

## Original Research Article

# Statistical Study of Air Pollutant Emissions from 1996 to 2017 in Domestic, Commercial, and Public Sectors Compared to the Agricultural Sector

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Domestic; Commercial; Agriculture**ABSTRACT**

This study aims to analyze pollutant and greenhouse gas emissions from various sectors, focusing on changes from 1996 to 2017. It emphasizes carbon dioxide (CO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and suspended particulate matter (SPM), and assesses emission reduction strategies. Air pollution data in Iran from 1996 to 2017 were collected, which included various pollutants and greenhouse gas emissions. The data distribution was examined using a test, and it was found that methane (CH<sub>4</sub>) production rates were not normally distributed in certain sectors. To compare greenhouse gas production across sectors, SPSS was utilized. CO<sub>2</sub> emissions rose significantly from 1996 to 2017, increasing from 72,261,611 tons to 139,254,025 tons, mainly due to increased fossil fuel use for heating and cooking. While NO<sub>x</sub> and SPM emissions also increased, their rises were less pronounced. Technological advances, such as catalytic converters, helped reduce these pollutants. CH<sub>4</sub> emissions dropped sharply after 2007 due to focused efforts. Stricter emission standards and promotion of renewable energy are needed, along with ongoing research and monitoring. The analysis shows that air pollution is complex and linked to different sectors and economic activities. While progress has been made in reducing some pollutants, CO<sub>2</sub> still needs urgent action. The study supports using renewable energy, stricter emission standards, and specific policies for agricultural emissions. Continuous monitoring and research are vital for assessing these strategies and achieving climate goals. The findings highlight the need for thorough emission reduction efforts to protect the environment and public health.

**Introduction**

Numerous environmental contaminants harm human health, leading to deaths and diseases. There is limited information about pollution in developing countries, highlighting the need for more research. Developed countries

typically respond to pollution only after health issues arise. Understanding the link between toxins and health is crucial, as measuring exposure can be complex. Pollution occurs when harmful substances contaminate air, water, and soil, impacting health through various exposure methods. Industrialization contributes to the release of harmful pollutants, increasing the risk

of disease [1-3]. Ozone ( $O_3$ ) is a pollutant formed when sunlight reacts with  $NO_x$  and volatile organic compounds (VOCs), especially in warm weather. It contributes to photochemical smog in urban areas with high sunlight and vehicle emissions.  $O_3$  can harm health by irritating the respiratory system, causing issues such as bronchoconstriction and reduced lung function, especially in vulnerable groups. To mitigate ozone's harmful effects, controlling  $NO_x$  and VOC emissions is crucial, and issuing public health warnings during high  $O_3$  levels is recommended [4]. Sulfur oxides, or  $SO_x$ , consist of sulfur dioxide ( $SO_2$ ) and sulfur trioxide ( $SO_3$ ), mainly originating from human activities like burning fossil fuels such as coal, oil, and natural gas. These gases are harmful to health, leading to acid rain and respiratory problems. Acid rain results from  $SO_2$  in the atmosphere forming sulfuric acid, which can damage soil, plants, and aquatic life. Inhaling  $SO_2$  can irritate the respiratory system, causing coughing and breathing difficulties. Technologies and cleaner fuels play a significant role in reducing  $SO_x$  emissions, emphasizing the importance of limiting exposure and environmental impact [5].

Carbon monoxide (CO) is a dangerous gas that can harm health, produced when fossil fuels are burned. CO is colorless and odorless, making it difficult to detect, thereby earning the nickname "silent killer." It reduces the blood's ability to carry oxygen, leading to hypoxia. Symptoms range from headaches to unconsciousness, with high-risk groups including individuals with heart issues, children, and older adults. To prevent exposure, it is crucial to check devices, install CO detectors, and be vigilant for symptoms. If symptoms occur, seek fresh air and immediate medical assistance [6].

$NO_x$  gases, including nitric oxide (NO) and nitrogen dioxide ( $NO_2$ ), are harmful air pollutants primarily generated by high-temperature combustion in vehicles and power plants. These gases pose health risks such as respiratory problems and contribute to issues like photochemical smog, acid rain, eutrophication, and global warming. Various processes lead to the formation of  $NO_x$ , including nitrogen reacting with oxygen under high temperatures. To control  $NO_x$  emissions, methods like catalytic converters, Low- $NO_x$

burners, and government emissions standards can be utilized. Promoting cleaner energy sources and efficient traffic management helps reduce emissions from transportation. By implementing these strategies and embracing new technologies, the adverse effects of  $NO_x$  on health and the environment can be minimized [4,7].

The discovery of NO in the lungs has revolutionized our understanding of lung diseases and treatments. NO, produced by specific enzymes, helps widen blood vessels and relax airway muscles. It benefits conditions like pulmonary hypertension and can reduce inflammation. However, excessive NO can be detrimental to tissues and is linked to cancer, necessitating further research. Inhaled NO may assist in conditions like adult respiratory distress syndrome (ARDS) and asthma [7].

