Public Attention Index of Air Pollution Exposure from PM 2.5 in Thailand

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Abstract

Air pollution is a severe environmental threat in many developing countries, including Thailand. In 2020, Thailand was four times higher than the WHO annual air quality guideline value. The Royal Thai Government decided to make air pollution a national priority project and had a city-wide action plan to mitigate the PM2.5 exposures which is different in detail. The information failure on the severity of PM2.5 exposures is absent, according to uncovered airborne monitoring stations across 77 provinces, resulting in an ineffective solution and unmotivated self-protective behavior due to underestimating the risk posed by PM2.5 exposures. This study constructs the PM2.5 proxy index (Public attention index to PM2.5 exposure) by using internet search terms related to the PM2.5 issue from Google Trends to capture public attention to PM2.5 exposures. The findings of this study will grow beneficial for policymaking and future research which is novelty in environmental economics research papers, especially in the particulate matter context.

Keywords: PM2.5, Index, Internet Search Data, Google Trends

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Introduction

Air pollution is a severe environmental threat in many developing countries, including Thailand (WHO, 2022). The PM2.5 pollutions is not a short-term crisis. It is one of the issues that Thailand has faced for a long time, and there is no ideal solution to this problem. Aside from automobile exhaust, emissions from industrial plants and construction sites, as well as crops burning ahead for the new planting seasons such as maize, off-season rice, and sugarcane farming, all contributed to the rising of PM2.5 exposure (Kasikorn Research Center, 2023).

Thailand was ranked as the 28th most polluted country out of 98 countries with an annual average PM2.5 rating of 24.30 micrograms per cubic meter in 2019 and reduced to 18.10 micrograms per cubic meter in 2020, ranked 57th. However, it was four times higher than the WHO annual air quality guideline value (WHO, 2022).

Exposure to PM2.5 can be characterized as a public good because those who create PM2.5 have a negative externality on others (Pholphirul, 2023). PM2.5 is the problem of politics, production, and public behavior. Thus, in order to address PM2.5 exposure, it is crucial to understand the sources of the problem from all related parties. The issue with air pollution from PM2.5 exposure is from the production of industry and agriculture, as well as human activity in urban and rural areas, which both act as creators and receivers of PM2.5 exposure (Poapongsakorn et. al., 2023).

According to the research of Attavanich (2022), the average social cost of PM2.5 across 74 provinces of Thailand in 2019 was 2.17 trillion baht annually. The concern on the issue of PM2.5 exposure is increasing among the general public in Thailand. In 2019, the Thai Government decided to make the issue of air pollution as a national priority project. Thailand had an action plan to mitigate the PM2.5 exposure that varied by the province in terms of details. Aside from sprinkling water to reduce PM2.5 particles in the air, the government has explored initiating actions to mitigate the PM2.5 issue in the short term such as lowering vehicle emissions of black smoke by prohibiting the operation of vehicles with diesel engines or prohibiting people from burning rubbish in public places. These actions are considered as temporary policies and do not address the root of the cause, which is the challenges of law and regulation (Chulalongkorn University, 2021). Efforts must be jointly together in order to address the PM2.5 issue, including individuals, communities, private agencies, industries, policymakers, and enforcers, across all branches of government.

In 2020, Thailand had airborne monitoring stations that measure PM2.5 concentration levels in 37 provinces and 57 provinces in 2023 out of 77 provinces, resulting in the absence of data in the provinces that have no airborne monitoring station. This has become one of the most important problems in formulating appropriate policies to address PM2.5 issue. The findings of this study will grow beneficial for policymaking and future research which is novelty in environmental economics research papers, especially in the particulate matter context.

The rise in PM2.5 levels adversely affects both public health and Thailand's key economic sector, particularly tourism. When PM2.5 primarily stems from human activities, the focus of the solution should target those accountable for its creation. Analyzing public awareness of PM2.5 in Thailand becomes a crucial tool for policymakers. Addressing the PM2.5 issue, understanding public awareness, exploring the factors influencing public attention, and protection behavior to avoid and shield against hazardous PM2.5 are hence critically imperative.

Literature Review

Although PM 2.5 is not the only component of air pollution, it is considered as a common proxy indicator for air pollution because it affects more people than do other pollutants. (WHO, 2021; WHO, 2020 cited in Hemmati, Dabbaghi, Mahmoudi, 2020). A thorough understanding of the risks posed by air pollution is essential information for developing specific air pollution response policies.

The internet search data is an effective tool for tracking public attention (Misra & Takeuchi, 2020; Ryu & Min, 2020) and can be used as a proxy for missing data apart from data received from airborne monitoring stations. (Liu et al., 2019; Ryu & Min, 2020; Nazar & Plata-Nazar, 2021). There are studies that use internet search data to predict the present and the near future of the unemployment rate (Tuhkuri, 2015), to measure the effect of the company's stock price and volatility (Liu et. al., 2020), to examine public attention to spatial and seasonal changes in air pollution exposure (Nazar & Plata-Nazar, 2021; Xu et. al., 2022), and to construct an indicator to measure public attention to environmental pollution issues (Jiang et. al., 2015; Yang et. al., 2019).

There have been studies on PM2.5 in Thailand, such as ChooChuay et al. (2020) and Chirasophon & Pochanart (2020), which studied the composition of PM2.5 in the air in Bangkok. Amnuay Lojaroen, Parasin & Limsakul (2022) and Fold et al. (2020) studied the health impacts of PM2.5. Nonthapot, Sihabutr & Lean (2024) studied the impact of PM2.5 on the tourism sector in Thailand. However, there has not yet been a study on creating a proxy index for PM2.5. This study is the first to be carried out internet search data to construct a proxy index for the PM2.5 issue in Thailand.

Data Collection and Research Methodology

Data Collection

(1) PM2.5 concentration level and Airborne monitoring station: The 24-hour average of PM2.5 concentration levels in micrograms per cubic meter of 2020 are secondary data collected on a daily basis from airborne monitoring station in 37 provinces, which were grouped into 7 regions. There are 68 airborne monitoring stations in Thailand, 12 stations are in Bangkok, eleven are in Greater Bangkok, 16 stations are in Northern, 11 stations are in Eastern, 7 stations are in Southern and 5 stations are in Northeastern. (Table A.1 and Table A.2 in Appendix A). These data were provided by the Air Quality and Noise Management Bureau, Pollution Control Department, Ministry of Natural Resources and Environment.

(2) Internet search term: The internet search term "PM2.5" and others related to the PM2.5 issue, total 25 selected terms. The other related terms in both Thai and English, representing the most frequently co-searched terms within the same search session as "PM2.5" for the specified period, category, and geographical location. These data were extracted from Google Trends, encompassing all 77 provinces of Thailand, with monthly-averaged spanning from January 1, 2020, to December 31, 2020. The search volume is quantified on a normalized scale ranging from 0 to 100. A value of 0 indicates that the relative search volume for the selected term is below 1 percent of the peak popularity observed within the given parameters (time period, category, and location). Conversely, a value of 100 denotes the highest search popularity for the selected term.

(3) Willingness to Pay and Economic and Social Costs: The Willingness to Pay and Economic and Social Costs are the secondary data from the report Knowledge about the impact

of Air Pollution on the Thai Economy and Society (Attavanich, 2023). The data was calculated from the basic necessity information survey conducted by the Ministry of Interior in 2019, which collected 12,925,826 households distributed throughout all provinces of Thailand, and the air quality data in 2019 from the Pollution Control Department, Ministry of Natural Resources and Environment.

Data processing

(1) PM2.5 concentration data: The PM2.5 concentration levels data, collected on a daily basis from 68 airborne monitoring stations' codes, was categorized into 37 provinces in which the airborne were located. Then the PM2.5 computed data in 37 provinces were classified into 7 regions based on the Air Quality and Noise Management Bureau's division criteria (Table 1 in Appendix A). For provinces that have no airborne station and PM2.5 concentration level data were given "0" to their concentration value.

(2) Internet search terms: The internet search terms "PM2.5" and other related terms, in Thai and English, that related to the PM2.5 exposure issue from Google Trends of 77 provinces were collected. The value of search terms that less than 1 were given as "0". The group of selected internet search terms, as a representative of the search that related to the issue PM2.5, are calculated to proof the correlation and statistically significant with the 24-hour average of PM2.5 concentration levels. The correlations test by the Pearson correlation coefficient and the p-value, using the STATA program to compute Bivariate correlation analysis (Table A). There are 18 internet search terms that are statistically significantly positive at 0.01 level, 1 term is statistically significantly positive at 0.05 level, and 6 terms are not statistically significant. Of these, 3 terms are high, 12 terms are moderate, 6 terms are low, and 4 terms are very low correlated to the 24-hour average of PM2.5 concentration levels. The higher the correlation, the more effectively the selected keywords can be used to capture an individual's attention toward the PM2.5 exposure issue through online search behavior.

Table 1: Correlation Between the Internet Search Terms and PM2.5 Concentration Levels.

