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Study on the Production of Greenhouse Gases in the Industrial and Power Plant Sectors of Iran from 1996 to 2017

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ABSTRACT

Coal use is declining due to policies and competition, leading to lower emissions. Central and Eastern Europe are working towards reducing Sulfur dioxide (SO_2) and Nitrogen oxides (NO_x) emissions, while Iran is transitioning to gas and modern technologies to reduce pollution. This study focuses on Iran's greenhouse gas emissions from 1996 to 2017 in these sectors. A literature review was conducted on pollutants such as NO_x, SO_2, and Carbon dioxide (CO_2) using sources like Google Scholar. Data on emissions from Iran's sectors from 1996 to 2017 were analyzed using SPSS v27. In the power plant sector, NOx emissions increased from 84,442 tons in 1996 to 651,833 tons in 2017, while SO_2 emissions decreased from 365,467 tons to 239,623 tons. Methane emissions in the industrial sector have decreased due to advancements in technology and stricter regulations. In the industrial sector, both NO_x and CO_2 emissions also increased. The rise in NO_x emissions is attributed to the growing energy demands, particularly in developing regions. Fossil fuels are major emitters of NO_x, underscoring the importance of advancing technology and transitioning to cleaner fuels. SO_2 levels decreased due to regulations, but CO_2 emissions rose alongside industrial expansion. Solutions to these challenges include adopting renewable energy sources and low-carbon technologies. While Carbon monoxide (CO) emissions increased, methane emissions declined due to technological advancements. Suspended Particulate Matter levels increased with economic growth, and nitrous oxide emissions rose with higher energy demands. Combatting climate change requires solutions such as renewable energy, low-carbon technology, and education.

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Introduction

Coal-fired power plants use the Rankine cycle to generate electricity by converting heat energy into mechanical work. The process starts with coal combustion to produce high-pressure steam, which then drives a steam turbine connected to a generator. Key components of this cycle include the boiler, turbine, condenser, pump, and feedwater heater. Subcritical plants operate below critical pressure, while supercritical plants operate above it. Advanced ultra-supercritical plants function at temperatures above 700 °C to achieve higher efficiency. As the demand for electricity rises, coal and renewables play crucial roles, underscoring the importance of carbon capture, storage, and high-efficiency technologies for a cleaner future. A comprehensive understanding of coal power generation is vital to grasp its significance in the global energy landscape [1]. Coal-fired power plants in the United States are decreasing in use due to environmental policies and competition from natural gas and renewable energy sources. Despite this decline, coal still significantly contributes to CO_2, SO_2, and NO_x emissions. Data from 1990 to 2020 shows a noticeable reduction in these pollutants, largely due to the Clean Air Act, its amendments, and improved emission control technologies. The transition from coal to cleaner natural gas and the growth of wind and solar energy are key factors in this decline [2].

An analysis of the twelve largest coal-fired power plants reveals varying emissions profiles, with Texas's Martin Lake Power Plant being the largest SO_2 emitter, and Alabama's James H. Miller Jr. Power Plant notable for CO_2, CH_4, and N_2O emissions. These emissions impact human health and contribute to environmental issues like acid rain and climate change. TROPOMI satellite data highlights high methane levels in oil and gas regions and elevated nitrogen dioxide in urban areas, but overall emissions from coal plants in the eastern US have decreased, emphasizing the ongoing challenges of managing air quality and underscoring the need for satellite data, ground monitoring, and strict regulations. Further research is necessary to fully understand these impacts [2, 3].

To reduce sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions in Central and Eastern European (CEE) countries, various technologies and energy systems are utilized. The Energy Flow Optimization Model-Environment (EFOMENV) is employed to find cost-effective energy solutions and assess strategies for emission reduction, aiming to integrate these technologies into existing energy systems in CEE [4]. Methods to lower SO_2 include Flue Gas Desulfurization (FGD) and transitioning to low-sulfur coal. NO_x emissions can be reduced with Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) by adding ammonia or urea. Improving energy efficiency in industries also helps. High-efficiency technologies like Combined Heat and Power (CHP), renewable energy sources, and Carbon Capture and Storage (CCS) can significantly reduce emissions while being cost-effective compared to Western nations [4-7].

In Iran, our country, fossil fuel power plants are also used to generate electricity, leading to air pollution. However, the shift towards using combined cycle power plants fueled by gas, as well as transitioning from coal to natural gas, has resulted in better environmental outcomes. The adoption of new technologies has further improved pollution levels. Despite increased production of certain pollutants due to the country's electricity needs, progress is being made towards mitigating these impacts.

Materials and Methods

Literature review

A comprehensive review of keywords related to pollutants was conducted, focusing on air pollutants such as NO_x, SO_2, CO_2, SO_3, C_O, CH_4, and SPM. This analysis involved searching online databases like Google Scholar and Scopus to explore relevant scientific literature and resources on air pollution.

Data collection

Initially, data and information on air pollution metrics were collected, specifically examining the emissions of various pollutants and greenhouse gases across different sectors in Iran. This dataset included emissions measured in tons for pollutants like NO_x, SO_2, CO_2, SO_3, CO, CH_4, SPM, and N_2O, specifically from the power generation and industrial sectors between 1996 and 2017. The data was sourced from the Statistical Center of Iran's database, accessible at https://amar.org.ir [6, 7].

Data distribution analysis

The normal distribution of the data was evaluated using the one-sample Kolmogorov-Smirnov test. This analysis focused on the emissions of pollutants and greenhouse gases from power plant sectors, revealing that variables related to carbon monoxide production rates did not follow a normal distribution. Conversely, other variables showed characteristics of a normal distribution. Similarly, in the analysis of emissions from the industrial sector, it was observed that the CH_4 production rate variable also deviated from the normal distribution [8].

Descriptive and analytical statistics study

A comprehensive descriptive and comparative analysis of greenhouse gas emissions in the power generation and industrial sectors from 1996 to 2017 was carried out using SPSS v27 software. The study examined the relationships among various greenhouse gas emissions by applying Pearson, Spearman, and Kendall correlation tests. Additionally, differences in pollutant concentrations between the power plant and industrial sectors were assessed using independent samples tests and the Mann-Whitney U test [8].

Methods

The study is a cross-sectional analysis of air pollutant production in Iran from 2000 to 2017. Its aim is to evaluate trends and patterns of emissions, which are crucial for understanding environmental health and informing policies. The research utilizes data from the Statistical Center of Iran to assess the types and quantities of pollutants and their impact on people and the ecosystem. The study applies statistical methods to analyze the distribution of air pollutants and may help steer future research on the causes, health impacts, and solutions to air pollution in the Islamic Republic of Iran.

