the use of renewable energy sources, and encourage enterprises to reduce coal consumption to reduce $SO_2$ emissions. For economically developed regions, the government should promote to increase the proportion of clean energy and promote the use of new energy vehicles to further reduce sulfur dioxide emissions.

China's solid waste pollution is still serious, and solid pollutants are still showing an upward trend in the short term. The government should encourage enterprises to adopt cleaner production techniques and technologies to reduce the generation of solid waste from source. At the same time, the international advanced solid waste management experience and technology should be introduced to China to improve waste recycling and utilization.

## 5. Conclusion

In this paper, the EKC hypothesis for air pollution, water pollution and solid waste in seven regions of China has been investigated based on the panel data of 31 provinces in during 2003 to 2021. Results indicated that there exists an inverted U-shape curve for the relationship between economic growth and air pollution, water pollution and solid waste pollution at country level. The panel unit root tests indicate that all variables are integrated on the order of one, I(1). Cointegration test shows that there is long-run relationship in the panel data. Then DOLS (dynamic ordinary least squares) estimator indicates that the EKC hypothesis is valid at country level and all regions except southwest region.

For the water pollution, there exist an inverted N-shaped curve in south region, and inverted U-shaped curve in other regions. All the regions have entered a downward phase on the right side of the curve, indicating that water pollution decrease with economic growth. The north, east and central region have higher inflection points because that these regions entered a fast-paced phase of economic growth before other regions. Northwest and southwest regions have lower inflection points due to the late start of industrialization.

For the air pollution, there is an inverted N-shaped EKC in north and southwest region, but inverted U-shaped EKC in other regions. All the regions have entered a downward phase on the right side of the curve, indicating that economic growth would promote the reduction of waste air emission. Industrial base northeast region and highly urbanized north region have higher inflection points.

For the solid waste pollution, EKC is not supported in southwest region, but inverted N-shaped is validated in south region and inverted N-shaped curve is observed in other regions. The inflection point is high and most provinces have not reached it. Pollution from solid waste has not received enough attention, Governments should carry out policy to prevent and control the solid pollutants generation, promote cleaner production technologies, encourage the use of environmentally friendly materials and increase the recycling of solid wastes to minimize pollution.

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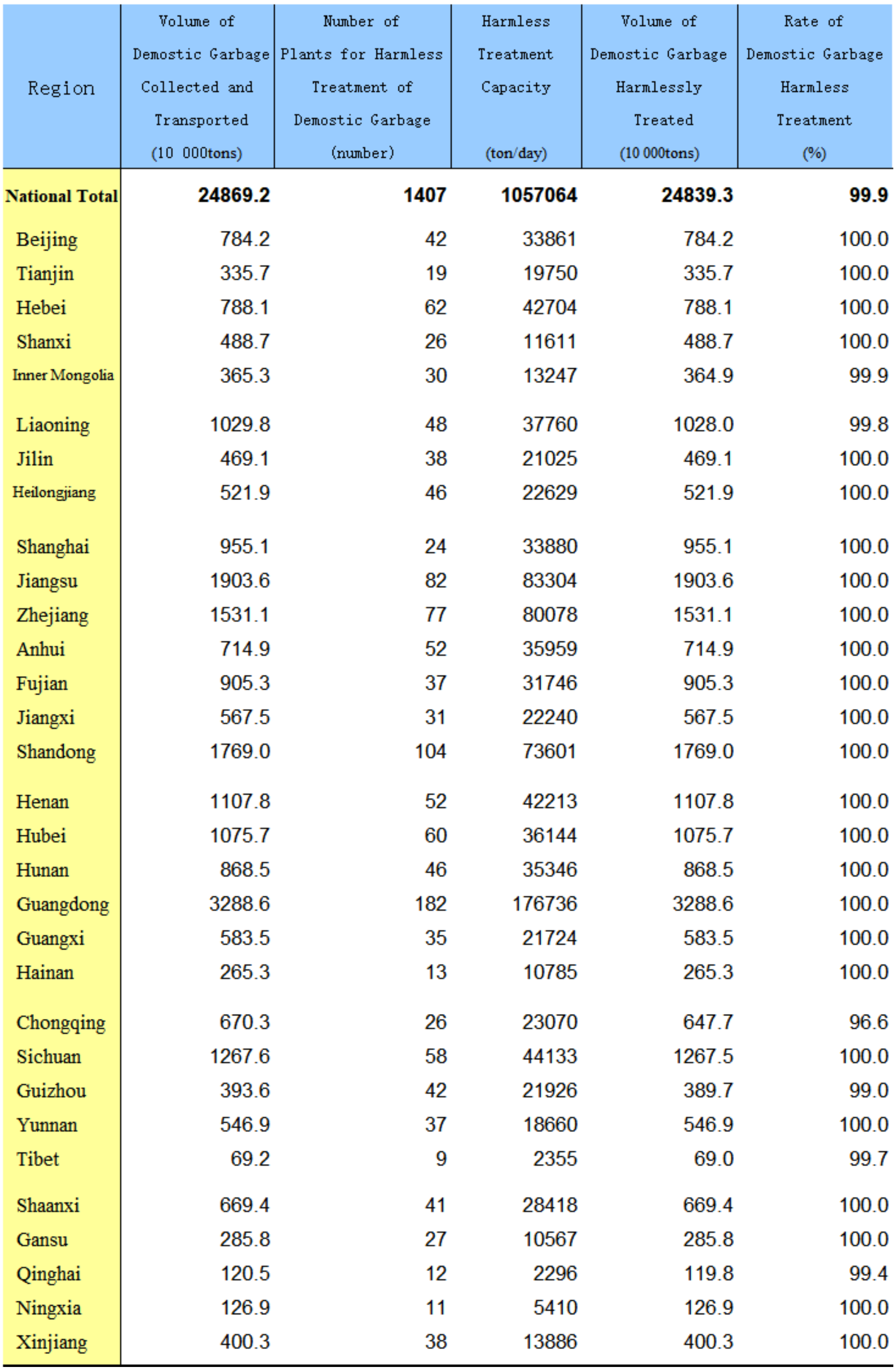
# Appendic