Pearson's Correlation Coefficient	PM2.5	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
PM2.5	1																									
(1) pm 2.5	.617**	1																								
(2) pm	.656**	.960**	1																							
(3) ฝุ่น	.560**	.923**	.908**	1																						
(4) ฝุ่น pm 2.5	.538**	.935**	.909**	.893**	1																					
(5) ค่า pm	.560**	.715**	.708**	.715**	.708**	1																				
(6) ค่า pm 2.5	.561**	.903**	.889**	.832**	.931**	.712**	1																			
(7) pm 2.5 วัน นี้	.555**	.817**	.783**	.756**	.799**	.645**	.823**	1																		
(8) ค่า ฝุ่น	.592**	.932**	.909**	.893**	.925**	.770**	.917**	.768**	1																	
(9) ค่า ฝุ่น pm	.323**	.479**	.519**	.580**	.564**	.724**	.548**	.526**	.538**	1																
(10) ค่า ฝุ่น pm 2.5	.636**	.868**	.860**	.830**	.852**	.791**	.880**	.747**	.849**	.650**	1															
(11) ฝุ่น pm 2.5 วัน นี้	.505**	.762**	.764**	.746**	.809**	.706**	.849**	.881**	.804**	.645**	.756**	1														
(12) ค่า pm 2.5 วัน นี้	.496**	.791**	.792**	.783**	.814**	.634**	.863**	.776**	.832**	.609**	.796**	.843**	1													
(13) ค่า pm วัน นี้	.517**	.831**	.813**	.780**	.822**	.714**	.870**	.742**	.836**	.608**	.851**	.837**	.858**	1												
(14) pm 2.5 คือ	.187	.229*	.276*	.244*	.321**	.256*	.280*	.128	.244*	.231*	.286*	.182	.314**	.149	1											
(15) pm คือ	.329**	.163	.264*	.202	.256*	.345**	.265*	.163	.241*	.410**	.336**	.350**	.245*	.134	.465**	1										
(16) ค่า ฝุ่น วัน นี้	.540**	.862**	.832**	.853**	.870**	.808**	.863**	.731**	.926**	.608**	.832**	.769**	.818**	.823**	.253*	.285*	1									
(17) ค่า ฝุ่น pm วัน นี้	.252*	.466**	.478**	.519**	.518**	.671**	.538**	.543**	.511**	.890**	.628**	.657**	.633**	.662**	.175	.276*	.601**	1								
(18) หน้ากาก pm 2.5	.494**	.720**	.749**	.741**	.760**	.516**	.724**	.572**	.731**	.443**	.643**	.644**	.707**	.686**	.414**	.290*	.714**	.412**	1							
(19) ค่า ฝุ่น pm 2.5 วัน นี้	.425**	.748**	.762**	.749**	.794**	.729**	.843**	.714**	.788**	.742**	.822**	.831**	.866**	.847**	.346**	.311**	.811**	.764**	.744**	1						
(20) วัด pm 2.5	.221	.393**	.452**	.395**	.403**	.540**	.435**	.432**	.422**	.700**	.492**	.537**	.532**	.553**	.180	.210	.492**	.807**	.352**	.630**	1					
(21) pm 2.5 bangkok	.195	.326**	.405**	.468**	.343**	.368**	.231*	.239*	.319**	.517**	.297**	.304**	.243*	.265*	.146	.296**	.326**	.429**	.393**	.292**	.455**	1				
(22) pm 2.5 เชียงใหม่	.202	.346**	.356**	.290*	.367**	.515**	.470**	.454**	.397**	.659**	.508**	.564**	.588**	.598**	.136	.129	.476**	.800**	.246*	.675**	.829**	-.017	1			
(23) เช็ค pm 2.5	.370**	.500**	.532**	.611**	.550**	.733**	.511**	.476**	.566**	.838**	.606**	.597**	.506**	.558**	.228*	.444**	.609**	.705**	.459**	.644**	.521**	.648**	.382**	1		
(24) pm 2.5 เช็ค	.111	.226*	.320**	.311**	.195	.194	.120	.123	.199	.270*	.153	.161	.131	.154	.098	.154	.193	.248*	.295**	.153	.541**	.863**	-.005	.370**	1	
(25) หน้ากาก กัน pm 2.5	.111	.226*	.320**	.311**	.195	.194	.120	.123	.199	.270*	.153	.161	.131	.154	.098	.154	.193	.248*	.295**	.153	.541**	.863**	-.005	.370**	1.000**	1

Note: Author's Calculation.

The internet search terms are grouped to 5 groups based on coefficient correlations, Group 1, only the internet search terms that are statistically significantly positive at 0.01 level with a high correlation ($0.60 \leqslant r \leqslant 0.79$) to PM2.5 concentration levels were selected. Group 2 consisted of the internet search terms that are statistically significant positive at the 0.01 and 0.05 levels, with high and moderate correlation ($0.40 \leqslant r \leqslant 0.59$) to the PM2.5 concentration levels. The criteria for Group 3 and Group 4 are similar to Group 1 and 2, respectively, with the difference that Group 3 and 4 do not contained search terms with no "PM2.5". Every criterion is present in Table B. The coefficient correlations of 5 groups are used as data for 5 alternative cases to calculate the PAI_PM2.5 index: Group 1 for Case 1, Group 2, 3, 4, 5 for Case 2, 3, 4, 5 respectively.

Table 2: Correlation Between the Groups of Internet Search Terms and PM2.5 Concentration Levels.

Group	Related Terms	Sig. Level	Size of Correlation	Internet Search Term
1	All	0.01	High	pm, ค่า ฝุ่น pm 2.5 (level dust pm 2.5), pm 2.5
2	All	0.01 and 0.05	High and Moderate	ค่า ฝุ่น (level dust), ค่า pm 2.5 (level pm 2.5), ฝุ่น (dust), ค่า pm (level pm), pm 2.5 วัน นี้ (pm 2.5 today), ค่า ฝุ่น วัน นี้ (level dust today), ฝุ่น pm 2.5 (dust pm 2.5), ค่า pm วัน นี้ (level pm today), ฝุ่น pm 2.5 วัน นี้ (dust pm 2.5 today), ค่า pm 2.5 วัน นี้ (level pm 2.5 today), หน้ากาก pm 2.5 (mask pm 2.5), ค่า ฝุ่น pm 2.5 วัน นี้
3	PM2.5	0.01	High	ค่า ฝุ่น pm 2.5, pm 2.5
4	PM2.5	0.01 and 0.05	High and Moderate	ค่า pm 2.5, pm 2.5 วัน นี้, ฝุ่น pm 2.5, ฝุ่น pm 2.5 วัน นี้, ค่า pm 2.5 วัน นี้, หน้ากาก pm 2.5, ค่า ฝุ่น pm 2.5 วัน นี้
5	All	All	All	All Search terms are selected

Note: Author’s Calculation.

Research Methodology

The public attention index to PM2.5 (PAI_PM 2.5) is defined as:

$$\mathbf{I_{t,i}} = \left\{ \frac{(\mathbf{K_{t,i}}/\mathbf{G_{t,i}})}{\max\limits_{\mathbf{t}} (\mathbf{K_{t,i}}/\mathbf{G_{t,i}})} \right\} \times \mathbf{100} \qquad ; \mathbf{t = 1, 2, \dots, f} \qquad (1)$$

$$\mathbf{K_{t,i}} \in \left(\mathbf{K_{1,i}},\ \mathbf{K_{2,i}},\ \dots, \mathbf{K_{f,i}}\right)$$

$$\mathbf{G_{t,i}} \in \left(\mathbf{G_{1,i}},\ \mathbf{G_{2,i}},\ \dots, \mathbf{G_{f,i}}\right)$$

$$\mathbf{K_{t,i}} = \sum_{\mathbf{t=1}}^{\mathbf{T}} \mathbf{k_{t,i}}$$

where I_(t,i) denotes the public attention index to PM2.5 exposure for province i at period t. K_(t,i) denotes the group of selected internet search terms k that related to the issue of PM2.5 exposure for province i at period t. G_(t,i) denotes the total amount of internet search terms that related to PM2.5 exposure issue for province i at period t. By dividing K_(t,i) by G_(t,i), is to removes the rising trend of search volume in Google Trends, because search volumes in Google Trends have increased many-fold which led to duplicate data. Moreover, when forming statistical variables from the text corpus, it is necessary to take into account that the search terms changed over time (Google Trends, 2023). Then, the Bivariate Pearson correlation analysis was employed to investigate the relationship between the PAI_PM 2.5 index, 24-hour average of PM2.5 concentration levels (PM2.5), Economics and social cost for PM2.5 (COST), and Marginal willingness to pay to reduce PM2.5 by 1 microgram per cubic meter per year (WTP).

Results and Discussion

The correlation analysis between the PAI_PM2.5 index and PM2.5 concentration data illustrates a statistically significant at 0.01 level (p-value = 0.01) with positive correlation for Case1, 2, 3, 5, and 0.05 level (p-value = 0.05) for Case4 of index calculation. The size of the correlation coefficient of Case1 (r=0.660) and Case5 (r=0.624) is high whereas Case2 (r=0.542) is moderate and Case3 (0.359) and Case4 (r=0.286) is low.

The correlation analysis between the PAI_PM2.5 index and COST illustrates a statistically significant at 0.01 level (p-value=0.01) with positive correlation in every case of index calculation. The size of the correlation coefficient of every case is moderate, for Case1 (r=0.404), Case2 (r=0.336), Case3 (r=0.571), Case 4 (r=0.554), and Case5 (r=0.356).

The correlation analysis between the PAI_PM2.5 index and WTP illustrates a statistically significant positive correlation at 0.01 level (p-value=0.01) for Case1, 3, 4, and 0.05 level (p-value=0.05) for Case2, and 5. The size of the correlation coefficient of Case3 (r=0.536) and Case4 (r=0.559) is moderate, and low for Case1 (r=0.357), Case2 (r=0.277), and Case5 (r = 0.275).

The significance of the coefficient correlation of the PAI_PM2.5 index with PM2.5, COST, and WTP shows that the PAI_PM2.5 index can represent the level of public attention to the issue of PM2.5 which varies according to the degree of PM2.5 exposures (PM2.5), Economic and Social cost (COST) and Willingness to pay for reducing PM2.5 (WTP). The correlation coefficient is presented in Table C.