Results

Investigating greenhouse gas emissions in the power plant sector

In the power plant sector, emissions of nitrogen oxides (NO_x) increased significantly from 84,442 tons in 1996 to 651,833 tons in 2017. This increase is much greater than in the industrial sector and is linked to how fuel is consumed and electricity is generated. Sulfur dioxide (SO_2) emissions decreased from 365,467 tons in 1996 to 239,623 tons in 2017. This reduction is attributed to environmental regulations and advancements in technology and fuel types, which help reduce environmental harm as SO_2 can contribute to acid rain and health issues (Figure 1, Table 1).

Carbon dioxide (CO_2) emissions climbed from 53,531,273 tons in 1996 to 182,746,913 tons in 2017, reflecting a significant increase in human-caused carbon emissions. This trend correlates with global industrialization, economic growth, and increased energy use from burning fossil fuels, raising concerns regarding climate change. The production of sulfur trioxide (SO_3) gas decreased from 5,582 tons in 1996 to 2,044 tons, influenced by environmental regulations, technology improvements, and operational changes in the power plant sector (Figure 1, Table 1).

Carbon monoxide (CO) emissions rose alarmingly from 99 tons in 1996 to 156,100 tons in 2017, requiring a detailed investigation into the reasons behind this increase and its implications. While the types of power plants and energy sources used are not specified, various factors likely driving this rise need to be examined along with their environmental impacts and possible remedies.

Methane (CH_4) gas production dropped from 4,095 tons in 1996 to 3,701 tons in 2017, due to factors such as technology advances, regulatory changes, economic incentives, and shifts in energy consumption (Tables 1, and 2).

Suspended Particulate Matter (SPM) pollution rose from 11,682 tons in 1996 to 25,159 tons in 2017. SPM consists of tiny particles like dust, soot, and ash in the air, particularly influencing health when inhaled. Primary sources of SPM include industrial activities, vehicle emissions, power generation (especially from coal), agricultural practices, biomass burning, and natural events. Nitrous oxide (N_2O) emissions from power plants also increased from 457 tons in 2007 to 471 tons in 2017. N_2O is a potent greenhouse gas that significantly contributes to global warming. The rise in N_2O emissions is linked to growing energy demand and may be affected by advancements in technology, with some plants reducing emissions while others continue to use older systems (Tables 1, and 2).

Investigating greenhouse gas emissions in the industrial sector

NO_x production in the industrial sector increased from 97,969 tons in 1996 to 167,395 tons in 2017. Despite this increase, control measures may have mitigated growth due to the expansion of industrial sectors in Iran during this time. SO_2 production decreased significantly from 277,961 tons in 1996 to 93,053 tons in 2017, indicating positive environmental progress likely due to cleaner technologies and stricter regulations. Conversely, CO_2 production rose sharply from 43,067,348 tons in 1996 to 102,852,284 tons in 2017, reflecting a concern for climate change as industrial activities and fossil fuel reliance increased (Table 1).

SO_3 production also saw a decline from 4,154 tons in 1996 to 1,306 tons in 2017, a positive development as SO_3 contributes to acid rain. Meanwhile, CO emissions showed a small increase from 21,665 tons in 1996 to 22,955 tons in 2017, indicating a need for ongoing monitoring due to its toxic nature and effect on air quality. CH_4 production decreased significantly from 6,647 tons in 1996 to 2,067 tons in 2017, which is favorable given methane's impact on climate change and suggests improved management practices (Table 1).

SPM production grew from 11,330 tons in 1996 to 17,154 tons in 2017, raising environmental concerns as these particles can harm health. Different industrial activities may contribute to this increase. N_2O production decreased from 325 tons in 2007 to 252 tons in 2017, though further data is needed for a comprehensive analysis since data before 2007 is unavailable (Table 1).

Understanding these emissions trends over the 21 years from 1996 to 2017 highlights the impact of industrial activities on air quality and climate. A deeper analysis is needed on specific sectors producing these emissions and the technologies and policies in use to control them. Evaluating the effectiveness of these measures compared to international standards could help improve strategies for sustainable industrial growth in Iran. Identifying the relationship between industrial growth, energy use, and emissions could further enhance these efforts (Tables 1, and 2).

Table 1: displays pollutants and greenhouse gas emissions from the power plant sector and the industry sector

Year	NO_x		SO_2		CO_2		SO_3		CO		CH_4		SPM		N_2O	
	Industrial	power	Industrial	power	Industrial	power	Industrial	power	Industrial	Power	Industrial	power	Industrial	power	Industrial	power

1386	1385	1384	1383	1382	1381	1380	1379	1378	1377	1376	1375
156066	132628	128072	115758	116127	123421	121924	131898	110562	108295	111071	97969
181230	172332	147661	139215	123953	123022	117325	110524	101555	89026	89906	84442
343218	138673	136847	121566	336564	329913	325379	306186	306641	322711	316235	277961
467663	192733	140220	124142	254413	319937	344647	324968	296025	241197	348622	365467
79398458	62353065	58837915	51671339	50207812	55497527	55133186	62098703	48726566	46503723	49755989	43067348
120041574	110207121	95793611	90672668	81268496	79883288	75748770	71538577	65837684	57997179	57313772	53531273
5112	1995	1979	1785	5059	4940	4875	4585	4599	4838	4698	4154
3110	2943	2139	1894	3884	4885	5264	4963	4520	3683	5324	5582
22767	16527	22065	19920	19067	16607	21445	21412	17413	22809	19451	21665
234	222	198	189	171	163	151	144	133	118	109	99
2071	6351	7335	6712	6737	6336	7170	7147	6234	7250	6630	6647
3001	6614	5302	4865	4168	4598	4652	4356	3973	3347	4106	4095
17432	15269	14614	12544	12916	13963	13823	14389	12399	12468	13622	11330
21848	20728	16810	15537	13427	14283	14172	13261	12110	10320	11938	11682
325	-	-	-	-	-	-	-	-	-	-	-
457	-	-	-	-	-	-	-	-	-	-	-

1396	1395	1394	1393	1392	1391	1390	1389	1388	1387
167395	162488	157225	173129	162924	168065	162056	168212	166167	171331
651833	641280	627724	651610	678024	629392	634884	574741	563998	554784
93053	101396	107646	172715	171867	202589	190465	300397	343374	393220
239623	295919	437381	627934	910658	823623	709408	497354	608395	580348
102852284	98693387	94462067	100392669	93437617	94598785	91536175	88554272	84862090	85929907
182746913	171686990	174010543	177744913	179825215	174664087	165184877	154777386	150328219	147031875
1306	1438	1545	2530	2516	2996	2806	4467	5116	5868
2044	2480	4158	4586	6574	5319	5130	3538	3465	3186
22955	23981	16663	21945	15669	14687	24553	32295	33740	25550
156100	160434	162624	177660	162707	161831	148500	137857	151517	166939
2067	2003	1931	2138	2023	2075	2009	2135	2137	2285
3701	3622	4201	4243	4725	4273	4087	3522	3345	3299
17154	16712	16029	17793	16968	17228	16776	18143	18278	19107
25159	25155	30330	31105	36199	31957	30724	25528	24873	23715
252	247	239	279	267	279	270	316	329	362
471	485	630	654	803	698	666	531	510	491

Source: Energy Balance Sheet, Ministry of Energy, Deputy for Electricity and Energy Affairs [6, 7].
"-": line mean that no data is available for them.