Collection, Transportation and Treatment of Municipal Domestic Garbage by Region (2021)



| Region | Volume of Demostic Garbage Collected and Transported (10 000tons) | Number of Plants for Harmless Treatment of Demostic Garbage (number) | Harmless Treatment Capacity (ton/day) | Volume of Demostic Garbage Harmlessly Treated (10 000tons) | Rate of Demostic Garbage Harmless Treatment (%) |
|---|---|---|---|---|---|
| **National Total** | **24869.2** | **1407** | **1057064** | **24839.3** | **99.9** |
| Beijing | 784.2 | 42 | 33861 | 784.2 | 100.0 |
| Tianjin | 335.7 | 19 | 19750 | 335.7 | 100.0 |
| Hebei | 788.1 | 62 | 42704 | 788.1 | 100.0 |
| Shanxi | 488.7 | 26 | 11611 | 488.7 | 100.0 |
| Inner Mongolia | 365.3 | 30 | 13247 | 364.9 | 99.9 |
| Liaoning | 1029.8 | 48 | 37760 | 1028.0 | 99.8 |
| Jilin | 469.1 | 38 | 21025 | 469.1 | 100.0 |
| Heilongjiang | 521.9 | 46 | 22629 | 521.9 | 100.0 |
| Shanghai | 955.1 | 24 | 33880 | 955.1 | 100.0 |
| Jiangsu | 1903.6 | 82 | 83304 | 1903.6 | 100.0 |
| Zhejiang | 1531.1 | 77 | 80078 | 1531.1 | 100.0 |
| Anhui | 714.9 | 52 | 35959 | 714.9 | 100.0 |
| Fujian | 905.3 | 37 | 31746 | 905.3 | 100.0 |
| Jiangxi | 567.5 | 31 | 22240 | 567.5 | 100.0 |
| Shandong | 1769.0 | 104 | 73601 | 1769.0 | 100.0 |
| Henan | 1107.8 | 52 | 42213 | 1107.8 | 100.0 |
| Hubei | 1075.7 | 60 | 36144 | 1075.7 | 100.0 |
| Hunan | 868.5 | 46 | 35346 | 868.5 | 100.0 |
| Guangdong | 3288.6 | 182 | 176736 | 3288.6 | 100.0 |
| Guangxi | 583.5 | 35 | 21724 | 583.5 | 100.0 |
| Hainan | 265.3 | 13 | 10785 | 265.3 | 100.0 |
| Chongqing | 670.3 | 26 | 23070 | 647.7 | 96.6 |
| Sichuan | 1267.6 | 58 | 44133 | 1267.5 | 100.0 |
| Guizhou | 393.6 | 42 | 21926 | 389.7 | 99.0 |
| Yunnan | 546.9 | 37 | 18660 | 546.9 | 100.0 |
| Tibet | 69.2 | 9 | 2355 | 69.0 | 99.7 |
| Shaanxi | 669.4 | 41 | 28418 | 669.4 | 100.0 |
| Gansu | 285.8 | 27 | 10567 | 285.8 | 100.0 |
| Qinghai | 120.5 | 12 | 2296 | 119.8 | 99.4 |
| Ningxia | 126.9 | 11 | 5410 | 126.9 | 100.0 |
| Xinjiang | 400.3 | 38 | 13886 | 400.3 | 100.0 |

Source: China Statistical Yearbook (2022)

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Ke Wang
21/05/2024

## Resümee

### Keskkonna Kuznetsi kõvera uuring Hiinas: piirkondlik paneelanalüüs

Ke Wang

Käesolevas töös uuritakse seost veereostuse, õhusaaste, tahkete jäätmete saastatuse ja majanduskasvu vahel, tuginedes keskkonna Kuznetsi kõvera (EKC) teooriale. Seose empiiriliseks hindamiseks kasutatakse Hiina provintside paneelandmeid aastatel 2003–2021. Paneelandmete ühikjuure testid näitavad, et kõik muutujad on integreeritud suurusjärgus üks. Kointegratsiooni test näitab, et paneelandmetes on pikaajaline seos. Seejärel näitab DOLS (dünaamiline vähimruutude meetodi) test, et EKC hüpotees kehtib nii riigi tasandil kui ka kõigis piirkondades, välja arvatud edelapiirkond. Tahkejäätmete reostuse ja edelapiirkonna majanduskasvu vahel on positiivne seos. Lisaks selgub analüüsist, et majanduskasv aitab kaasa vee- ja õhusaaste vähenemisele, kuid suurendab tahkete jäätmete saastet, mistõttu valitsused peavad pöörama rohkem tähelepanu tahkete jäätmetega saastele.