Particulate matter (PM) and polycyclic aromatic hydrocarbons (PAHs) pose health risks by entering the respiratory system and potentially causing cancer. PM, especially PM<sub>2.5</sub>, can lead to respiratory problems and increase the risk of heart diseases by inducing inflammation. High exposure to PM is associated with premature death, cognitive decline, and neurodegenerative diseases. PAHs, present in burnt organic materials, may cause mutations and impact lung health. Implementing policies, taking personal actions, and educating the public are crucial in reducing exposure and lowering health risks. Continued research aims to enhance our understanding of these pollutants [8].

PAHs are pollutants originating from burning organic materials like coal, oil, and wood, stemming from both human activities and natural sources such as wildfires. These toxic substances can cause mutations and cancer. Bioremediation utilizing bacteria and fungi can be beneficial. This review explores their environmental impact, sources, persistence, and health risks. PAHs can disrupt cell processes and weaken immunity. They enter the environment and can be broken down by microorganisms, light, or chemicals. Understanding PAHs is crucial in mitigating their health and environmental risks [9].

Asbestos fibers can lead to lung diseases depending on their type, size, and lung function.

Larger fibers tend to stay in larger airways, while smaller fibers can reach deeper areas. Some fibers, like crocidolite, can cause significant damage and lead to diseases such as asbestosis and lung cancer. They can stimulate cell growth in the pleura, potentially resulting in mesothelioma [10].

In the present study, we examined the emission of air pollutants based on statistics published by the Statistical Center of Iran on the energy balance sheet from 1997 to 2017, and we showed its changes.

## Materials and Methods

### Literature review

Initially, we conducted a review of keywords related to pollutants, including air pollutants such as  $\text{NO}_x$ ,  $\text{SO}_2$ ,  $\text{CO}_2$ ,  $\text{SO}_3$ ,  $\text{CO}$ ,  $\text{CH}_4$ , and SPM, using online databases such as Google Scholar and Scopus. We reviewed scientific literature and databases regarding air pollution.

### Data collection

Initially, we gathered data on air pollution statistics, specifically focusing on pollutant and greenhouse gas emissions from various sectors in Iran. This data included emissions in tons of pollutants such as  $\text{NO}_x$ ,  $\text{SO}_2$ ,  $\text{CO}_2$ ,  $\text{SO}_3$ ,  $\text{CO}$ ,  $\text{CH}_4$ , SPM, and  $\text{N}_2\text{O}$  from the domestic, commercial, public, and agricultural sectors between 1996 and 2017. The information was sourced from the database of the Statistical Center of Iran.

### Data distribution analysis

A one-sample Kolmogorov-Smirnov Test was used to analyze the normal distribution of the data. In this study focusing on pollutant and greenhouse gas emissions from the domestic and commercial sectors, it was found that the  $\text{CH}_4$  gas production rate variables were not normally distributed in these sectors. However, the other variables showed a normal distribution.

Similarly, in the agricultural sector analysis of pollutant and greenhouse gas emissions, it was observed that the  $\text{CH}_4$  gas production rate variable did not follow a normal distribution,

while the other variables exhibited normal distribution patterns [11].

### Descriptive and analytical statistics study

The descriptive study and comparison of greenhouse gas production in the domestic, commercial, and agricultural sectors from 1996 to 2017 was conducted using SPSS v27 software. The correlation between the productions of various greenhouse gases was investigated using the Pearson Correlation statistical test and Spearman's correlation test. The difference in the pollutants' concentrations between the domestic and commercial sectors, compared to the agricultural group, was investigated using the Independent Samples test and Mann-Whitney U test [11].

## Results and Discussion

### *The amount of pollutants and greenhouse gas emissions from the domestic, commercial, and public sectors is significant*

Our descriptive results show the amount of pollutant and greenhouse gas emissions from the domestic, commercial, and public sectors, as well as agriculture, measured in tons. The gas most produced was  $\text{CO}_2$ , which increased from 72,261,611 tons in 1996 to 139,254,025 tons in 2017 in the domestic, commercial, and public sectors, corresponding to population growth and national development. In the domestic and commercial sectors, the production of  $\text{NO}_x$  and SPM gases grew less than  $\text{CO}_2$  during the period from 1996 to 2017 (Table 1 and Figures 1 and 2).

$\text{NO}_x$  and SPM gases increased less than  $\text{CO}_2$  emissions from 1996 to 2017 in the domestic and commercial sectors. We must look into the emission trends and the factors that influence the production of these gases.  $\text{NO}_x$  are formed when fossil fuels burn at high temperatures in power plants, vehicles, and industrial processes [12,13]. They significantly contribute to smog and acid rain and can harm both the environment and human health. SPM consists of small solid or liquid particles in the air from various sources, including combustion,

construction, and dust storms, which can cause respiratory problems and health issues [14].

CO<sub>2</sub> is a greenhouse gas released from human activities like burning fossil fuels for energy, deforestation, and industrial activities. It is the main cause of global climate change as it traps heat in the atmosphere [15].