Table 3: Pearson's Correlation Coefficient between Public Attention Index to PM2.5, PM2.5 Concentration Levels, Economics and Social Cost for PM2.5, and Marginal Willingness to Pay to Reduce PM2.5.

Pearson's Correlation Coefficient	PM2.5[a]	COST[b]	WTP[c]	Case1[d]	Case2[e]	Case3[f]	Case4[g]	Case5[h]
PM2.5[a]	1							
COST[b]	.259*	1						
WTP[c]	.207	.978**	1					
Case1[d]	.660**	.404**	.357**	1				
Case2[e]	.542**	.336**	.277*	.759**	1			
Case3[f]	.359**	.571**	.536**	.493**	.523**	1		
Case4[g]	.286*	.554**	.559**	.444**	.512**	.848**	1	
Case5[h]	.624**	.356**	.275*	.823**	.888**	.524**	.467**	1

Note: Author's Calculation.

a 24-hour average of PM2.5

b Economics and Social cost for PM2.5

c Marginal WTP to reduce PM2.5 1 micrograms per cubic meter

d Public attention index for PM2.5 exposure for Case 1 which included only the internet search terms that are statistically significantly positive at 0.01 level with a high correlation ($0.60 \leq r \leq 0.79$) to PM2.5 concentration levels.

e Public attention index for PM2.5 exposure for Case 2 which included the internet search terms that are statistically significant positive at the 0.01 and 0.05 levels, with high and moderate correlation ($0.40 \leq r \leq 0.59$) to the PM2.5 concentration levels.

f Public attention index for PM2.5 exposure for Case 3 which included only the internet search terms that are statistically significantly positive at 0.01 level with a high correlation ($0.60 \leq r \leq 0.79$) to PM2.5 concentration levels, but excluded the search terms "PM2.5".

g Public attention index for PM2.5 exposure for Case 4 which included the internet search terms that are statistically significant positive at the 0.01 and 0.05 levels, with high and moderate correlation ($0.40 \leq r \leq 0.59$) to the PM2.5 concentration levels, but excluded the search terms "PM2.5".

h Public attention index for PM2.5 exposure for Case 5 which included the internet search terms that are statistically significant positive at the 0.01 and 0.05 levels, with high ($0.60 \leq r \leq 0.79$) and moderate correlation ($0.40 \leq r \leq 0.59$) to the PM2.5 concentration levels.

The PAI_PM2.5 index based on Case1 is the best approach to represent an individual's attention on the issue of PM 2.5 exposure issue through the internet search behavior. Because the correlation coefficient of Case1's PAI_PM2.5 index and PM2.5 is the highest among all cases (r=0.660) and has a higher correlation with COST (r=0.404) and WTP (r=0.357) than Case5 (r of PM2.5=0.624, r of COST=0.356, and r of WTP=0.275).

Table 4: PM2.5 Concentration Level and Public Attention Index to PM2.5

Region/Province	PM2.5	PAI_PM2.5		Region/Province	PM2.5	PAI_PM2.5
Bangkok	**23.17**	**100**		**Northeastern**	**25.71**	**33**
Greater Bangkok	**22.08**	**62**		Khon Kaen	29.09	47
Nonthaburi	20.29	77		Nakhon Ratchasima	27.01	40
Samut Prakan	22.87	63		Chaiyaphum	N/A	38
Pathum Thani	22.10	63		Loei	22.85	37
Nakhon Pathom	20.22	58		Maha Sarakham	N/A	37
Samut Sakhon	24.93	51		Nakhon Phanom	N/A	35
Northern	**29.96**	**67**		Nong Khai	25.67	33
Chiang Mai	30.91	98		Ubon Ratchathani	23.93	33
Phrae	30.93	93		Udon Thani	N/A	33
Phayao	32.17	89		Roi Et	N/A	31
Nan	28.74	83		Sakon Nakhon	N/A	30
Lampang	27.55	82		Yasothon	N/A	29
Tak	27.99	76		Kalasin	N/A	28
Chiang Rai	36.23	75		Buri Ram	N/A	28
Lamphun	27.37	70		Surin	N/A	28
Kamphaeng Phet	N/A	64		Si Sa Ket	N/A	26
Mae Hong Son	32.30	61		Bueng Kan	N/A	0
Uttaradit	N/A[a]	56		Nong Bua Lam Phu	N/A	0
Phitsanulok	N/A	56		Mukdahan	N/A	0
Sukhothai	N/A	50		Amnat Charoen	N/A	0
Nakhon Sawan	25.35	44		**Western**	**22.96**	**38**
Phetchabun	N/A	40		Ratchaburi	22.96	42
Phichit	N/A	36		Phetchaburi	N/A	36
Uthai Thani	N/A	0		Prachuap Khiri Khan	N/A	36
Central	**23.02**	**48**		**Southern**	**14.07**	**31**
Phra Nakhon Si Ayutthaya	23.10	53		Phuket	14.51	41
Saraburi	28.79	50		Songkhla	19.38	38
Kanchanaburi	26.45	49		Narathiwat	14.46	36
Ang Thong	N/A	48		Surat Thani	14.53	34
Suphan Buri	N/A	47		Yala	11.53	34
Chai Nat	N/A	45		Krabi	N/A	33
Lopburi	N/A	43		Pattani	N/A	31
Samut Songkhram	13.75	0		Trang	N/A	29
Sing Buri	N/A	0		Nakhon Si Thammarat	N/A	28
Eastern	**19.77**	**47**		Phang-nga	N/A	28
Rayong	18.29	56		Phatthalung	N/A	24
Chon Buri	18.87	51		Chumphon	N/A	23
Prachin Buri	24.83	48		Satun	10.01	19
Chachoengsao	18.90	48		Ranong	N/A	0
Sa Kaeo	17.94	45				
Trat	N/A	43				
Nakhon Nayok	N/A	43				
Chanthaburi	N/A	41				

Note: Author's Calculation.

a N/A is the province where PM2.5 concentration data is not available because that province has no airborne monitoring station.

In 2020, on a regional basis, Bangkok had the highest Public Attention Index for PM2.5 exposure (PAI_PM2.5 index = 100). They were subsequently followed by Northern (PAI_PM2.5 index = 67), Greater Bangkok (PAI_PM2.5 index = 62), Central (PAI_PM2.5 index = 48), Western (PAI_PM2.5 index = 38), and Southern (PAI_PM2.5 index = 31).

The top 10 provinces with the highest PAI_PM2.5 index are Bangkok (PAI_PM2.5 index = 100), Chiang Mai (PAI_PM2.5 index = 98), Phrae (PAI_PM2.5 index = 93), Phayao (89), Nan (PAI_PM2.5 index = 83), Lampang (PAI_PM2.5 index = 82), Nonthaburi (PAI_PM2.5 index = 77), Tak (PAI_PM2.5 index = 76), Chiang Rai (PAI_PM2.5 index = 75), and Lamphun (PAI_PM2.5 index = 70), respectively.

Eight out of ten provinces in the Northern have high levels of PM2.5 concentration level which is higher than WHO guidelines (WHO, 2021). In Northern Thailand, the main causes of high PM2.5 exposure are wildfires, crop residue burning, and waste burning (Pollution Control Department, 2021). Nonthaburi in Greater Bangkok and Bangkok also have high levels of PM2.5 concentration that exceed WHO guidelines. The causes are mainly from on-road transportation and construction sites.

There are 33 provinces, including 11 provinces in the Northeast, 7 provinces in the South, 6 provinces in the North, 4 provinces in the Centrals, 3 provinces in the East, and 2 provinces in the West, that have the PAI_PM2.5 index but no airborne monitoring stations in 2020.

In 2022, airborne monitoring stations were installed in 17 provinces, while 16 provinces still had none. Even if there is no report on PM2.5 concentration level due to no airborne monitoring station in that province, the existence of the PAI_PM2.5 index points out that the alerts from PM2.5 exposure can bring people's attention through public attention to the risk of air pollution, apart from measured levels of airborne pollutants.

The findings of this study will grow beneficial for policymaking and future research which is novelty in environmental economics research papers, especially in the particulate matter context. Because it captures public attention toward the risk from PM2.5 exposure through internet search behavior that can be used as a confounding factor in forming efficient policy to mitigate PM2.5 exposure beside PM2.5 concentration level.

The PAI_PM2.5 index represents public attention towards the risks from PM2.5 exposure and related precautionary behaviors. It provides crucial information for formulating policies to safeguard against PM2.5 and improve air quality, which in turn can effectively promote both inbound and outbound tourism.

Overall, this paper presents a novel and potentially impactful approach to measuring public attention to air pollution issues, especially for PM2.5. It makes a significant contribution to the field of environmental economics and public health monitoring. The methodology developed here could serve as a model for similar studies in other regions or for different environmental concerns.

The policy implications from this study are;

1. In areas where PAI_PM2.5 percentage rankings are lower than PM2.5 percentage rankings, public awareness levels are lower than PM2.5 concentration levels. In these areas, public awareness campaigns may be needed.

There are 37 provinces in Central, Northeastern, Western, and Southern which PAI_PM2.5 percentage rankings lower than PM2.5 percentage rankings. There are 37 provinces in Northern and Eastern which PAI_PM2.5 percentage rankings more than PM2.5

percentage rankings. There is one province, Kamphaeng Phet, which PAI_PM2.5 percentage rankings equal to PM2.5 percentage rankings.

2. In areas with high PM2.5 rankings, air quality improvement efforts should be focused.

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Appendix A

Table A.1: The division criteria of Air Quality and Noise Management Bureau.