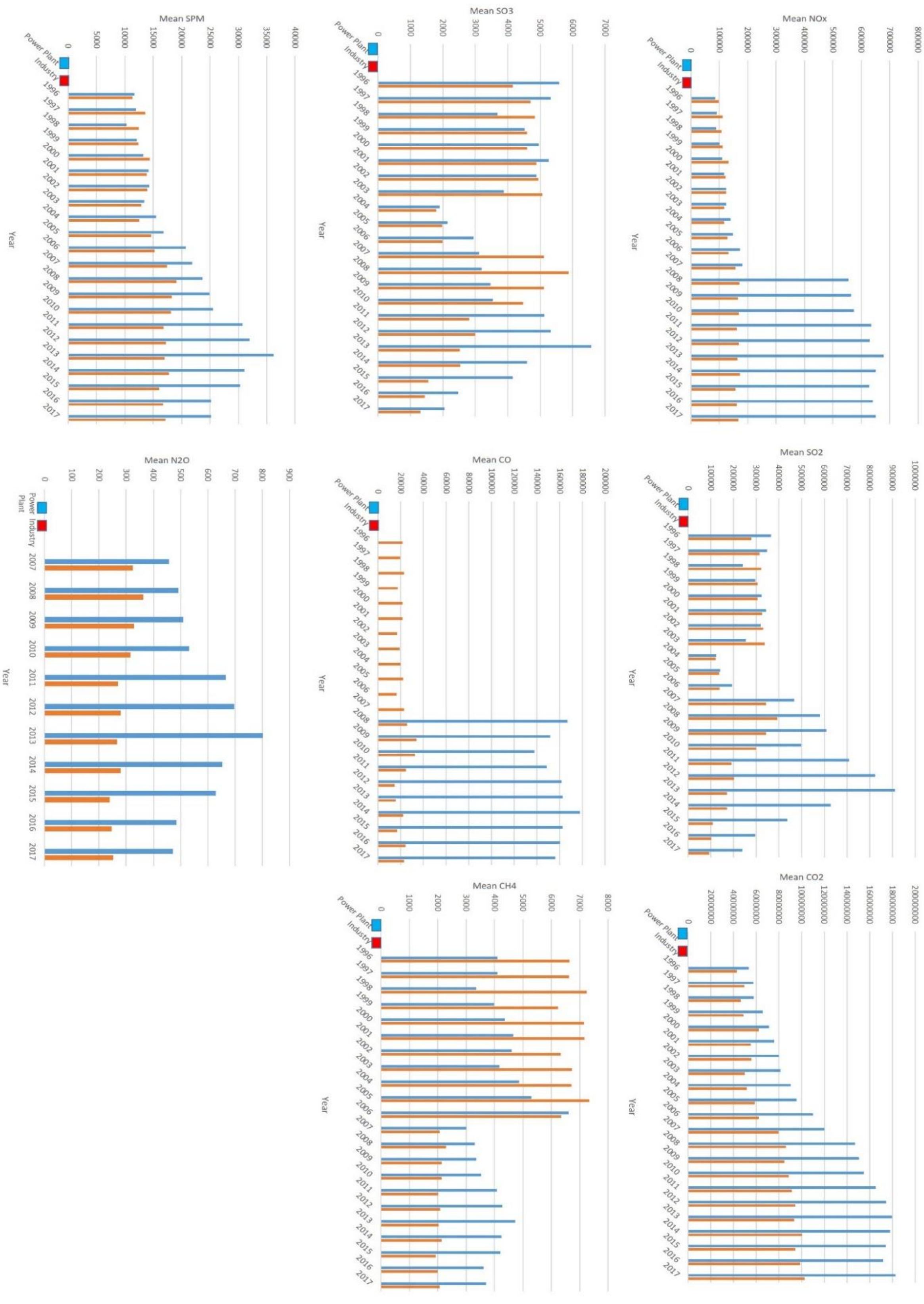

Figure 1: displays the pollutants and greenhouse gas emissions from the power plant and industry sectors [6].

Table 2: provides a descriptive analysis of the variables being studied

	Power					Industry				
Variables	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
NO_x	22	84442	678024	349475	256034	22	97969	173129	141490	25465
SO_2	22	124142	910658	415939	215250	22	93053	393220	242664	98125
CO_2	22	-	1.83E+08	1.2E+08	48014218	22		102852284	72662312	21087747
SO_3	22	1894	6574	4030	1291	22	1306	5868	3600	1496
CO	22	-	177660	72186	81071	22		33740	21508	4810
CH_4	22	3001	6614	4186	786	22	1931	7335	4428	2420
SPM	22	10320	36199	20948	7962	22	11330	19107	15407	2290
N_2O	11	457	803	581	114	11	239	362	287	39

Data distribution

In the power plant sector, only the annual carbon monoxide production index did not have a normal distribution, while the rest of the indices had a normal distribution. The reason for the non-normal distribution was the sudden increase in carbon monoxide production, which was 234 tons in 2007 and reached 166,939 tons in 2008.

In the industrial sector, methane production did not have a normal distribution and suddenly decreased from 6351 tons in 2006 to 2071 tons in 2007. In the industrial sector, the rest of the pollution indices had a normal distribution. In all studied samples, the data showed that the pollution indices NO_x, SO_2, and CO had a non-normal distribution. The rest of the indices had a normal distribution (Table 3).

Correlation among studied indices in the power plant sector

In the power plant sector, the indices for SPM, CO_2, SO_2, and NO_x show a direct and significant correlation with the year index. Compared to previous years of the study (1996), the production of these gases has increased. This increase indicates the government's continuous efforts to boost electrical energy production despite the aging power plant facilities. This necessitates more investments to enhance and increase the efficiency and effectiveness of power plants. Additionally, the type of power plants and the type of fuel they consume also play a role in this issue. The increase in pollutant production is linked to the type of fuel consumed and the combustion process in power plants.