Energy consumption patterns indicate that the domestic sector mainly uses fossil fuels for heating, cooking, and power generation, contributing to CO<sub>2</sub> emissions. However, improvements in energy efficiency and cleaner fuel use can help reduce CO<sub>2</sub> emissions. The commercial sector also accounts for significant energy use, particularly for heating, lighting, and power, which are major CO<sub>2</sub> sources [15]. Technological advancements in the last few decades have led to developments in emission reduction technologies for both CO<sub>2</sub> and pollutants like NO<sub>x</sub> and SPM. For instance, catalytic converters and low-NO<sub>x</sub> burners have been introduced to lower NO<sub>x</sub> emissions, along with filters and other devices to reduce SPM emissions [14-16]. Regulatory measures from governments, such as the U. S. clean air act and the European Union's Emission Trading System, aim to limit pollutant emissions. These regulations mainly target pollutants with immediate health and environmental impacts, such as NO<sub>x</sub> and SPM, leading to a slower growth rate for these gases compared to CO<sub>2</sub> [16]. The economic growth often results in increased energy consumption and emissions, particularly in rapidly industrializing nations. However, service-oriented economies and increased digitalization may lead to a separation of CO<sub>2</sub> emissions from economic growth [17]. The energy mix is shifting towards renewable sources like wind and solar, which produce minimal emissions, but this shift can also make some reliance on fossil fuels necessary during peak demand times [17]. Previous studies suggest that a multi-faceted approach, including both traffic management and technological improvements in the transport sector, has contributed to the observed reductions. However, the occasional increases in pollutant levels highlight the need for vigilant monitoring and adaptive policy measures to ensure sustained improvements in air quality. Further research into the specific causes of the pollutant

level increases observed between 2004 and 2006, and also from 2009 could provide further insights into the effectiveness of current regulations and guide future policy development [18]. In the domestic and commercial sectors, there has been a significant decrease in the production of pollutant gases SO<sub>2</sub>, SO<sub>3</sub>, CO, CH<sub>4</sub>, and N<sub>2</sub>O compared to 1996. This reflects efforts to control air pollutants from 1996 to 2017. For instance, SO<sub>2</sub> production decreased from 202,557 tons in 1996 to 26,289 tons, while SO<sub>3</sub> dropped from 2,589 tons in 1996 to 255 tons in 2017. Between 1996 and 2017, Iran significantly reduced emissions of harmful gases like SO<sub>2</sub>, SO<sub>3</sub>, CO, and N<sub>2</sub>O. This improvement is due to various efforts, including regulatory, technological, and economic actions aimed at controlling air pollution. Although air quality has improved, ongoing monitoring of other pollutants and greenhouse gases is still necessary. Key points include a notable decrease in emissions of SO<sub>2</sub>, SO<sub>3</sub>, CO, and N<sub>2</sub>O, driven by cleaner energy, emission control technologies, regulatory standards, industrial efficiency, and economic changes. Specific strategies to reduce CO include stricter vehicle standards and enhanced industrial processes, while for N<sub>2</sub>O; the focus is on agricultural reforms and industrial upgrades [19]. Understanding the effectiveness of these emission reductions requires consideration of baseline emissions and the impact of other pollutants. Continuous monitoring is essential for verifying emission levels and assessing long-term health and environmental effects. Overall, the reductions achieved in Iran highlight the importance of sustained effort and broader attention on air quality improvement [20].

#### *The number of pollutants and greenhouse gas emissions from the agriculture sector is significant*

In the agricultural sector, CO<sub>2</sub> gas production increased from 11,646,976 tons in 1996 to 12,978,687 tons in 2017, which is not a significant increase. However, NO<sub>x</sub>, SO<sub>2</sub>, CH<sub>4</sub>, SO<sub>3</sub>, CO, SPM, and N<sub>2</sub>O decreased in 2017 compared

to 1996. This indicates better control of pollutants in the agricultural sector compared to the domestic and commercial sectors (Table 1).

CO<sub>2</sub> emissions increased by 1,331,711 tons, or roughly 11.4%, during this period, attributed to global population growth and increased food demand. The intensification of agricultural practices to meet this demand may have led to the rise in CO<sub>2</sub> emissions despite control measures. Changes in land use, like deforestation for agriculture, could have reduced carbon capture capacity, contributing to higher CO<sub>2</sub> levels. On a positive note, pollutants like NO<sub>x</sub>, SO<sub>2</sub>, CH<sub>4</sub>, CO, SPM, and N<sub>2</sub>O decreased. These reductions are likely due to technological advancements improving energy efficiency, adoption of sustainable agricultural methods like precision farming and better manure management, stricter environmental regulations promoting cleaner practices, and increased utilization of renewable energy sources [21,22].