Region	Province	Airborne Monitoring Station	
		Code	Name
Bangkok	Bangkok	(02T)	Bansomdejchaopraya Rajabhat University
		(03R)	Kanchanapisek Roadside
		(05T)	Thai Meteorological Department Bangna
		(10T)	National Housing Authority Klongchan
		(11T)	National Housing Field Huaykwang
		(12T)	Nonsi Witthaya School
		(50R)	Chulalongkorn Hospital
		(52R)	Thonburi Power Sub-Station
		(53R)	Chokchai Metropolitan Police Station
		(54R)	Dindaeng Community Flat
		(59T)	The Government Public Relations Department
		(61T)	Bodindecha (Sing Singhaseni) School
Greater Bangkok	Nakhon Pathom	(81T)	Prapa Nakhon (Tap Water) Reservoir
	Nonthaburi	(13T)	Department of Disease Control, Ministry of public Health
		(13T_OLD)	Electricity Generating Authority of Thailand
		(22T)	Sukhothai Thammathirat Open University
	Pathum Thani	(20T)	Bangkok University, Rangsit Campus
	Samut Prakan	(08T)	Department of Empowerment of Persons with Disabilities
		(16T)	South Bangkok Power Plant, Electricity Generating Authority of Thailand
		(17T)	Residence for Dept. of Mineral Resources
		(18T)	Samut Prakan Provinacial Hall
		(19T)	Bang Phli National Housing Authority
	Samut Sakhon	(14T)	Samutsakhon Highways District
		(27T)	Samutsakhonwittayalai School
Central and western	Ayutthaya	(21T)	Ayutthaya Wittayalai School
	Kanchanaburi	(79T)	Air quality near Kanchanaburi Meteorological Station
	Lop Buri	(99T)	Meteorological Station Lopburi
	Prachuap Khiri Khan	(103T)	Hua Hin Weather Forecast Station
	Ratchaburi	(26T)	Regional Environmental Office 8 Air Pollution

Region	Province	Airborne Monitoring Station	
		Code	Name
	Samut Songkhram	(84T)	Samut Songkhram Provincial Health Office
	Saraburi	(24T)	Na Phralan Police Station
		(25T)	Khao Noi Fire Station
	Suphan Buri	(85T)	Suphanburi Provincial Stadium
Northern	Chiang Mai	(35T)	Chiang Mai Provincial Hall
		(36T)	Yupparaj Wittayalai School
	Chiang Rai	(57T)	Provincial Office of Natural Resources and Environment Chiang Rai
		(73T)	Mae Sai District Public Health Office
	Kamphaeng Phet	(94T)	Sirichit Thai Cultural Conservation Park
	Lampang	(37T)	Lampang Meteorological Station
		(38T)	Ban Sop Pat Sub-District Health Promoting Hospital
		(39T)	Ban Tha Si Health Promoting Hospital
		(40T)	Mae Moh Provincial Waterworks Authority Office
	Lamphun	(68T)	Lamphun Meteorological Station
	Mae Hong Son	(58T)	Provincial Office of Natural Resources and Environment Mae Hong Son
	Nakhon Sawan	(41T)	Nakhon Sawan Provincial Irrigation Office
	Nan	(67T)	Nan Town Municipality
		(75T)	Chalermprakiat Hospital
	Phayao	(70T)	Phayao Stadium
	Phetchabun	(97T)	Petchbura Park
	Phichit	(95T)	Phichit Stadium
	Phitsanulok	(86T)	Chom Nan Chalermprakiat Park
	Phrae	(69T)	Thai Meteorological Department
	Sukhothai	(96T)	Le Thai Community
	Tak	(76T)	Tak Non-Formal Education Center
	Uthai Thani	(98T)	Chaloem Phrakiat Park Station 80th birthday celebration
	Uttaradit	(92T)	72nd Anniversary King Bhumibol Public Park, Uttaradit
Northeastern	Buri Ram	(101T)	Buriram City Hall
	Khon Kaen	(46T)	Water Resources Office 4
	Loei	(72T)	Her Majesty the Queen's 60th Birthday Anniversary Botanical Garden
		(72T_OLD)	Legal Of Loei Provincial Public Health Office
	Mukdahan	(102T)	Mukdahan Province Stadium
	Nakhon Phanom	(88T)	Meteorological stations, Nakhon Phanom

Region	Province	Airborne Monitoring Station	
		Code	Name
	Nakhon Ratchasima	(47T)	Municipal Waste Water Pumping Station, Nakhon Ratchasima
	Nong Khai	(82T)	Nong Thin Public Park
	Salok Nakhon	(90T)	Meteorological stations, Sakon Nakhon
	Ubon Ratchathani	(83T)	OTOP Product Display and Distribution Center, Ubon Ratchathani
	Udon Thani	(91T)	Nong Prajak Public Park, Udon Thani
Eastern	Chachoengsao	(60T)	Thung Sadao Subdistrict Municipality, Plaeng Yao District
	Chantharaburi	(100T)	Chanthaburi Meteorological Station
	Chon Buri	(32T)	Laem Chabang Municipal Stadium
		(33T)	Health Promotion Hospital Bankhaohin
		(34T)	Environment and Pollution Control Office 13
	Prachin Buri	(77T)	Ban Bu Yai Bai Community Hall
	Rayong	(28T)	Pluakdaeng District Health Office
		(29T)	Health Promotion Hospital Maptaput
		(30T)	Rayong Provincial Agriculture Office
		(31T)	Rayong Field Crops Research Center
		(74T)	Government Center, Rayong
	Sa Kaeo	(71T)	Sri Aranyothai Kindergarten School
	Trat	(87T)	Trat Stadium
Southern	Nakhon Si Thammarat	(89T)	Elderly health promotion and rehabilitation center
	Narathiwat	(62T)	Narathiwat City Hall
	Phuket	(43T)	Phuket Public Health Center
	Satun	(80T)	Satun City Hall
	Songkhla	(44T)	Hat Yai City Municipality
	Surat Thani	(42T)	Regional Environmental Office 14
	Trang	(93T)	Trang Polytechnic Vocational College
	Yala	(63T)	Sanam Chang Phueak Park
		(78T)	Child Development Center, Betong Municipality

Note. Adapted from Pollution Control Department, Ministry of Natural Resources and Environment.

Table A.2: The List of Airborne Monitoring Stations per Province.

Number of stations per province	**Province**
1	Ayutthaya, Buri Ram, Chachoengsao, Chantharaburi, Kamphaeng Phet, Kanchanaburi, Khon Kaen, Lamphun, Lop Buri, Mae Hong Son, Mukdahan, Nakhon Pathom, Nakhon Phanom, Nakhon Ratchasima, Nakhon Sawan , Nakhon Si Thammarat, Narathiwat, Nong Khai, Pathum Thani, Phayao, Phetchabun, Phichit, Phitsanulok, Phrae, Phuket, Prachin Buri, Prachuap Khiri Khan, Ratchaburi, Sa Kaeo, Salok Nakhon, Samut Songkhram, Satun, Songkhla, Sukhothai, Suphan Buri, Surat Thani, Tak, Trang, Trat, Ubon Ratchathani, Udon Thani, Uthai Thani , and Uttaradit
2	Chiang Mai, Chiang Rai, Loei, Nan, Samut Sakhon, Saraburi, and Yala
3	Chon Buri and Nonthaburi
4	Lampang
5	Rayong and Samut Prakan
12	Bangkok

Note. Author's Calculation.

Environmental Management Accounting – A Systematic Literature Review, Framework and Agenda for Future Research

Linh Thi Phuong Nguyen[1] and Sakun Boon-itt[2]

Abstract

This paper aims to provide a comprehensive knowledge structure of environmental management accounting (EMA) research, identify research thematic foci and research gaps, and suggest future research trends for scholars and academic researchers. By using the systematic literature review method, the paper reviews 57 academic articles in international journals from the Scopus database. In addition, content analysis was also used to analyze the important research themes and current gaps and recommend future research directions. Findings show that the research on EMA is in an emerging trend. The study presented the landscape of EMA through publication trends, the most popular journals, top theories used, and leading methodologies. Significant research themes and promising research areas in EMA were identified. Finally, this paper constructed a comprehensive conceptual framework and proposed several potential research models for future investigation. This paper has contributed to structuring intellectual knowledge in this field, building a comprehensive framework for EMA research area, and suggesting potential future research questions.

Keywords: Environmental Management Accounting, Systematic Literature Review, Future Trends

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Research on the Intensity of Industrial Pollution Emissions and Its Influencing Factors in China's Urbanization Process

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Abstract

With the rapid development of industrialization in China, the issue of industrial pollution has become extremely serious. The purpose of this study is to collect and organize data from 31 provinces in China over a ten-year period from 2013 to 2022, and to conduct an empirical analysis of the factors influencing industrial pollution emission intensity. Furthermore, an in-depth analysis of the causes was carried out, and targeted policy recommendations were proposed based on the research findings. Focusing on industrial exhaust pollution (SO2) emission intensity, the study utilized the OLS model and individual fixed effect model analysis method to explore the relationship between exhaust pollution (SO2) emission intensity and regional GDP, population size, total energy consumption, the structure of the tertiary industry, level of foreign investment, and technological input. The research findings indicate that industrial SO2 emission intensity is influenced by factors such as regional economic level, population size, structure of the tertiary industry, technological input, utilization of foreign investment, and energy intensity. Overall, an increase in population size, the structure of the tertiary industry, and foreign investment utilization will lead to an increase in pollutant emissions; whereas an increase in regional GDP, technological input, and energy intensity will help reduce pollution intensity.