Similarly, in the power plant sector, the SPM pollutant production index has a direct correlation with other pollution indices studied, with significant correlations found with N_2O, NO_x, SO_2, and CO_2. There is also a direct and significant correlation between the CO_2 and NO_x indices. The same applies to the correlation between the SO_2 and NO_x pollution indices, as well as the SO_2 pollution index with N_2O, SPM, SO_3, and CO_2 pollution indices. Additionally, a direct and significant correlation exists between the CO_2 pollution index and N_2O and SPM pollution indices. Moreover, there is a direct and significant correlation between the CH_4 and N_2O pollution indices, as well as between the N_2O and SPM pollution indices. In the power plant sector, the year variable has a direct and significant correlation with the CO pollutant gas production variable. Based on the Spearman correlation test, a direct and significant correlation is observed between the production of NO_x, SO_2, CO_2, and SPM pollutant gases with the production of CO pollutant gas (Tables 4, and 5).

Table 3: presents the results of the One-Sample Kolmogorov-Smirnov Test for the studied variables

One-Sample Kolmogorov-Smirnov Test									
Variables		NO_x	SO_2	CO_2	SO_3	CO	CH_4	SPM	N_2O
Power Plane	N	22	22	22	22	22	22	22	11
	Kolmogorov-Smirnov Z	1.36	0.861	0.79	0.514	1.679	0.665	0.762	0.717
	Asymp. Sig. (2-tailed)	0.05	0.448	0.56	0.955	0.007	0.769	0.608	0.682
Industry	N	22	22	22	22	22	22	22	11
	Kolmogorov-Smirnov Z	1.015	1.041	0.880	1.026	0.725	1.464	0.798	0.742
	Asymp. Sig. (2-tailed)	0.254	0.229	0.421	0.243	0.669	0.028	0.548	0.640
All studied samples	N	44	44	44	44	44	44	44	22
	Kolmogorov-Smirnov Z	2.613	1.386	1.112	1.039	2.395	0.881	1.316	0.868
	Asymp. Sig. (2-tailed)	0.000	0.043	0.169	0.23	0.000	0.419	0.063	0.438

Asymp. Sig. (2-tailed)>0.05 mean data distribution is normal.

Table 4: presents a Pearson correlation calculated between air pollutant indices and other variables exhibiting a normal distribution in the power plant sector

Variables		**N_2O**	**SPM**	**CH_4**	**SO_3**	**CO_2**	**SO_2**	**NO_x**
Year	Pearson Correlation	0.208	.900**	-0.115	-0.246	.976**	.456*	.915**
	Sig. (2-tailed)	0.539	0.000	0.611	0.269	0.000	0.033	0.000
	N	11	22	22	22	22	22	22
NO_x	Pearson Correlation	0.501	.928**	-0.272	-0.002	.969**	.679**	
	Sig. (2-tailed)	0.116	0.000	0.221	0.993	0.000	0.001	
	N	11	22	22	22	22	22	
SO_2	Pearson Correlation	.811**	.762**	-0.263	.586**	.619**		
	Sig. (2-tailed)	0.002	0.000	0.237	0.004	0.002		
	N	11	22	22	22	22		
CO_2	Pearson Correlation	0.556	.958**	-0.172	-0.115			
	Sig. (2-tailed)	0.076	0.000	0.444	0.612			
	N	11	22	22	22			
SO_3	Pearson Correlation	.963**	0.097	0.034				
	Sig. (2-tailed)	0.000	0.669	0.882				
	N	11	22	22				
CH_4	Pearson Correlation	.931**	-0.068					

	Sig. (2-tailed)	0.000	0.765					
	N	11	22					
SPM	Pearson Correlation	.983**						
	Sig. (2-tailed)	0.000						
	N	11						

***. Correlation is significant at the 0.01 level (2-tailed).*
**. Correlation is significant at the 0.05 level (2-tailed).*

Table 5: Shows Spearman's correlation between CO and other variables studied in the power plant section

Spearman's rho	**Power**	**N_2O**	**Year**	**NO_x**	**SO_2**	**CO_2**	**SO_3**	**CH_4**	**SPM**
CO	**Correlation Coefficient**	0.409	.921**	.924**	.501*	.935**	-0.203	-0.101	.921**
	Sig. (2-tailed)	0.212	0	0	0.018	0	0.366	0.654	0
	N	11	22	22	22	22	22	22	22
**. Correlation is significant at the 0.01 level (2-tailed).									
*. Correlation is significant at the 0.05 level (2-tailed).									

Correlation among studied indices in the industrial sector

In the industrial sector, there is a significant and inverse correlation between the year variable and the N_2O, SO_3, and SO_2 variables. This indicates a shift in fuel usage and improvements in infrastructure and equipment within industrial centers. Conversely, the production of CO pollutants in the industrial sector is not correlated with the year variable. The year variable does show a direct and significant correlation with the SPM, CO_2, and NO_x pollutant variables in the industrial sector. Additionally, the production of CO_2 gas is directly and significantly correlated with the production of SPM and NO_x pollutants. CO_2 gas production is also directly and significantly correlated with the production of N_2O, SO_3, and SO_2 pollutant gases in the industrial sector. Furthermore, the production of SPM pollutants is directly correlated with the production of CO, NO_x, CO_2, and N_2O pollutant gases. SO_2 is directly correlated with N_2O and SO_3 pollutant gases in the industrial sector. Lastly, N_2O and SO_3 pollutant gases show a direct and significant correlation in the industrial sector. Based on Spearman's correlation test, the production of the CH_4 pollutant gas in the industrial sector is inversely correlated with the year index. This indicates that less of this gas is produced and released in industrial sectors during the study period. Changing the type of fuel clearly affects the production of methane gas. The methane (CH_4) gas production index has a significant and inverse correlation with the CO_2 pollutant gas production index, as well as with NO_x and SPM. Conversely, it has a direct and significant correlation with N_2O gas production (Tables 6, and 7).

Correlation between groups (power plant or industry) and air pollutants

According to Kendall's correlation analysis between the power plant and industrial sectors, there is a significant difference in the production rates of air pollutants. Specifically, the production of CO_2, SO_2, and SPM pollutants was notably higher in the power plant sector compared to the industrial sector. Overall, the production rates of all pollutants studied, except for carbon monoxide and methane, were higher in the power plant sector (Table 8).