The decline in certain pollutants could improve air quality, potentially reducing the risk of respiratory diseases and acid rain. However, the continuous increase in CO<sub>2</sub> emissions highlights the importance of ongoing efforts to address climate change in agriculture. The complex interactions between different greenhouse gases, each with varying atmospheric lifetimes, must be considered in a comprehensive evaluation of the sector's environmental impact [22,23].

This analysis emphasizes the need for specific policies to address environmental issues in agriculture. Incentives for climate-smart farming practices, investments in low-emission technologies, and promotion of soil health and carbon capture can help mitigate agricultural emissions. Encouraging reduced food waste and promoting more plant-based diets may also alleviate the environmental impact by reducing demand for resource-intensive livestock production [21-23].

The evaluation should adhere to the environmental science principles, focusing on atmospheric chemistry, nutrient cycles, and climate science. Understanding the sources and sinks of these gases, their atmospheric interactions, and how different farming practices affect emissions is essential for making informed decisions. For example, utilizing biochar can reduce CH<sub>4</sub> and N<sub>2</sub>O emissions, while integrating crop and livestock systems may enhance nutrient management and decrease overall emissions [24].

It is crucial to acknowledge the limitations of the data and uncertainties in emissions estimates. Changes in measurement methods, data gaps, and variations in farming practices can impact the accuracy of the analysis. Some emissions may be underreported due to the complexity of agriculture [21-24].

#### *Data distribution*

The results of the one-sample Kolmogorov-Smirnov Test indicated that only the CH<sub>4</sub> gas production variable across the domestic, commercial, public, and agricultural sectors did not have a normal distribution, while other air pollutants did. The K-S Test is a statistical tool that checks if a sample comes from a specific distribution, such as the normal distribution. The findings suggest that CH<sub>4</sub> gas production in these sectors does not follow a normal pattern and that production sharply decreased in a controlled manner after 2007 (Table 2).

The claim that CH<sub>4</sub> gas production sharply decreased in a controlled manner after 2007 requires detailed analysis for a proper understanding. CH<sub>4</sub> is a strong greenhouse gas with a much higher global warming potential than CO<sub>2</sub> over a century. It is mainly released through human activities such as fossil fuel extraction, agriculture, landfills, and wastewater treatment, as well as natural events like wetlands and wildfires [25].

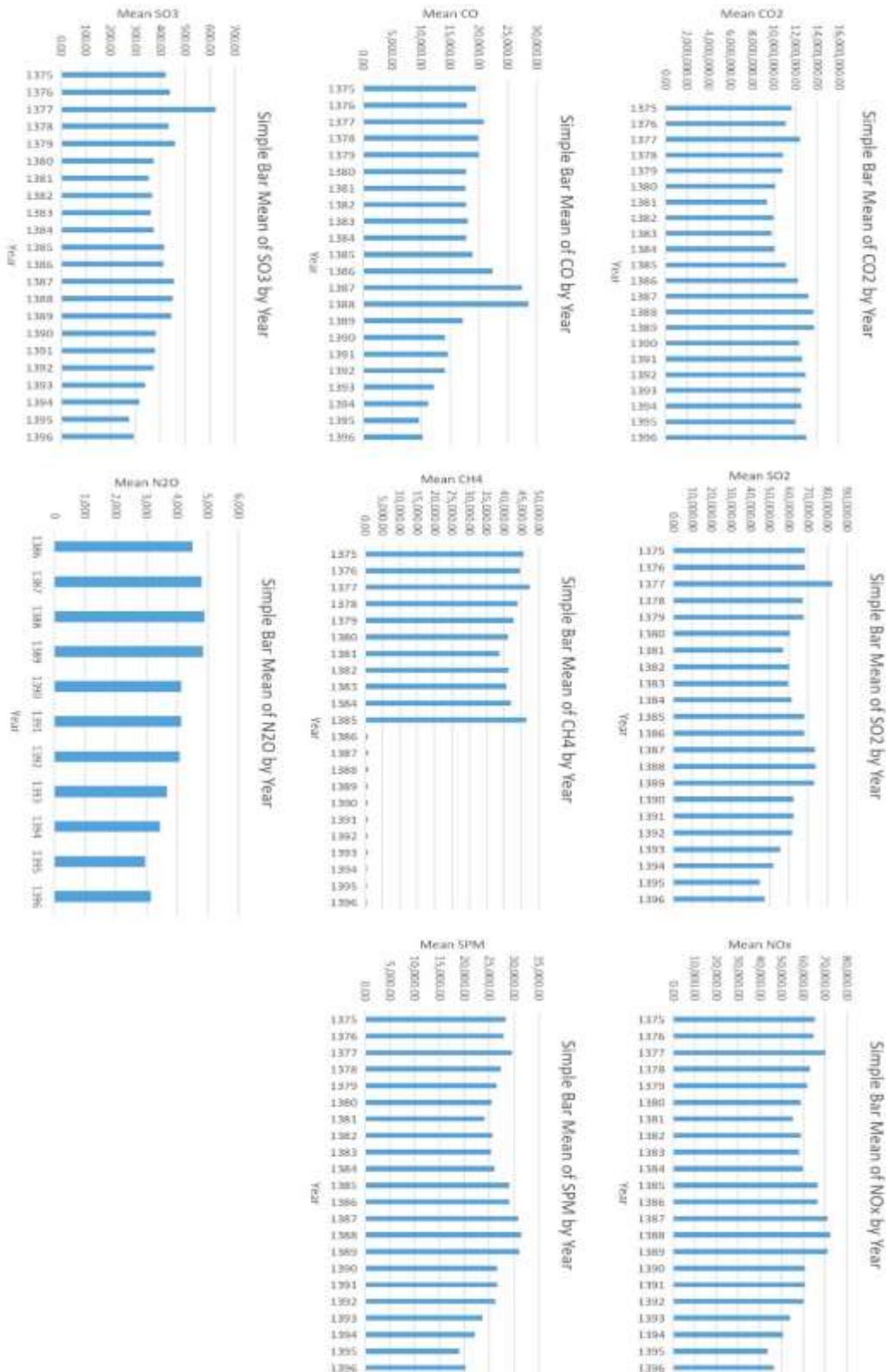
**Table 1:** Pollutants and greenhouse gas emissions from the domestic, commercial, public sectors, and agriculture sector