Keywords: Industrial Waste Gas (so_2) Pollution; OLS Model: Individual Fixed Effect Model

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1. Introduction

1.1 Background

With China's rapid economic development, environmental problems have become increasingly worrisome. The contradiction between economic development and environmental protection has gradually emerged, with industrial pollution being the basis of environmental problems. Industrial pollution refers to the release of pollutants into the environment due to technology, equipment or management during industrial processing activities, which will cause pollution and damage to the environment. With the rapid industrialization and expansion, pollution continues to increase, causing harmful effects on the environment. environment. environment and human health.

For example, between 2000 and 2005, China incurred direct economic losses of 16.6 billion yuan due to water pollution. A large amount of industrial wastewater and sewage was discharged directly into rivers and lakes without treatment, posing a serious threat to people's production and livelihoods. Currently, China still ranks first globally in terms of pollutant emissions. In 2015, urban industrial wastewater, industrial sulfur dioxide (SO2), and industrial smoke and dust emissions accounted for 27.1%, 83.7%, and 80.1% of the total national pollution emissions, respectively. Faced with such severe challenges, the country has fully implemented strategies for industrial pollution control, making comprehensive compliance with emission standards for industrial pollution sources one of the 25 major national ecological and environmental protection projects. The report of the 20th National Congress of the Communist Party of China once again emphasized the development concept of "our country's sky is bluer, mountains are greener, and water is cleaner," calling for deepening environmental pollution prevention and control efforts, continuously fighting for blue skies, clean water, and pure land, basically eliminating heavy pollution weather, basically eliminating black and odorous water bodies in cities, strengthening the prevention and control of soil pollution sources, improving the level of environmental infrastructure construction, and promoting the improvement of urban and rural living environments. Industrial pollution is not only limited to cities but is also gradually increasing in rural areas, causing serious impacts on ecological environments and human health. Industrial pollution not only disrupts ecological balance and affects crop growth and food safety but also exacerbates global environmental problems. Long-term inhalation of harmful substances gradually increases the harm to the human body and exacerbates psychological problems. Therefore, this paper chooses industrial pollution in China as the research object, aiming to explore the intensity of industrial pollution emissions and their influencing factors in depth, and provide scientific basis for formulating effective environmental protection policies.

1.2 Purpose

Firstly, conducting an assessment of the present industrial pollution emission intensity; secondly, exploring the determinants of industrial pollution emission intensity; and thirdly, formulating specific policy suggestions based on the research results. These suggestions will include actions for industrial pollution regulation, environmental conservation policies, and urbanization planning strategies. The primary goal is to reduce industrial pollution discharges, improve environmental standards, and promote the sustainable advancement of both the economy and the environment. The research methodology will entail a comprehensive analysis of industrial pollution emission intensity through data collection and statistical modeling. Additionally, a detailed review of environmental policies and regulations will be conducted to identify potential gaps and areas for improvement. The study aims to provide valuable insights for policymakers, industry stakeholders, and environmental advocates to collectively work towards a greener and more sustainable future.

The article collected and analyzed data from 31 provinces in China over a decade from 2013 to 2022, discussing empirical research on the factors affecting industrial pollution emission intensity and conducting an in-depth analysis of its causes. The data from these 31 provinces more clearly reflect the current state of industrial development and pollution in China. The study does not include data from Taiwan Province, the Tibet Autonomous Region, or the Hong Kong and Macau Special Administrative Regions. Focusing on industrial emissions of gaseous pollutants (SO2), this study utilizes the Ordinary Least Squares (OLS) model and individual fixed effect model analysis method to investigate the relationship between SO2 emission intensity and regional gross domestic product (GDP), population, Technology expenditure, Tertiary industry structure, energy intensity, and the utilization of foreign capital.

The innovation:

- Comprehensively analyze the multiple factors affecting industrial pollution emissions: consider not only the traditional factors of industrial structure and technological level, but also the influence of factors such as regional gross domestic product, population size, level of foreign investment, and total amount of energy, so as to comprehensively grasp the mechanism of influencing industrial pollution emissions.

- Data support: In-depth study of the spatial distribution and temporal changes of industrial pollution emissions using big data and panel data methods.

- Policy Recommendations; To put forward our policy recommendations for the results of the study, which will provide scientific basis for governmental decision-making and environmental protection practice policies.

Exploration of Sustainable Development: By studying the intensity of industrial pollution emission and its influencing factors, the thesis aims to explore the path of sustainable development, promote the coordinated development of economic growth and environmental protection, and provide theoretical support and practical guidance for realizing sustainable economic and social development.

2. Literature review

Many scholars, both domestically and internationally, have conducted in-depth research on the relationship between environmental pollution and social development factors.

The attention of the international academic community to industrial pollution issues dates back to an earlier period. In the 1990s, scholars focused on the inverted "U" relationship between pollution and economic development, proposing the well-known "Environmental Kuznets Curve" theory. Shim (2012) [3] examined the influence of cement industry growth on environmental contamination and the reclamation of abandoned mines in the Meipu region. The study uncovered that despite the favorable geographic conditions and presence of three cement plants in the vicinity, the expansion of the cement sector could result in pollution, jeopardizing agriculture, residential areas, and public health. This situation could potentially lead to conflicts between cement factories and local inhabitants. To tackle the challenges linked to abandoned mines, the feasibility of transforming them into amenities such as golf courses or gardens was explored to enhance the surrounding scenery and minimize environmental harm. Agami (2020) [1] evaluated the impact of the COVID-19 outbreak on air pollution in Israel, and the results indicated a significant influence on air quality, particularly in reducing pollution levels in the transportation and industrial sectors. Kalambe (2023) [2] delved into the various types of environmental pollution in India and proposed targeted measures to address these pollution issues.

In terms of the factors affecting industrial pollution in China, the existing literature has studied the factors affecting industrial pollution in various ways. Taking Jiangsu Province as an example, Wang (2006) found that industrial wastewater and gas emissions exhibit an "N"-shaped pattern, and pointed out the inverse "U"-shaped relationship between economic development and environmental quality. Wang (2011) conducted an empirical analysis on the influencing factors of industrial wastewater and gas emissions. The results indicated that industrial structure, energy structure, technological progress, foreign investment utilization, and policy interventions are all significant factors affecting the emissions of industrial wastewater and gas. Qin, Zhang, Zhao, Li, Duan, and Han (2022) [5] conducted an analysis of industrial agglomeration and pollution emissions aggregation characteristics in 91 prefectural-level cities in the Yellow River Basin of China from 2005 to 2020. They utilized the Durbin spatial panel model to explore the determinants of industrial pollution considering both direct and indirect impacts. The study findings indicated the presence of spatial convergence, with a notable global agglomeration pattern observed in industrial pollution within the Yellow River Basin. Factors such as population concentration, industrial composition, environmental regulations, foreign investment openness, and economic growth were identified as primary influencers on the region's industrial pollution. Chen, Yu, and Zhang (2023) [6] have reviewed China's industrial economic data from 1999 to 2021, depicting the spatial distribution and agglomeration characteristics of heavily polluting industries. Kong and Shi (2024) [9] used panel data from 30 provinces in China from 2010 to 2019 to empirically study the relationship between carbon emissions, population agglomeration, trade levels, capital investment, and economic growth through pooled regression and individual fixed effects models. Other scholars have also found that industrial wastewater and industrial emissions are major factors affecting environmental quality. Additionally, some researchers have examined industrial pollution from the perspective of regional disparities. While progress has been made in studying the factors influencing industrial pollution emissions during the urbanization process in China, there are still many unresolved issues that require further in-depth research.

3. Data

3.1 Research Object

There are different forms of industrial pollution, and for this research, industrial wastewater, industrial sulfur dioxide emissions, and industrial dust have been chosen as indicative measures [8]. Yet, because of insufficient data on the emission intensity of industrial wastewater and industrial dust in recent years, this study will assess industrial sulfur dioxide emissions as a substitute. This study adopts a literature review method, and uses empirical research methods such as the OLS model and the individual fixed effect model to analyze the relationship between industrial air pollution (SO2) emission intensity and factors such as regional GDP, population, total energy consumption, the structure of the tertiary industry, foreign investment levels, and technological expenditures.

3.1.1 Variable Selection

Industrial pollution results from human economic activities and is impacted by multiple factors. There exist numerous research avenues nationally and globally. This study aims to delve into the determinants of industrial SO2 emissions from six perspectives: energy intensity, regional GDP, population size, Technology expenditure, Tertiary industry structure, and the utilization of foreign capital.

Table 1: Definitions and Explanations of Variables

	Variables	Index	Definition	Code
Dependent variable	SO_2 emissions	industrial SO_2 emissions	industrial SO2 emissions (million tons)	SO_2
Explaining variable	regional GDP	regional GDP	regional GDP (billion loss)	GRP
	population size	End-of-year resident population	End-of-year resident population (million population)	POPULATIO N
	energy intensity	Total energy consumption	Total energy consumption (millions of standard coal)	ENERGY
	Technology expenditure	Transaction volume of the technology market	Transaction volume of the technology market (billion loss)	TE
	Utilization of foreign capital	Actual utilization of foreign direct investment	Actual utilization of foreign direct investment (million US dollars)	AFI
	Tertiary industry structure	Value added of the tertiary industry	Value added of the tertiary industry (billion loss)	TIS

The dependent variable SO2 represents the emission of industrial sulfur dioxide.

Explaining variable 1 Regional GDP. Regional GDP refers to the final result of the production activities of all resident units in a specific area over a certain period of time. Regional GDP is equal to the sum of the added value of each industry. According to the theory of Environmental Kuznets Curve, a relationship in the shape of an inverted "U" can be observed between economic development levels and pollution. This indicates that as economic development increases, pollution levels initially rise before declining. Particularly in urban settings, a rise in regional GDP signifies advancements in technology and environmental regulations. As a result, the pollution emission intensity in that region will decrease accordingly. A higher level of economic development typically indicates stronger environmental management capabilities and more substantial technological investment. However, in the early stages of industrialization, higher levels of pollution emissions, especially SO2 emissions, are often observed. As a result, the intensity of SO2 emissions tends to vary significantly across different stages of economic development.