Table 6: Pearson correlation was calculated between air pollutant indices and other variables that exhibited a normal distribution in the industrial sector

Variables		N_2O	SPM	CO	SO_3	CO_2	SO_2	NO_x
Year	Pearson Correlation	-.894**	.800**	.135	-.608**	.952**	-.604**	.898**
	Sig. (2-tailed)	.000	.000	.548	.003	.000	.003	.000
	N	11	22	22	22	22	22	22
NO_x	Pearson Correlation	.313	.971**	.343	-.273	.968**	-.267	
	Sig. (2-tailed)	.348	.000	.118	.218	.000	.230	
	N	11	22	22	22	22	22	
SO_2	Pearson Correlation	.984**	-.118	.288	1.000**	-.428*		
	Sig. (2-tailed)	.000	.601	.194	.000	.047		
	N	11	22	22	22	22		
CO_2	Pearson Correlation	-.786**	.895**	.239	-.434*			
	Sig. (2-tailed)	.004	.000	.285	.044			
	N	11	22	22	22			
SO_3	Pearson Correlation	.983**	-.127	.283				
	Sig. (2-tailed)	.000	.574	.201				
	N	11	22	22				
CO	Pearson Correlation	.563	.425*					
	Sig. (2-tailed)	.071	.049					
	N	11	22					
SPM	Pearson Correlation	.903**						
	Sig. (2-tailed)	.000						
	N	11						
**. Correlation is significant at the 0.01 level (2-tailed).								
*. Correlation is significant at the 0.05 level (2-tailed).								

Table 7: Shows Spearman's correlation between CH_4 and other variables studied in the power plant section

Variables		Year	NO_x	SO_2	CO_2	SO_3	CO	SPM	N_2O
CH_4	Correlation Coefficient	-.806**	-.642**	0.321	-.776**	0.321	-0.107	-.612**	.861**
	Sig. (2-tailed)	0	0.001	0.145	0.000	0.145	0.636	0.002	0.001
	N	22	22	22	22	22	22	22	11
**. Correlation is significant at the 0.01 level (2-tailed).									
*. Correlation is significant at the 0.05 level (2-tailed).									

Table 8: Correlation between groups (power plant or industry) and studied variables

Kendall's tau_b		NO_x	SO_2	CO_2	SO_3	CO	CH_4	SPM	N_2O
Groups (power plant vs industry)	**Correlation Coefficient**	-0.195	-.366**	-.392**	-0.152	0.039	-0.001	-0.221	-.725**
	Sig. (2-tailed)	0.117	0.003	0.002	0.223	0.754	0.991	0.076	0.000
	N	44	44	44	44	44	44	44	22
**. Correlation is significant at the 0.01 level (2-tailed).									
*. Correlation is significant at the 0.05 level (2-tailed).									

Mean comparison between the power plant and the industrial sectors

The Mann-Whitney test for mean comparison between the two groups revealed a significant difference in the production of SO_2 gas, with the power plant sector emitting more pollutants than the industrial sector. However, the production of CO and NO_x gases did not show a significant difference between the two sectors.

According to the Independent Samples Test, there was a significant disparity in the production of CO_2, SO_3, and N_2O pollutants between the power plant and industrial sectors,

Table 9: Comparison of Mean Variables Between Sections

Independent Samples Test				Mann-Whitney U Test			
Variables	**t**	**df**	**Sig.**	**Variables**	**Mann-Whitney U**	**Z**	**Asymp. Sig. (2-tailed)**
N_2O	4.152	29.373	.000	**CO**	220	-0.516	0.606
CO_2	3.121	24.780	.005	**SO_2**	121	-2.84	0.005
SO_3	4.152	29.373	.000	**NO_x**	175	-1.573	0.116
SPM	.833	41	.409				

with the power plant sector emitting higher levels of these pollutants. In contrast, there was no significant difference in the production of SPM pollutants between the two groups (Table 9).

Discussion

Significant fluctuations in air pollutant emissions were observed during the study period

The focus of this discussion is on the increase in carbon monoxide (CO) emissions from power plants since 2008 and the reasons behind it. Fossil fuel power plants, especially those using coal, oil, and natural gas, are major contributors to CO emissions. To reduce these emissions, one must consider changes in energy production, environmental regulations, and technological advancements [3-4].

CO emissions can vary depending on the region and specific plants. Some areas may see an increase in emissions due to industrial expansion and higher energy demands, while others may lower emissions through strict regulations and cleaner energy sources. Analyzing energy consumption, environmental laws, fuel quality, technological advancements, and economic factors can help explain the rise in CO emissions since 2008. Accurate assessments require reliable data from organizations such as the International Energy Agency (IEA) or the U.S. Environmental Protection Agency (EPA) [1-3].

The text also mentions a decrease in methane (CH_4) emissions in the industrial sector in 2007, identifying major sources and potential reasons for the decline, such as technological advancements and regulations. Analyzing data from 2007 is crucial for understanding the significance of this decrease and its implications for methane emissions trends [4, 5].

In conclusion, the increase in carbon monoxide (CO) emissions from power plants since 2008 is mainly due to fossil fuel power plants, particularly those using coal, oil, and natural gas. To reduce these emissions, it is crucial to consider changes in energy production, environmental regulations, and technological advancements [3, 4]. CO emissions can vary by region and specific plants, with some areas experiencing an increase due to industrial growth and energy demand, while others may reduce emissions through regulations and cleaner sources. Understanding the increase in CO emissions involves examining energy usage, regulations, fuel quality, technology, and economic factors. Additionally, a decline in methane (CH_4) emissions in 2007 is noted, with major sources and reasons for this decrease identified, emphasizing the importance of analyzing data from that year [4, 5].

Discussion on the release of air pollutants from the industrial sector

Nitrogen oxides (NO_x) in the atmosphere make measuring emissions difficult. Researchers use various methods to estimate these emissions, such as bottom-up approaches that collect data on fuel use and space-based observations that compare actual atmospheric data to models. Space-based observations have significantly improved the accuracy of emission inventories, especially in North America and Europe. To enhance Iran's NO_x emissions inventory, more comprehensive studies using sources like satellites are necessary to refine emission factors and minimize errors, which will support air quality and climate initiatives [9].

It's important to compare NO_x emissions rates with industrial growth. If industrial growth exceeds NO_x emissions, it may show that control measures are working. Many countries have strengthened regulations on NO_x emissions over the last two decades, leading to better technologies [10].