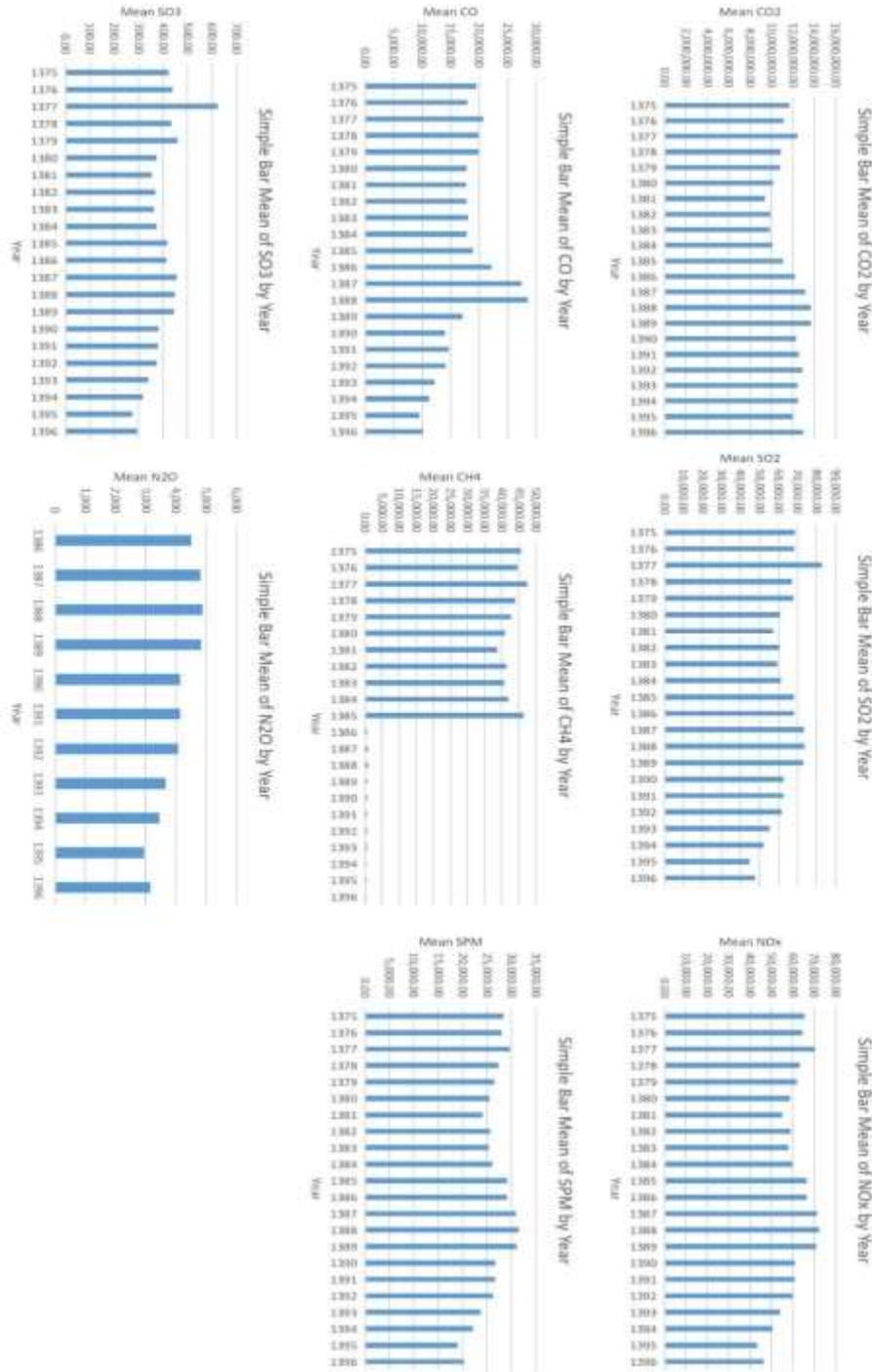
Year (Persian calendar)	NO <sub>x</sub>	SO <sub>2</sub>	CO <sub>2</sub>	SO <sub>3</sub>	CO	SPM	CH <sub>4</sub>	N <sub>2</sub> O
1383	1383	1384	1385	1386	1387	1388	1389	1390
58168	59898	66602	66599	71297	71297	72365	71174	60871
102344	107587	121164	130227	125663	125663	122915	119724	115934
59606	61370	68185	68065	73505	73505	73758	73105	62639
88260	86723	87244	144998	131633	131633	108508	95442	52887
9817952	10086878	11114290	12210019	13171237	13171237	13662214	13718063	12344301
107231678	111998352	125869250	142335125	135098420	135098420	138430655	133357597	136656129
363	373	415	414	457	457	449	444	381
939	934	956	1820	1647	1647	1325	1200	582
18044	17803	18968	22296	27439	27439	28545	17158	14128
72859	68082	71176	79796	67835	67835	55047	76435	47073
25347	26127	29072	29026	30956	30956	31487	31095	26593
10938	11355	12576	13506	13012	13012	11491	12000	11284
40754	41874	46453	726	805	805	827	741	642
12329	11513	11854	4246	4062	4062	4045	3827	3786
-	-	-	4508	4804	4804	4889	4834	4136
-	-	-	594	566	566	551	507	484