Explaining variable 2 Population size. The increase in population implies an expansion of production scale, which in turn leads to increased resource consumption and pollution.

Explaining variable 3 Tertiary industry structure. The industrial structure of a region is directly related to the intensity of industrial pollution emissions. High-polluting industries with high emissions pose a more significant threat to the environment. In particular, the development of heavy industry exacerbates pollution. Some tertiary sector activities, such as logistics and tourism, may increase energy consumption at an indirect level, which may lead to an increase in SO2 emissions.

Explaining variable 4 Technology expenditure. The advancement of science and technology can also play a positive role in environmental protection. Technological development can enhance resource consumption efficiency and improve production processes, thereby curbing the increase of pollution. Therefore, the higher the technical input, the lower the SO2 emission intensity in general.

Explaining variable 5 Utilization of foreign capital. Some researchers propose that foreign investments have a substantial influence on environmental pollution. On one hand, it could exacerbate pollution because foreign companies may not comply with local environmental laws and might utilize more aggressive production techniques. On the other hand, it could reduce pollution levels by bringing in cutting-edge technologies and managerial approaches, thereby encouraging environmentally friendly production methods and improving environmental governance standards. The impact of foreign investment on pollution depends on the type of industry it flows into. If it enters high-pollution industries, it may exacerbate sulfur dioxide (SO2) emissions, whereas investment in high-tech industries can help reduce SO2 emissions.

Explaining variable 6 Energy intensity. Energy intensity reflects the level of production technology and technological advancement. Energy consumption drives economic development, but it also leads to environmental pollution. Higher energy intensity indicates greater energy consumption per unit of economic output, which is often associated with increased SO2 emissions. Therefore, reducing energy intensity has become a key strategy in controlling pollution and reducing emissions.

The following are trend charts for each variable. The trend charts for each variable are derived from the National Bureau of Statistics of China, and the charts represent the average values for the 31 provinces.

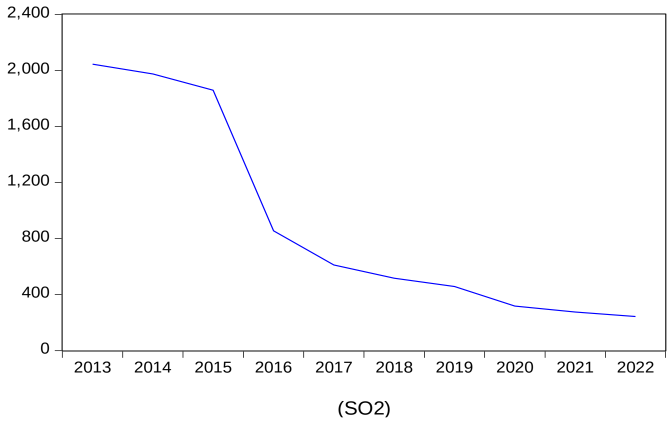

Figure 1: Industrial SO2 Emissions

Source: National Bureau of Statistics of China (https://www.stats.gov.cn/)

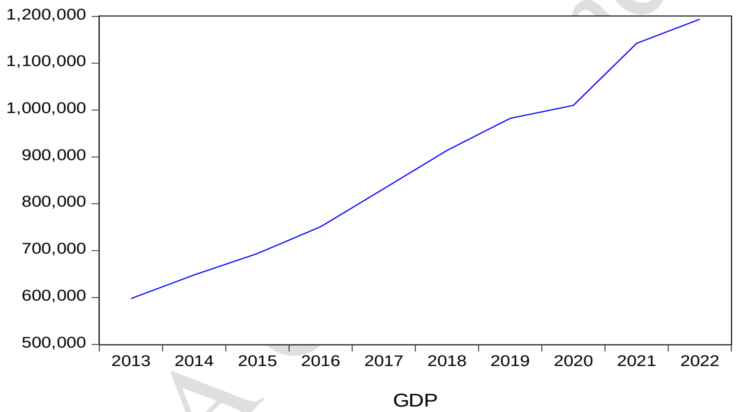

Figure 2: Regional GDP

Source: National Bureau of Statistics of China (https://www.stats.gov.cn/)

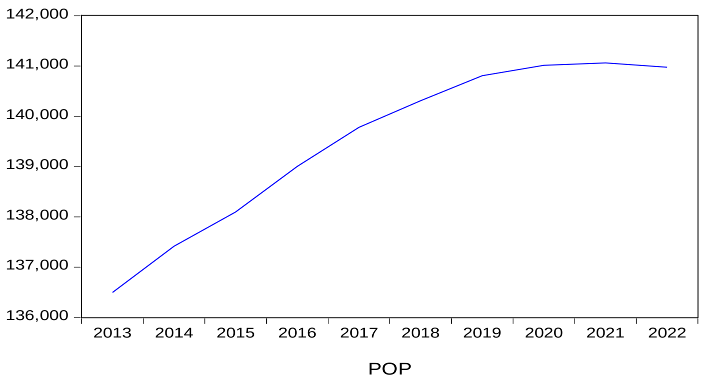

Figure 3: Population size

Source: National Bureau of Statistics of China (https://www.stats.gov.cn/)

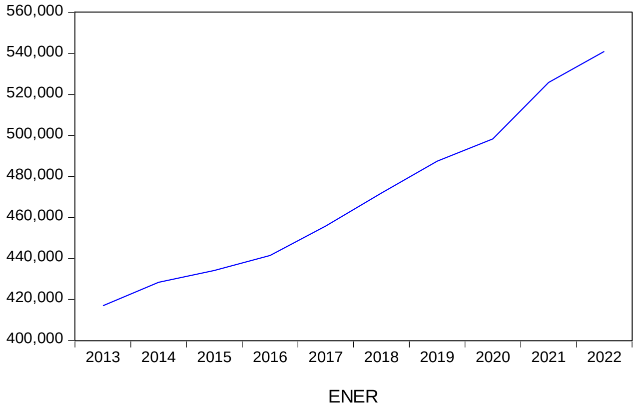

Figure 4: Energy intensity

Source: National Bureau of Statistics of China (https://www.stats.gov.cn/)

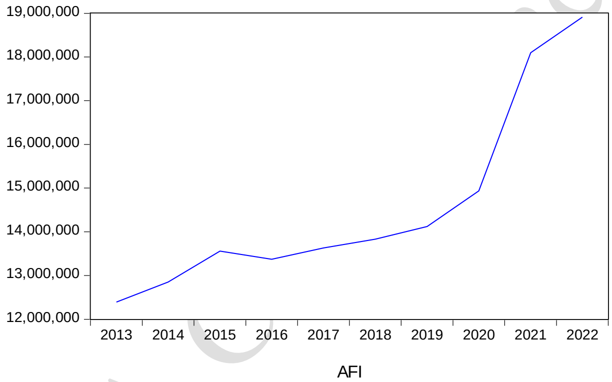

Figure 5: Utilization of foreign capital

Source: National Bureau of Statistics of China (https://www.stats.gov.cn/)

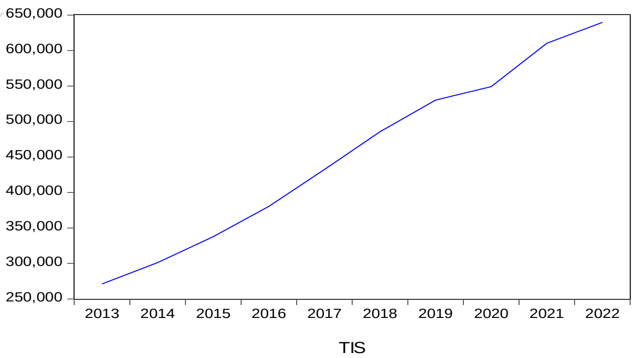

Figure 6: Tertiary industry structure

Source: National Bureau of Statistics of China (https://www.stats.gov.cn/)

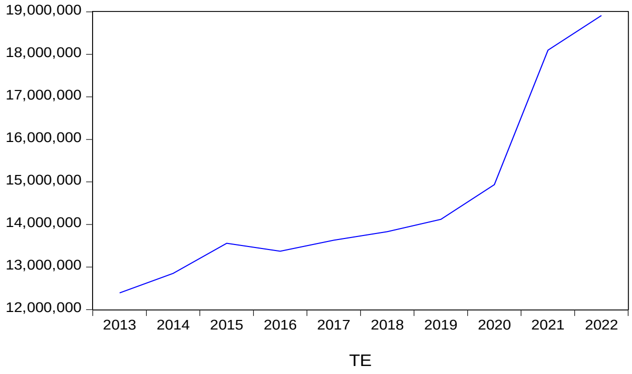

Figure7: Technology expenditure

Source: National Bureau of Statistics of China (https://www.stats.gov.cn/)

3.1.2 Descriptive statistics

Table 2: Descriptive statistics

Indices	Max.	Min.	St.dev.	Mean	kurtosis	Skewness	Jarqe-Bera
Ln SO2	5.10	-2.21	1.49	2.65	3.97	-1.04	67.91
Ln GRP	11.77	6.72	0.99	9.86	3.56	-0.78	35.49
Ln POPULATION	9.45	5.76	0.84	8.14	3.51	-0.93	48.18
Ln TIS	8.80	0.64	1.21	6.68	5.11	-1.07	103.98
Ln TE	7.19	-1.56	1.93	3.83	2.63	-0.49	11.32
Ln ENERGY	10.22	8.66	0.43	9.44	2.62	-0.15	2.75
Ln AFI	14.97	12.20	0.83	13.24	2.85	0.74	22.91

Based on the descriptive statistics, the maximum value of SO2 is 5.10, the minimum value is -2.21, the St.dev is 1.49, and the mean is 2.65. The maximum value of regional GDP is 11.77, the minimum value is 6.72, the St.dev is 0.99, and the mean is 9.86. The maximum value of population size is 9.45, the minimum value is 5.76, the St.dev is 0.84, and the mean is 8.14. The maximum value of the tertiary industry structure is 8.80, the minimum value is 0.64, the St.dev is 1.21, and the mean is 6.68. The maximum value of technology expenditure is 7.19, the minimum value is -1.56, the St.dev is 1.93, and the mean is 3.83. The maximum value of energy intensity is 10.22, the minimum value is 8.66, the St.dev is 0.43, and the mean is 9.44. The maximum value of utilization of foreign capital is 14.97, the minimum value is 12.20, the St.dev is 0.83, and the mean is 13.24. The Jarque-Bera test is related to skewness and kurtosis. If the absolute values of skewness are less than 3 and kurtosis are less than 10, it indicates that the data approximately conforms to a normal distribution within this range.