The use of cleaner technologies has greatly reduced sulfur dioxide (SO_2) emissions. Methods like flue-gas desulfurization (FGD) in power plants capture and remove SO_2 from exhaust [11]. Technologies such as wet scrubbers, spray dryers, and fabric filters are commonly used. Stricter government emission standards, like the U. S. Clean Air Act and the EU's Large Combustion Plant Directive, force industries to invest in controls and operate sustainably [11-13].

Switching from high-sulfur fuels like coal and oil to natural gas and lower-sulfur alternatives is important for reducing emissions. Natural gas produces less sulfur when burned, and reducing sulfur in fuel has cut SO_2 emissions from vehicles [13, 14].

The increased use of renewable energy sources such as wind, solar, and hydroelectric power reduces reliance on fossil fuels, which produce high SO_2 emissions. Improved energy efficiency in industries and power generation also helps decrease emissions [14, 15].

These reductions lead to less acid rain, improved air quality, and benefits to public health and ecosystems. Collaboration among governments, industries, and societies is vital for environmental progress [16].

The increase in CO_2 emissions from 1996 to 2017 is a major environmental problem, driven mainly by more industrial activities and fossil fuel use. The Environmental Kuznets Curve (EKC) hypothesis explains that while emissions increase with industrial growth, they may eventually decrease as environmental concerns rise, suggesting that industrial growth can be compatible with environmental protection [17].

The significant drop in sulfur trioxide (SO_3) production from 1996 to 2017 is a good sign for the environment and public health. This decrease is linked to lower sulfur dioxide (SO_2) emissions, which result from stricter environmental laws and better industrial methods to cut harmful pollutants [18].

SO_3 mainly comes from burning fossil fuels with sulfur and from making sulfuric acid, used in industries like fertilizers and chemicals. Since the 1990s, efforts to reduce SO_2 emissions, due to its connection to acid rain and breathing problems, have also lowered SO_3 emissions [11, 18].

Factors like a shift to cleaner fuels, better emission control technologies, and less industrial activity have helped reduce SO_3 production. To keep this trend, more research into cleaner energy and global cooperation is needed, along with increased public awareness [11, 12, and 18].

The increase in carbon monoxide (CO) emissions from 1996 to 2017 in industrial sectors is caused by several factors, such as the types of fuel used and the processes in industries. CO is a gas from the incomplete burning of fuels, mainly from fossil fuels in vehicles and power plants [19].

Key reasons for the rise in CO emissions include the type of fuel, with coal emitting more CO than cleaner fuels like natural gas. Poor fuel efficiency and certain industrial activities, especially in iron and steel production, also lead to higher emissions. The effectiveness of emission control technologies is crucial; if these technologies decline or are poorly maintained, emissions will rise [20].

Economic growth and energy use changes can further impact emissions, especially if environmental regulations are weakened. Accurate monitoring and reporting of emissions are important. CO poses serious health risks, so strategies to manage emissions include using cleaner fuels, advanced technologies, stricter standards, and regular inspections [19-21]. Research for cleaner processes is also necessary, highlighting the need for ongoing monitoring and effective measures for public health and environmental safety [21].

The decrease in methane [CH_4] production from 1996 to 2017 is a positive development for climate change. Methane is a potent greenhouse gas, much more effective than carbon dioxide (CO_2) at trapping heat. Various factors have led to lower methane emissions. Improved landfill practices, like gas capture systems, have reduced methane release. Stricter regulations in the natural gas industry and advancements in technology have also helped [22]. A decline in coal mining and the growth of renewable energy sources like wind and solar have contributed further. Ongoing development of methane reduction technologies and monitoring emissions is essential for continued progress [17, 22].

The increase of Suspended Particulate Matter (SPM) from 1996 to 2017 poses serious risks to the environment and public health. It is essential to pinpoint the sources of SPM, recognize its health and environmental consequences, and grasp how it spreads and can be controlled.

SPM includes solid and liquid particles in the air. Major sources of SPM rise include construction and demolition activities that create dust as cities expand. Industrial processes such as mining, manufacturing, and power generation, especially those using fossil fuels, release SPM. Vehicle emissions, particularly in busy areas, contribute significantly, along with increased traffic and poorly maintained roads that can suspend dust. Agricultural actions, like soil tilling and crop burning, add to the problem. Natural sources include dust from deserts and forest fires [23].

High levels of SPM result in serious health issues. Particles smaller than 10 micrometers and 2. 5 micrometers can enter the lungs, causing respiratory diseases and increasing the risk of heart diseases and early deaths. To control SPM, measures such as stricter air quality standards, new dust control technologies, and electric vehicles should be promoted. More research is needed to improve SPM measurement and understand its health effects [23, 24].

N2O, or nitrous oxide, is released during chemical manufacturing, fossil fuel burning, and agriculture. It is a major greenhouse gas, about 300 times more potent than carbon dioxide, and contributes to ozone depletion [25]. The recent drop in N_2O production may be due to several reasons. Technological improvements could have led to better methods for reducing emissions. Stricter environmental rules might have pushed industries to invest in emission-reducing technologies. Economic changes, such as lower demand for high-emission products, may also be a factor. Better data collection is important to confirm the reduction's permanence, and long-term data will help assess policy effectiveness [26].

Discussion on the release of air pollutants from power plants

Between 1996 and 2017, nitrogen oxides (NO_x) emissions from power plants increased due to rising global energy demand, especially in developing countries. The growth in electricity generation led to higher NO_x emissions unless technology and fuel sources improved [27].

The type of fuel used in power plants is crucial. Most plants burn fossil fuels like coal, oil, and natural gas, with coal and oil producing more nitrogen than natural gas. This reliance on high-emission fuels contributes to increased NO_x, unlike industries that adopt cleaner energy sources [9, 10].

Efficiency and technology affect emissions, as higher efficiency can lead to increased NO_x due to higher combustion temperatures. While the industrial sector has made progress in reducing NO_x emissions, similar advancements are lacking in the power sector. Retrofitting older plants with better emission controls can be expensive in developing areas, highlighting the need for strong policies and regulations. Analyzing emissions data related to fuel use, technology changes, and policies is essential for reducing emissions and ensuring a reliable energy supply [9, 10, 27].

The decrease in sulfur dioxide (SO_2) emissions in the power plant sector from 1996 to 2017 is due to environmental regulations, advancements in technology, and changes in fuel types. Lower SO_2 emissions help reduce the negative impacts of power generation, as sulfur dioxide is linked to acid rain, health problems, and climate change. Stricter environmental regulations have been implemented, including the Clean Air Act in the U.S. and the Large Combustion Plant Directive in Europe, which set limits on SO_2 emissions from power plants. These rules push the industry to adopt cleaner technologies to comply with standards [11-13].