Year (Persian calendar)		NO <sub>x</sub>	SO <sub>2</sub>	CO <sub>2</sub>	SO <sub>3</sub>	CO	SPM	CH <sub>4</sub>	N <sub>2</sub> O
	Agriculture								
	Domestic, commercial								
1396		1391							
46306	Agriculture	60900							
118398	Domestic, commercial	107302							
47675	Agriculture	62542							
26289	Domestic, commercial	53774							
12978687	Agriculture	12612274							
139254025	Domestic, commercial	127626346							
293	Agriculture	380							
255	Domestic, commercial	614							
10227	Agriculture	14690							
45706	Domestic, commercial	45552							
20237	Agriculture	26607							
11596	Domestic, commercial	10517							
544	Agriculture	649							
4141	Domestic, commercial	4019							
3152	Agriculture	4138							
509	Domestic, commercial	518							
		1392							
		60110							
		116644							
		61659							
		50646							
		12937229							
		138205055							
		1393							
		54004							
		115371							
		55519							
		37505							
		12474815							
		137269757							
		1394							
		50638							
		116893							
		51959							
		30076							
		12522887							
		139504993							
		1395							
		43483							
		127671							
		44795							
		38418							
		11966481							
		149008521							
		275							
		429							
		9594							
		52083							
		19000							
		12448							
		507							
		4348							
		2959							
		534							
		517							
		522							
		537							
		4087							
		487							
		4233							
		644							
		649							
		4019							
		4138							
		518							

(Source: Energy balance sheet, ministry of energy, deputy for electricity and energy affairs [1,2]).  
 "-": Line mean that no data are available for them.



**Figure 1:** The pollutants and greenhouse gas emissions from the domestic, commercial, and public sectors, with years presented in the Persian calendar format [1,2].



**Figure 2:** The pollutants and greenhouse gas emissions from the agriculture sector, with years presented in the Persian calendar format [1,2].

Fossil fuel extraction and use contribute substantially to CH<sub>4</sub> emissions, as it is a byproduct of oil and natural gas production. While increased drilling can lead to more emissions, advancements in technology and

stricter regulations can reduce CH<sub>4</sub> leaks. After 2007, some regions made efforts to capture and lower CH<sub>4</sub> emissions from oil and gas operations, leading to decreased emissions in places like the U.S. [26].



Agriculture is another major source of CH<sub>4</sub>, particularly from livestock and rice cultivation. Improved farming practices could help reduce these emissions, but global trends towards higher meat consumption and rice production may negate these improvements [27]. Better waste management strategies, including better capture of landfill gas for energy, can lead to lower CH<sub>4</sub> emissions too. Many regions may have introduced tougher regulations or new technologies after 2007 to lower emissions from waste management [28]. Climate policies and regulations have been developed globally, especially following the Paris Agreement, prompting nations to implement measures to cut CH<sub>4</sub> emissions. Economic conditions, like the 2008 financial crisis, can temporarily reduce industrial activities, thus potentially lowering emissions [28]. The natural gas boom in the U. S. post-2007 leads to the increased natural gas usage. Though this could raise CH<sub>4</sub> emissions, the overall move from coal to natural gas has lowered greenhouse gas emissions due to the cleaner burning of natural gas [29]. The information emphasizes the urgent need to reduce human-caused CH<sub>4</sub> emissions to combat climate change. CH<sub>4</sub> is a potent greenhouse gas, contributing significantly to global warming since the pre-industrial era. Emissions have risen rapidly since 2006, making it difficult to achieve the Paris Agreement goals. Immediate action is crucial, as CH<sub>4</sub> is expected to continue increasing through the 2020s. Reducing CH<sub>4</sub> can quickly decrease warming, and effective land management and fossil fuel transition are essential strategies. Urgent and significant reductions in CH<sub>4</sub> are needed, with strong policies to support cost-effective measures that also improve air quality. Global efforts must focus on monitoring and reducing emissions from agriculture, oil and gas, and waste management [25].