3.2 Data source

The article collected and compiled data from 31 provinces in China over the period of 2013-2022, spanning a decade, to empirically investigate the factors influencing industrial pollution emission intensity. The data collection and compilation were sourced from the National Bureau of Statistics of China, as well as the China Statistical Yearbook 2022 and China Statistical Yearbook 2023

4. Methodology

To investigate the determinants of air pollution (SO_2), considerations such as energy intensity, regional GDP, population size, tertiary industry structure, technology expenditure, and utilization of foreign capital were taken into account, and Constructed an Ordinary Least Squares (OLS) regression model and individual fixed effect model.

The following are mathematical formulas:

$$LNSO2 = \beta_1 + \beta_2(LNGRP) + \beta_3(LNPOPULATION) + \beta_4(LNAFI) + \beta_5(LNENERGY) + \beta_6(LNTIS) + \beta_7(LNTME) + B_{it} \quad (1)$$

$$LNSO2 = \alpha_1 + \alpha_2(LNGRP) + \alpha_3(LNPOPULATION) + \alpha_4(LNAFI) + \alpha_5(LNENERGY) + \alpha_6(LNTIS) + \alpha_7(LNTME) + \varphi_i + E_{it} \quad (2)$$

Where α_1 and β_1 are the intercept terms; α_i and β_i represent the coefficient parameters of the explanatory variables; φ_i denotes the individual effects that do not change over time; and B_it and E_it are the random disturbance terms.

5. Empirical results

5.1 Unit root test

Table 3: Model checking

Indices	LLC	ADF
SO2	0.0000	0.0000
GRP	0.0000	0.0442
POPULATION	0.0000	0.0015
TIS	0.0000	0.0002
TE	0.0000	0.0045
ENERGY	0.0000	0.0044
AFI	0.0000	0.0442

To evaluate the precision of the statistical findings, it is necessary to perform a unit root test. This test enables us to ascertain the consistency of the data, guaranteeing the dependability of our statistical results. The outcomes of the test reveal the rejection of both hypotheses, signifying the stability of all variables and their suitability for subsequent analysis.

5.2 Result analysis

Table 4: Results of model regression

Indices	OLS model	Individual fixed effect model	Random effects model
Ln GRP	-1.4938	-3.4119	-2.8207
Ln POPULATION	2.4908	3.1407	3.7537
Ln TIS	0.1270	0.1323	0.1809
Ln TE	-0.1742	-0.0346	-0.0728
Ln ENERGY	-0.7719	-0.3509	-0.5160
Ln AFI	0.0467	0.1345	0.1132
c	3.6414	11.7002	2.3940
Adj.R2	0.6705	0.9275	0.7844
F-statistic	70.5510	77.0789	130.7592

Using Eviews12 software, we conducted model estimation tests to quantitatively analyze the impact of each explanatory variable on SO2. We ran the OLS model, individual fixed effects model, and random effects model, obtaining the results shown in Table 4. All data confidence intervals are significant within the 5% range.

From Table 4, we can see the following:

1. When using the individual fixed effects model for analysis, we found that the panel data exhibits individual fixed effects R2=0.9397, and the OLS model R2=0.6705. Therefore, it is unreasonable to directly use the OLS model for analysis; 2. Further analysis using the individual fixed effects model confirms the presence of individual fixed effects in the panel data. To gain a more comprehensive understanding of the data characteristics, we then adopted the random effects model for further analysis; 3. In the analysis using the random effects model, the Hausman test value is 0.0000 < 0.01, indicating that the individual fixed effects model is more suitable for panel data analysis than the andom effects model.

From the regression results in Table 4, it can be observed that population size, utilization of foreign capital, and tertiary industry structure are significantly positively correlated with industrial SO2 emissions. Conversely, regional GDP, energy intensity, and technology expenditure are significantly negatively correlated with industrial SO2 emissions.

The mathematical formulas for the statistical results are as follows:

$$LNSO2 = 11.7002 - 3.4119(LNGRP) + 3.1407(LNPOPULATION) + 0.1345(LNAFI) - 0.3509(LNENERGY) + 0.1323(LNTIS) - 0.0346(LNTME) + \varphi_i + E_{it}$$

5.2.1. The size of the population

The size of the population. In terms of total amount, the regression coefficient between population size and industrial sulfur dioxide (SO2) emissions shows a significantly positive relationship. With the continuous growth in population size, industrial development has progressed rapidly, leading to a gradual rise in sulfur dioxide emissions from industrial sources. As urban populations expand, the demand for energy and production also increases, further driving industrial activities and resulting in higher emissions from industrial sources, including sulfur dioxide. Therefore, the expansion of the population size could worsen environmental pollution, especially the increase in sulfur dioxide emissions, which has detrimental effects on the environment and public health. This trend highlights the critical correlation between population size and industrial sulfur dioxide (SO2) emissions. As populations continue to increase, the surge in industrial activities contributes significantly to the emission of sulfur dioxide from various industrial sources. The expanding urban areas further intensify this environmental concern by escalating energy demands and production needs. Consequently, the rise in population size poses a substantial risk to environmental pollution, particularly the surge in sulfur dioxide emissions that pose severe threats to both the environment and public health. This trend highlights the critical correlation between population size and industrial sulfur dioxide (SO2) emissions. As populations continue to increase, the surge in industrial activities contributes significantly to the emission of sulfur dioxide from various industrial sources. The expanding urban areas further intensify this environmental concern by escalating energy demands and production needs. Consequently, the rise in population size poses a substantial risk to environmental pollution, particularly the surge in sulfur dioxide emissions that pose severe threats to both the environment and public health.

5.2.2. The structure of the tertiary industry

The structure of the tertiary industry. When considering the total amount, the correlation coefficient between the tertiary industry structure and industrial sulfur dioxide is significantly positive. This indicates that a higher percentage of the tertiary sector is associated with increased pollution levels. This suggests that China is still mostly in the phase of industrialization, with the impact of the tertiary sector on reducing industrial sulfur dioxide emissions not strongly evident. Despite the gradual increase in the share of the tertiary sector in the Chinese economy, its effectiveness in reducing industrial sulfur dioxide emissions remains inadequate. Therefore, it is crucial to strengthen the growth of the tertiary sector, improve its economic contribution, in order to effectively alleviate and decrease industrial sulfur dioxide emissions. In conclusion, enhancing the growth and efficiency of the tertiary sector is paramount in addressing the issue of industrial sulfur dioxide emissions in China. The positive correlation between the tertiary industry structure and pollution levels signifies the need for further development and improvement in this sector to combat environmental challenges. By increasing the economic contribution of the tertiary sector, China can strive towards a more sustainable and environmentally friendly industrial landscape.

5.2.3. Utilization of foreign capital

utilization of foreign capital. Utilizing foreign capital is positively correlated with industrial sulfur dioxide emissions. For every 1% increase in foreign capital utilization, there is a 0.1163% rise in industrial SO2 pollution intensity. This indicates that foreign-funded companies' investments and activities often lead to higher industrial emissions, causing increased pollution levels. The research findings underscore the direct link between the use of foreign capital and the escalation of industrial sulfur dioxide emissions. Such a connection highlights the significant impact that investments from foreign-funded companies can have on exacerbating pollution levels, particularly in industrial settings. This correlation sheds light on the need for sustainable practices and stringent environmental regulations in mitigating the adverse effects of increased industrial pollution.

5.2.4. Regional GDP.

Typically, the regression coefficient associating regional GDP with industrial sulfur dioxide is negative. A 1% rise in GDP in the area decreases industrial SO2 pollution intensity by 0.7409%. This can be attributed to the advancement of the regional economy and enhancements in the industrial structure that enable companies to implement eco-friendly and energy-efficient production techniques, consequently cutting down greenhouse gas discharges. As a result, there exists a significant correlation between regional GDP expansion and the mitigation of carbon dioxide emissions from the industrial sector. These findings underscore the importance of sustainable economic growth in reducing industrial pollution. The negative correlation between regional GDP and industrial sulfur dioxide levels highlights the positive impact of economic development on environmental sustainability. As regions advance economically and improve their industrial practices, they are able to adopt greener and more efficient production methods, leading to a decrease in greenhouse gas emissions. This interconnected relationship between regional economic expansion and the reduction of carbon dioxide emissions underscores the potential for eco-friendly growth strategies to drive environmental progress in industrial sectors.

