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Trends in Air Pollutants in Iran (2006-2023) and Comparative Analysis of Global CO_2 Emissions (2000-2022/2023)

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Abstract

This study presents a comprehensive analysis of air pollutant trends in Iran from 2006 to 2023 and a comparative examination of carbon dioxide (CO_2) emissions across Iran, the United States, Canada, and the United Kingdom from 2000 to 2022. By focusing on greenhouse gases (CO_2, CH_4, N_2O), suspended particulate matter (SPM), hydrocarbons (HC), sulfur oxides (SOx), nitrogen oxides (NOx), and carbon monoxide (CO), the research reveals statistically significant increases in most pollutants in Iran over the examined period. Utilizing rigorous statistical methods including the Kolmogorov-Smirnov test, Levene's test, Brown-Forsythe test, and Dunnett's T3, the study confirms significant temporal and interregional differences. The findings of this study revealed underscore transportation as a major contributor to emissions, both in Iran and globally, highlighting urgent needs for mitigation strategies in sectors such as transport, waste management, and energy. This dual-focus analysis provides crucial insights into local pollutant dynamics and positions Iran's emission trends within broader global patterns, offering evidence-based recommendations for environmental policy reform.

Keywords

Air Pollution, Greenhouse Gases, Iran, CO_2 Emissions, Comparative Analysis, Transportation Emissions, Statistical Analysis, Climate Change, SPM, Policy Recommendations

1. Introduction

This study combines an analysis of air pollutant trends in Iran (2006-2023) with a comparative analysis of CO_2 emissions across Iran, the United States, Canada, and the United Kingdom (2000-2022). Air pollution poses a significant global challenge, with transportation being a major contributor to deteriorating air quality and climate change. Globally, the transportation sector accounts for approximately 32% of CO2 emissions and 27% of total greenhouse gases (GHGs) [1]. In regions like the European Union, road transport consumes 81% of the sector's energy and generates over 72% of its GHG emissions, far outpacing contributions from air (13.3%), marine (12.8%), and rail (0.5%) transport [1]. Similarly, transportation consumes nearly half of all fossil fuels worldwide, contributing about one-quarter of CO_2 emissions from fossil fuel combustion [2]. Notably, while Canadians constitute only 0.5% of the global population, Canada's share of global GHG emissions is approximately 2% [3]. However, between 1990 and 2010, while Canada's per capita GHG emissions decreased by nearly 5%, its total GHG emissions grew by 17% [3]. In the United States, transportation has surpassed the power sector since 2016 to become the leading GHG emitter [4], with passenger light-duty vehicles alone responsible for nearly 60% of the sector's emissions [4]. These statistics underscore transportation's critical role in global emissions, a focus central to this study's examination of air pollutants in Iran and CO_2 trends across Iran, the United States, Canada, and the United Kingdom.

Transportation's environmental footprint extends beyond CO_2, encompassing a suite of air pollutants—CH_4, N_2O, HC, SOx, NOx, CO, and particulate matter (SPM)—that threaten both climate stability and public health. Road transport, in particular, dominates emissions profiles [5], contributing roughly 20% of global CO_2 emissions [5]. In India, for example, motorized traffic is projected to increase energy demand and carbon emissions fivefold by 2020 from 2000 levels [2]. Exacerbated by traffic congestion that amplifies emissions through increased fuel use during idling and stop-and-go conditions [2]. Unlike the power sector, which has curbed emissions via renewable energy shifts [4], transportation faces persistent barriers, including regulatory inconsistencies [4] and the lack of widespread GHG-free fuel alternatives [4]. Understanding these patterns and variations over time is essential for crafting effective mitigation strategies. Such long-term analyses are crucial for understanding the evolving environmental landscape in rapidly industrializing nations, particularly where the interplay of economic growth and environmental policy can lead to complex emission dynamics.

This study's primary objective is to assess changes in air pollutant concentrations and identify significant trends across these regions and periods. For Iran, we analyzed greenhouse gases (CO_2, CH_4, N_2O) alongside SPM, HC, SOx, NOx, and CO from 2006 to 2023, revealing notable increases, particularly in GHGs. For the broader comparison, we reviewed CO_2 emissions from 2000 to 2022 across four nations, highlighting transportation's role in shaping these trends. To ensure robust analysis, we employed a rigorous statistical methodology. Data normality was confirmed using the Kolmogorov-Smirnov test, followed by Levene's test to assess variance equality. Where variances were unequal (sig < 0.05), the Brown-Forsythe test was applied, and Dunnett's T3 test facilitated mean comparisons, providing a solid foundation for evaluating pollutant variations across timeframes and regions. This dual focus on Iran's diverse pollutants and multi-national CO_2 trends addresses the urgent need to mitigate transportation-related emissions, offering insights into both local and global environmental challenges.