#### *Mean comparison of pollutant production rates*

A statistical comparison of air pollutant production rates between the domestic and commercial sectors and the agricultural sector was conducted using the Independent-Samples Mann-Whitney U test for data with a non-normal distribution and the Independent-Samples test

for data with a normal distribution. The results showed no significant difference for any of the studied indicators.

#### *Correlation among the variables studied in the domestic, commercial, public, and agricultural sectors*

In both areas of study, including the production of air pollutants in the domestic, commercial, public, and agricultural sectors, the correlation statistics were nearly identical. The year index showed a positive correlation with CO<sub>2</sub> pollutant gas production, indicating that more CO<sub>2</sub> gas was produced in the final years of the study compared to the initial years, in line with population growth during that time. In contrast, the year index had a negative correlation with the production of other pollutant gases in our study, as determined by the Pearson Correlation test for indicators with a normal distribution and the Spearman's correlation test for indicators with a non-normal distribution.

This suggests a decrease in pollutant gas production over time, indicating progress towards cleaner air. The CO<sub>2</sub> gas production index demonstrated a significant inverse correlation with the CH<sub>4</sub> gas production index ( $r = -0.518, p = 0.018$ ).

The pollutant production indices of NO<sub>x</sub>, SO<sub>2</sub>, CO<sub>2</sub>, SO<sub>3</sub>, CO, SPM, and N<sub>2</sub>O showed positive correlations with each other, although in some cases, these correlations were not significant (Tables 3 and 4).

The analysis indicates that the production of air pollutants in the domestic, commercial, public, and agricultural sectors exhibit similar correlations over time, with the year index playing a crucial role in these correlations. The positive correlation between the year index and production reflects the increase in CO<sub>2</sub> emissions alongside population growth, consistent with rising energy consumption and industrial activity [15-17].

In contrast, the negative correlation of the year index with the production of other pollutant gases suggests that emission reduction efforts have had a tangible impact over time. This encouraging trend may be attributed to various factors, including stricter environmental

regulations, technological advancements, and the adoption of cleaner energy sources [18].

**Table 3:** Pearson correlation that was calculated between air pollutant indices and other variables that exhibited a normal distribution as per the one-sample Kolmogorov-Smirnov test

		Year	N <sub>2</sub> O	SPM	CO	SO <sub>3</sub>	CO <sub>2</sub>	SO <sub>2</sub>
NO <sub>x</sub>	Pearson correlation	-0.489*	1.000**	0.998**	0.837**	0.834**	0.228	0.966**
	Sig. (2-tailed)	0.021	0.000	0.000	0.000	0.000	0.308	0.000
	N	22	11	22	22	22	22	22
SO <sub>2</sub>	Pearson correlation	-0.574**	1.000**	0.947**	0.796**	0.948**	0.198	
	Sig. (2-tailed)	0.005	0.000	0.000	0.000	0.000	0.377	
	N	22	11	22	22	22	22	
CO <sub>2</sub>	Pearson correlation	0.582**	0.632*	0.238	0.018	0.151		
	Sig. (2-tailed)	0.005	0.037	0.287	0.936	0.504		
	N	22	11	22	22	22		
SO <sub>3</sub>	Pearson correlation	-0.610**	0.997**	0.797**	0.681**			
	Sig. (2-tailed)	0.003	0.000	0.000	0.000			
	N	22	11	22	22			
CO	Pearson correlation	-0.529*	0.860**	0.832**				
	Sig. (2-tailed)	0.011	0.001	0.000				
	N	22	11	22				
SPM	Pearson correlation	-0.459*	1.000**					
	Sig. (2-tailed)	0.032	0.000					
	N	22	11					
N <sub>2</sub> O	Pearson correlation	-0.926**						
	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 4:** Spearman's correlation between the CH<sub>4</sub> index and the studied other variables

	Spearman's correlation	NO <sub>x</sub>	SO <sub>2</sub>	CO <sub>2</sub>	SO <sub>3</sub>	CO	SPM	N <sub>2</sub> O	Year
CH <sub>4</sub>	Correlation Coefficient	0.521*	0.580**	-0.501*	0.606**	0.688**	0.495*	0.982**	-0.914**
	Sig. (2-tailed)	0.013	0.005	0.018	0.003	0.000	0.019	0.000	0.000
	N	22	22	22	22	22	22	11	22

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

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

The correlation analysis between the year index and pollutant production rates suggests a positive trend for CO<sub>2</sub>, which aligns with the general understanding of increased emissions due to growing energy consumption and industrial activities. In contrast, the negative correlations for other gases such as N<sub>2</sub>O, SO<sub>2</sub>, CO, and SPM imply that emission reduction efforts may have had some effect over the study period. However, the lack of significant correlation between the sectors for these pollutants indicates that the differences in production rates may not be solely attributable to sector-specific activities [19, 20].