5.2.5. Technology investments

Upon reviewing overall data, the negative correlation between technology investments and industrial sulfur dioxide emissions is significant. A mere 1% rise in technology investments results in a reduction of industrial SO2 pollution by 0.01595%. These aspects can be observed in the enhancement and optimization of production efficiency through technological advancements, heightened energy utilization, and safeguarding the production environment, consequently mitigating the adverse impacts of pollution. Therefore, it can be concluded that technology plays a crucial role in reducing industrial sulfur dioxide emissions. The positive impact of technology investments on production efficiency, energy utilization, and environmental protection is evident in the significant decrease in pollution levels. This correlation highlights the importance of utilizing technology to mitigate the adverse effects of pollution on the industrial sector.

5.2.6. Energy intensity.

When it comes to quantity, the correlation coefficient between energy consumption and industrial sulfur dioxide is significantly negative. For every 1% enhancement in energy efficiency, the level of industrial SO2 pollution diminishes by 0.294%. This achievement is facilitated by technological progress that heightens energy efficiency and output. By placing emphasis on energy efficiency through effective production techniques, energy consumption and greenhouse gas emissions are curtailed in products relative to conventional methods. This enhancement in energy efficiency plays a crucial role in reducing industrial sulfur dioxide pollution levels. Through advancements in technology and effective production techniques, energy consumption and greenhouse gas emissions are minimized, marking a significant progress towards sustainable industrial practices.

6. Conclusion and policy implications

Industrial pollution, as a prevalent issue affecting human health, social progress, and sustainable development, has attracted considerable attention domestically and internationally. This paper, based on data from 31 provinces in China from 2013 to 2022, explores the main factors influencing industrial sulfur dioxide (SO2) emission intensity, aiming to provide reference for government policies on environmental protection and pathways to sustainable development.

The research findings are as follows:

The intensity of industrial SO2 emissions is mainly affected by the regional GDP, population size, tertiary industry structure, technology expenditure, utilization of foreign capital, and energy efficiency. Generally, an increase in population size, tertiary industry structure, and utilization of foreign capital to raise the overall pollutant levels. Conversely, an increase in regional GDP, technology expenditure, and energy efficiency helps in reducing pollution levels.

6.1 Policy suggestion:

In light of the various factors that influence industrial SO2 emission intensity, I propose the following policy recommendations aimed at reducing pollution levels:

6.1.1. Refine the Tertiary Industry Framework:

While advancing the tertiary sector, it is essential to prioritize the expansion of low-pollution, high-value-added service industries, such as finance, technology, and information services, to lessen the environmental impact associated with the growth of the tertiary sector. Furthermore, fostering innovation within these industries can lead to the creation of eco-friendly practices that not only bolster economic growth but also promote responsible consumption and production.

6.1.2. Regulate Population Growth:

We have developed a thorough and detailed demographic strategy to effectively mitigate the swift increase in population size while ensuring that population growth aligns with China's economic and social progress. Additionally, it is crucial to prioritize the enhancement of urban planning and resource management frameworks to reduce the significant burden on the natural environment in heavily populated regions.

6.1.3. Direct Foreign Investment Towards Sustainable Industries:

Revise foreign investment policies to draw in more capital for efficient, green industries and clean technology sectors, while minimizing the influx of foreign investment into traditional, high-pollution industries. This practice promotes innovation in the local economy. By streamlining the approval process for projects that meet sustainability criteria, a more favorable investment climate can be created, encouraging domestic and foreign stakeholders to prioritize green initiatives.

6.1.4. Enhance Investment in Technology and Innovation:

Augment research and development expenditures in environmental technologies and clean energy to propel technological progress and diminish SO2 emissions. Encourage businesses to embrace innovation and implement energy-efficient, emission-reducing technologies. Establish partnerships between academic institutions and industry leaders to foster collaboration in research initiatives. Implement tax incentives for businesses that prioritize sustainable practices and invest in green technology. Encourage the development of public-private partnerships to leverage resources and expertise, ultimately leading to impactful innovations that can transform our approach to environmental challenges.

6.1.5. Support Regional Economic Advancement:

Encourage green economic initiatives to stimulate regional gross domestic product (GDP) while placing a strong emphasis on environmental sustainability, ensuring a harmonious relationship between economic growth and pollution management. Additionally, it is essential to foster partnerships between local businesses and governments to encourage innovative practices that align with green initiatives. By investing in renewable energy sources and supporting sustainable agriculture, we can create job opportunities that not only contribute to the economic fabric of the region but also enhance the quality of life for residents. Incentives for businesses that adopt eco-friendly technologies can further stimulate growth, while educational programs can raise awareness about the importance of preserving our environment amidst economic development.

6.1.6. Improve Energy Efficiency:

Continue to promote energy efficiency initiatives, advocate for the restructuring of industrial sectors to decrease the prevalence of high-energy-consuming industries, and incentivize the adoption of energy-saving equipment and technologies to further curtail SO2 emission intensity. Additionally, I plan to collaborate with local governments to establish stricter regulations on emissions, incentivizing businesses to transition towards cleaner alternatives. By fostering partnerships between public and private sectors, we can develop innovative solutions and allocate resources more effectively, paving the way for a sustainable future. Moreover, raising public awareness on the importance of energy conservation will empower communities to embrace these practices in their daily lives, ultimately leading to a collective reduction in our environmental footprint.

These recommendations take into account the influence of multiple factors on industrial SO2 emission intensity and strive to harmonize economic progress with environmental stewardship, thereby gradually reducing pollution levels.

6.2 Sustainable development path:

1) Optimizing industrial structure involves expediting the shift of traditional industries towards high-tech and environmentally friendly sectors. This includes promoting the progress of renewable energy sources like solar, wind, and bioenergy. Through increased investments

in sustainable technology research and development, we can boost industrial production efficiency and decrease dependence on non-renewable resources. It is crucial to enact policies that incentivize the adoption of green technologies and practices to lower resource usage and minimize environmental pollution. Encouraging eco-innovation and backing the establishment of a circular economy will further bolster a sustainable and resilient industrial framework. Fostering a sustainable industrial ecosystem demands rigorous commitment from stakeholders across various sectors. By promoting eco-friendly practices and technologies, we pave the way for a more resilient and environmentally conscious future. Embracing renewable energy sources not only reduces our ecological footprint but also drives innovation and efficiency in industrial processes. Implementing strategic policies and investing in green initiatives are essential steps towards achieving a balanced and sustainable industrial structure.Strengthening the utilization of environmental protection technology involves boosting investments in researching and applying environmental protection technology, encouraging companies to adopt clean production practices and effective environmental management to diminish industrial influence on the environment.

2) Intensify efforts for environmental protection: Strengthening the implementation of environmental policies and regulations to ensure compliance in all sectors. This includes imposing severe fines and penalties for misconduct. Improving the environmental monitoring system to provide accurate information on pollution levels, enabling a faster and better response to the environment. Additionally, to promote the conservation and restoration of natural resources and the environment through targeted programs such as reforestation, habitat protection and sustainable land use planning. Involve communities and stakeholders in environmental management programs to jointly promote environmental protection and sustainable use of natural resources in the future.

3) Promote green and low-carbon development by encouraging enterprises to adopt clean production technologies and eco-friendly manufacturing processes to reduce carbon emissions and waste generation. Boost the development and utilization of sustainable energy sources, facilitate the transformation of the energy mix, and reduce dependence on non-renewable resources. Supporting eco-friendly initiatives is crucial in our current climate crisis. By promoting the adoption of clean production technologies and sustainable energy sources, we can work towards reducing carbon emissions and minimizing waste generation. Encouraging enterprises to embrace these practices not only benefits the environment but also contributes to a more sustainable future. Boosting the utilization of renewable resources and transforming our energy mix are vital steps in reducing our dependence on non-renewable sources

4) Enhance international cooperation: Engage proactively in international environmental partnerships to tackle worldwide challenges. This entails adopting and executing state-of-the-art environmental technologies and management strategies from prominent entities globally. By incorporating these innovative solutions, we can elevate our environmental norms and accomplish enhanced sustainability. Moreover, strive to reinforce global environmental governance through international treaties, collaborative endeavors, and joint research undertakings. This collaborative strategy will streamline the sharing of expertise, resources, and optimal approaches, promoting the worldwide agenda for sustainable development and environmental safeguarding. Foster collaborations with international entities, non-governmental organizations, and other nations to collectively confront climate change, biodiversity depletion, and other critical environmental issues, nurturing a unified endeavor for a healthier planet. Promote a culture of eco-consciousness by embracing cutting-edge environmental practices and forging alliances with leading global players. Through active participation in international environmental initiatives, we can fortify our commitment to

sustainable development and ecological preservation. Embrace cross-border partnerships and collaborative efforts to combat pressing environmental challenges such as climate change and biodiversity loss. Together, let's pave the way for a greener, healthier planet through shared knowledge, resources, and impactful strategies.

5) By adhering to the sustainable development pathway outlined previously, it is feasible to significantly decrease industrial sulfur dioxide emissions. This entails fostering synchronized growth between the industrial sector and the ecological environment, establishing a solid foundation for future sustainable development endeavors. Through employing strategic measures to improve industrial practices, promote eco-friendly approaches, and leverage state-of-the-art technologies, we can effectively mitigate the adverse impacts of industrial activities on air quality and environmental health. This holistic approach ensures a balanced equilibrium between economic progress and environmental protection, laying the groundwork for a more sustainable future. Achieving a smooth transition to sustainable practices necessitates a collective effort involving key stakeholders across various sectors. Integrating renewable energy sources, implementing efficient waste management systems, and fostering innovation in green technologies are essential measures in realizing this goal. Embracing a holistic sustainability approach sets the stage for a greener future, where economic prosperity and ecological preservation coexist harmoniously.

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