Technological improvements, such as flue-gas desulfurization (FGD) systems, have significantly reduced SO_2 emissions. FGD methods like wet limestone scrubbing and dry sorbent injection capture sulfur dioxide from flue gases before they are released into the air, turning it into manageable solid waste [11, 12].

Additionally, there has been a shift in fuel usage from high-sulfur coal to natural gas and renewable energy. Natural gas produces less sulfur, and renewable sources like wind and solar do not emit SO_2. Enhanced efficiency in fossil fuel combustion and the use of low-sulfur coal also contribute to lower emissions [12, 13, and 19]. Market-based policies, such as cap-and-trade systems, encourage power plants to reduce emissions. Understanding SO_2's chemistry is crucial to grasping the overall drop in emissions and its role in combating climate change [11-13, 28].

The production of sulfur trioxide (SO_3) gas decreased from 1996 to 2017 due to several reasons, including environmental rules, technology improvements, and changes in how power plants operate. Stricter laws aimed at reducing sulfur dioxide (SO_2) emissions helped lower SO_3 production. The Clean Air Act Amendments of 1990 and similar global policies contributed to these reductions [29]. Technological advancements like flue gas desulfurization systems and switches to low-sulfur coal or natural gas also cut emissions, leading to a decrease in sulfur oxide emissions [11, 13].

CO_2 emissions mainly come from burning fossil fuels, which trap heat in the atmosphere and cause the greenhouse effect. To reduce emissions, we should focus on renewable energy, improve energy efficiency, and use Carbon Capture and Storage (CCS), along with afforestation and reforestation. Governments can promote low-carbon technologies using carbon taxes or cap-and-trade systems. International efforts, like the Paris Agreement, are crucial for reducing emissions [30]. From 1996 to 2017, CO_2 emissions rose significantly due to industrialization and economic growth, especially in countries like China and India that heavily rely on fossil fuels. Population growth also increased energy demands. This rise in CO_2 affects climate change, causing issues like melting ice caps and extreme weather. Solutions include a shift to renewable energy and global cooperation in limiting emissions [17, 30, and 31].

Carbon monoxide (CO) emissions from power plants increased from 1996 to 2017. This rise is due to higher global energy demand from population growth, urbanization, and economic development, leading to more operations in power plants. If these plants mainly use fossil fuels, CO emissions can rise, especially if coal is favored over cleaner sources. Older technologies and weak regulations may also contribute to higher emissions [30, 31]. The increased CO emissions cause serious environmental issues, affecting air quality and health. Strategies like switching to cleaner energy, improving pollution controls, enforcing regulations, and promoting reforestation can help reduce CO emissions. International collaboration and monitoring are essential to combat air pollution and climate change [31, 32].

The decrease in methane gas production from power plants is due to several factors, including better technology, new regulations, economic incentives, and changes in energy use. Advances in natural gas engines and turbines have improved efficiency and lowered emissions, while newer systems like combined cycle gas turbines produce less methane than older plants [33]. Stricter environmental laws, such as the Clean Air Act Amendments and the EU's Emissions Trading System, have encouraged cleaner technologies. The rise of renewable energy sources has also decreased dependence on fossil fuels [34]. Improved natural gas extraction methods and upgraded pipeline systems have further reduced leaks. Economic factors and investments in methane capture technologies play important roles in these trends [35].

The increase in SPM (Suspended Particulate Matter) pollution from 1996 to 2017 can be linked to various environmental and industrial factors. SPM is made up of small particles in the air, like dust and soot, primarily produced by industrial activities such as mining, construction, vehicle emissions, power generation (especially coal), agricultural practices, biomass burning, and natural events like dust storms [23, 24].

This rise in SPM is often associated with economic growth, leading to more construction and energy usage, which increases emissions. Population growth and urbanization also add to the problem by raising demand for resources and creating more traffic. The use of coal and fossil fuels, particularly where laws are weak, contributes further to SPM levels [36]. Climate change can also worsen SPM through more frequent dust storms. Effective environmental regulations and better enforcement are crucial for understanding SPM trends, and researchers should analyze specific data on sources and policies to develop reduction strategies [23, 24, and 36].

The emissions of nitrous oxide (N_2O) from power plants increased from 2007 to 2017. N_2O is a strong greenhouse gas that warms the planet more than carbon dioxide. Its emissions primarily come from burning fossil fuels and biological processes in soils and water [24, 26].

The rise in emissions is due to higher global energy demand, varying technology use in power plants, and the influence of environmental regulations. Increased coal use raises N_2O emissions more than natural gas. Additionally, systems meant to control nitrogen oxides (NO_x) emissions may accidentally raise N_2O emissions if not properly optimized. A review of emission data, technology changes, regulatory impacts, and other factors is needed to fully understand these emissions [26, 37].

Correlation among air pollution variables in the industrial sector

The data indicates significant changes in the industrial sector during the study period regarding pollutant emissions and their relationship with the year variable. These changes can be attributed to advancements in technology, stricter regulations, and shifts in fuel usage. The decreasing emissions of N_2O, SO_3, and SO_2 over time suggest that industrial centers are adopting cleaner technologies and adhering to stricter environmental regulations, representing a positive step towards reducing air pollution and combating climate change [38].

In contrast, the production of SPM, CO_2, and NO_x pollutants has increased over the years. This could be due to increased industrial activities or the presence of different types of industries contributing to higher emissions. For instance, increased manufacturing or fossil fuel power generation could lead to higher CO_2 emissions, while heightened traffic and energy consumption could result in elevated SPM and NO_x levels [18-20].

There is a direct and significant correlation between CO_2 and SPM, NO_x, and N_2O emissions in the industrial sector, highlighting the interconnectedness of these pollutants. CO_2, a major greenhouse gas, primarily stems from combustion, while SPM and NO_x are related to air quality concerns. N_2O, another greenhouse gas, is often emitted alongside CO_2 during fossil fuel combustion, suggesting that efforts to reduce CO_2 emissions may also help decrease other pollutants [11-13].

The correlation between SPM and various pollutant gases suggests they may have similar sources, potentially originating from fossil fuels that produce sulfur and nitrogen compounds during combustion. A similar relationship exists between N_2O and SO_3 from specific industrial processes [1-3].

Lastly, the inverse relationship between CH_4 and the year variable, along with its connections to CO_2, NO_x, and SPM, indicates that reducing CH_4 emissions aligns with the trends of these other pollutants. This implies that utilizing cleaner fuels or enhancing methane capture can decrease CH_4 pollution. The strong inverse correlation between CH_4 and CO_2 suggests that reducing CH_4 emissions may also result in higher emissions of CO_2. This is crucial because of methane's significant impact on global warming. Continuous monitoring and policy efforts are essential for effectively managing and reducing air pollution (Tables 6, and 7) [1, 3, and 27].