The interrelationships between the pollutants, as indicated by their correlation coefficients,

likely stem from common sources and formation processes, particularly combustion. For example, significant positive correlations between CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub>, CO, and SPM suggest a shared origin from burning fossil fuels. These findings underscore the complexity of air pollution and the importance of considering the multifaceted nature of the problem [21-25].

Addressing CO<sub>2</sub> emissions requires a combination of strategies, including energy efficiency, renewable energy adoption, carbon capture technologies, and changes in individual behaviors. Similarly, tackling PM, SO<sub>2</sub>, and CO involves implementing stricter emission standards for vehicles and industrial processes, promoting cleaner energy sources, and

enhancing public awareness and monitoring efforts [26-29].

For NO<sub>x</sub>, solutions include installing catalytic converters in vehicles, using low-NO<sub>x</sub> burners, and enforcing stringent emission standards in power plants and other industrial sources. Additionally, promoting electric vehicles and alternative fuels can significantly reduce NO<sub>x</sub> emissions [28,29]. The significant inverse correlation between CO<sub>2</sub> and CH<sub>4</sub> production indices ( $r = -0.518$ ,  $p = 0.018$ ) is noteworthy. This suggests that as CO<sub>2</sub> emissions increase, CH<sub>4</sub> emissions tend to decrease. This could be due to changes in energy consumption patterns, such as a shift from fossil fuels with higher CH<sub>4</sub> content (like natural gas) to those with higher CO<sub>2</sub> emissions (like coal or oil). Alternatively, it may indicate improvements in CH<sub>4</sub> capture or mitigation strategies in certain sectors, such as landfills or livestock management practices. CH<sub>4</sub> emissions can be mitigated through better management of landfills, agricultural practices, and fossil fuel extraction [28,29]. The positive correlation between pollutant production indices of NO<sub>x</sub>, SO<sub>2</sub>, CO<sub>2</sub>, CO, SO<sub>3</sub>, and SPM is consistent with the common sources of these pollutants, particularly in the context of combustion processes. Fossil fuel combustion in power plants, vehicles, and industrial processes typically results in the production of multiple pollutants. For instance, coal and oil combustion can release both CO<sub>2</sub> and SO<sub>2</sub>, while traffic emissions contribute to NO<sub>x</sub> and SPM [5-8]. N<sub>2</sub>O reduction requires a focus on agricultural practices, industrial processes, and wastewater treatment. Reducing SO<sub>2</sub> emissions involves implementing flue gas desulfurization technology in power plants, switching to low-sulfur fuels, and enforcing emission standards for industrial activities [12-15].

However, it is important to consider the specific context and sources of each pollutant when interpreting these correlations. For example, while CO<sub>2</sub> emissions are primarily a concern for climate change, other pollutants like NO<sub>x</sub>, SO<sub>2</sub>, and SPM have direct health implications due to their role in forming smog and acid rain. Thus, while a reduction in these gases is beneficial for overall air quality, the relationships between them may be complex and influenced by various sector-specific factors

[12-15]. The outcomes of this study underscore the intricate interplay between various pollutants and the sectors contributing to their production. To effectively manage and reduce the health risks associated with these toxins, comprehensive strategies are necessary. These strategies should be informed by continuous research and monitoring to ensure they are tailored to the specific context and effectively address the complex nature of air pollution [28-34]. Spearman's correlation analysis between the variables of the studied groups (domestic and commercial versus agricultural) showed no correlation with all the pollution indices studied ( $r = 0.00$ ,  $p = 1.00$ ). This result was consistent with the analysis of the difference in pollutant concentrations between the two groups based on the Independent Samples Test and Mann-Whitney U test.

## Conclusion

In our study, we found that the domestic sector heavily relies on fossil fuels, and improving energy efficiency is necessary to reduce emissions. Government regulations play a crucial role in minimizing pollutants that pose health risks, and while renewable energy usage is increasing, fossil fuels are still necessary at times. In agriculture, CO<sub>2</sub> emissions experienced a slight increase from 1996 to 2017, while NO<sub>x</sub> and other pollutants decreased due to technological advancements. Continuous monitoring and specific policies for agricultural emissions are important. Our study reveals emissions from various sectors, indicating no significant differences in pollutant production rates. The present study emphasizes the importance of integrated approaches that consider broader environmental and economic factors that influence pollutant production. Future research should focus on refining these strategies and enhancing our understanding of the health impacts of air pollution to better protect public health and the environment in both developed and developing countries.

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## Conflict of Interest

There are no conflicts of interest in the current study.

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