Correlation between air pollution variables in the power plant sector

The information presented suggests a comprehensive analysis of pollutant emissions from the power plant sector over time. The observed correlations between the annual index and the indices for SPM (sulfur particles), CO_2 (carbon dioxide), SO_2 (sulfur dioxide) and NO_x (nitrogen oxides) indicate a trend towards increasing pollutant levels, probably due to growing energy demand and possibly inadequate emission control technologies in aging power plants. This trend highlights the need for further investment in the energy sector to improve efficiency and reduce emissions [1, 14 and 18].

The direct and significant correlations between different pollution indices (N_2O, NO_x, SO_2, CO_2, SPM) indicate mutual relationships in the production and emission processes in power plants. These relationships can be explained by the similarities between the combustion processes and chemical reactions involved in power generation. For example, the combustion of fossil fuels such as coal and oil, which have a high sulfur and nitrogen content, can lead to the formation of SPM, SO_2 and NO_x. Similarly, the combustion of fossil fuels, regardless of sulfur content, generally leads to CO_2 emissions [1, 2 and 14].

The direct and significant correlation between the CO_2 and NO_x indices can be explained by the fact that both gases are primary products of combustion in power plants. The oxidation of carbon in the presence of oxygen yields CO_2, while the reaction between nitrogen and oxygen at high temperatures leads to the formation of various nitrogen oxides (NO_x). The presence of excess oxygen in the combustion process can also influence the formation of these gases [1-3, 14].

The significant correlation between SPM and other pollutants (N_2O, NO_x, SO_2, and CO_2) suggests that the emission control systems in place may not effectively capture and remove SPM, allowing it to be co-emitted with these gases. This highlights the importance of implementing advanced emission control technologies capable of handling a broad spectrum of pollutants. Moreover, the direct and significant correlation between the CH_4 (Methane) and N_2O (Nitrous Oxide) indices may indicate that methane, a potent greenhouse gas, is being released during the power generation process, possibly through leakage or incomplete combustion. This further emphasizes the need for monitoring and controlling emissions from power plants, as methane has a much higher global warming potential than CO_2 (Tables 4, and 5) [1, 2, 14, 18].

Mean value comparison of air pollution variables between the groups (power plant or industry)

Power plants produce more sulfur dioxide (SO_2) than other industries, making them a major source of air pollution. This is mainly due to the high sulfur content in fossil fuels such as coal and oil, which release SO_2 during combustion [3].

In addition to SO_2, power plants also emit large amounts of carbon dioxide (CO_2), as electricity generation from fossil fuels results in CO_2 emissions. Even with improved efficiency, the high fuel input still leads to significant CO_2 emissions [1, 2].

While power plants primarily emit SO_2, the oxidation of SO_2 can also produce sulfur trioxide (SO_3) depending on temperature, catalysts and oxygen content. In addition, nitrogen oxide (N_2O) emissions are higher in power plants, especially those that use combustion, as nitrogen-containing fuels are burned and nitrogen oxides (NO_x) are formed at high temperatures and pressures (Tables 8, and 9) [1-3].

Comparison with countries that have a similar energy structure or with regional countries such as Saudi Arabia or China

The development of Chinese policy to combat air pollution has taken place in three phases. In the first phase, from 1980 to 2005, the measures were ineffective due to rapid industrial growth, weak enforcement and low public awareness. Local governments focused on economic development rather than the environment, and outdated technologies slowed progress. In the second phase, which lasted from 2006 to 2012, the 11th Five-Year Plan set new targets such as a 10 percent reduction in sulfur dioxide emissions and introduced economic incentives such as a carbon tax. While these targets were met, new pollutants such as $PM_{2.5}$ and O_3 became a major problem. Starting in 2013, severe smog led to comprehensive reforms, including the 2015 Air Quality Law, stricter standards and efforts to reduce $PM_{2.5}$ and SO_2 emissions, and increased inspections and investment in renewable energy [40]. The Arabian Peninsula (AP) is facing serious environmental problems due to rapid urbanization, industrialization and high energy consumption. The affected countries -

Saudi Arabia, the United Arab Emirates, Kuwait, Qatar, Bahrain and Oman - are struggling with air pollution, which is exacerbated by frequent sandstorms. The main pollutants include particulate matter, greenhouse gasses, nitrogen dioxide and sulfur dioxide, which are harmful to human health, contribute to climate change and affect ecosystems. In Qatar, CO_2 emissions amounted to 40.31 tons per capita in 2010, mainly due to the oil and gas industry. Saudi Arabia is also struggling with high emissions from the cement industry, which is due to the extensive construction activity associated with economic growth and population growth. Data from the Aerosol Robotic Network (AERONET) shows that man-made particles mix with desert dust and affect the regional climate and air quality. To overcome these challenges, it is crucial to implement policies for cleaner energy supply, better industrial practices and sustainable urban growth, which requires cooperation between these countries [41]. Analysis of the IAEC indicator shows that developed countries such as the UK and the US have historically had significantly higher cumulative per capita emissions than the global average and developing countries. This is important information for discussions on climate justice, as it underlines the responsibility of developed countries to take a leadership role in reducing emissions and supporting the transition of developing countries to a low-carbon economy [42].

Conclusion

Since 2007, methane (CH_4) emissions in the industrial sector have decreased due to technological progress and stricter regulations. Analyzing data from 2007 is crucial to understanding this decline. However, measuring pollutants such as nitrogen oxides (NO_x) can be challenging. Methods such as fuel consumption data and atmospheric observations have helped to improve accuracy. Technological advances have also played a role in reducing sulfur dioxide (SO_2) emissions by encouraging the use of cleaner fuels and enforcing stricter regulations. This has prompted industry to invest in emissions controls, resulting in improved air quality and a decrease in acid rain. From 1996 to 2017, CO_2 emissions have increased due to industrial activity and the use of fossil fuels, but growing environmental awareness can help reduce emissions. The decline in sulfur trioxide (SO_3) production indicates success in reducing SO_2 levels, but further efforts are needed to keep SO_3 levels low and promote cleaner technologies. Suspended particulate matter (SPM) levels have increased, highlighting the importance of increased monitoring and public awareness. The decrease in nitrogen oxide (N_2O) emissions is likely the result of advances in technology and regulations, highlighting the importance of continuous data collection for emission reduction strategies, especially in light of increasing coal use.

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Conflict of Interest

There are no conflicts of interest in the current study.

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