This study's methodology was designed to rigorously analyze air pollutant gases in Iran from 2006 to 2023 and CO_2 emissions across Iran, the United States, Canada, and the United Kingdom from 2000 to 2022, ensuring a comprehensive and statistically robust evaluation. The approach encompasses data collection from diverse, credible sources and employs a combination of statistical tests and comparative emission estimation techniques to validate findings and contextualize transportation's role in emission trends.

2. Data Collection

To conduct a comprehensive analysis of air pollutant trends, data were meticulously collected from reputable platforms and official national and international records. The datasets encompassed a broad spectrum of air pollutants, including greenhouse gases (GHGs: CO_2, CH_4, N_2O), sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), and suspended particulate matter (SPM), as well as general CO_2 emissions.

For the analysis of air pollutant concentrations in Iran, annual data spanning from 2006 to 2023 were acquired. This dataset comprised yearly concentrations of GHGs (CO_2, CH_4, N_2O), SOx, NOx, CO, and SPM. For the broader comparative analysis of CO_2 emissions, yearly total data for Iran, the United States, Canada, and the United Kingdom were collected covering the period from 2000 to 2022.

The data collection relied on the following key sources:

- Kaggle: This platform provided access to a variety of publicly available environmental datasets, which included air quality metrics and historical emissions records.
- Worldometer: This source was utilized for real-time and updated statistics on various environmental indicators, particularly for general CO_2 emissions data.
- Official Government and Environmental Agencies: To ensure accuracy and authority, national records were obtained directly from environmental and

statistical bodies within Iran, the United States, Canada, and the United Kingdom. These sources provided crucial official data that grounded the analysis.

Collectively, these diverse and credible sources enabled a robust multi-national comparison, leveraging both open-access platforms and authoritative governmental data to effectively reflect the influences of transportation, industrial activities, and other sectors on emission trends over the specified periods.

3. Data Analysis/Result

This section systematically outlines the statistical methodologies applied and presents the key findings derived from the analysis of air pollutant trends in Iran and comparative CO_2 emissions across multiple nations.

3.1. Overall Comparison of Air Pollutants in Iran (2006-2023)

3.1.1. Statistical Methodology

Prior to the main analyses, data normality was assessed using the Kolmogorov-Smirnov test, which confirmed that the datasets met the condition of normality. Levene's test was employed to examine the homogeneity of variances. As the result indicated unequal variances (sig < 0.05), the Brown-Forsythe test was used for robust variance comparison, and Dunnett's T3 test was subsequently applied for post-hoc mean comparisons.

The overall hypothesis for this comparison was:

- **Null Hypothesis (H0):** There is no statistically significant difference among air polluting gases in Iran.
- **Alternative Hypothesis (H1):** There is a statistically significant difference among air polluting gases in Iran.

3.1.2. Results

The Brown-Forsythe test was conducted to compare the overall means of different air pollutants in Iran between 2006 and 2023.

As shown in **Table 1**, the calculated test statistic is significant ($p < 0.001$). This indicates that the null hypothesis is rejected, and the alternative hypothesis is accepted, confirming with 95% confidence that there is a statistically significant difference among the mean concentrations of air pollutants in Iran over the study period.

Table 1. Brown-forsythe test results for overall comparison of air pollutants in Iran (2006-2023).

Test type	Statistical value	The significance of the test
Brown-Forsythe	1778.31	<0.001

Further mean comparisons of each air pollutant were conducted using the Dunnett T3 test, as detailed in **Table 2**.

Table 2. Mean comparison of air polluting gases in Iran using Dunnett T3 test (2006-2023).

Air Polluting Gases	Mean	Mean Comparison
Greenhouse Gases	188.33	d
SPM	264.12	c
CH_4	52.50	G
N_2O	23.92	H
HC	2150.61	A
SOx	102.22	F
NOx	1814.94	B
CO	2050.36	A
CO_2	111.91	E

Categories sharing the same letter in the "Mean Comparison Category" column do not exhibit a statistically significant difference in their mean values, whereas categories with different letters indicate a statistically significant difference. For instance, HC (Category A) and CO (Category A) do not differ significantly from each other, and both represent the highest average values. Conversely, CO_2 (Category E) shows a statistically significant difference from SOx (Category F) as they do not share common letters. Visual representations of annual trends for each pollutant gas from 2006 to 2023 are presented in the subsequent figures (**Figures 1-9**).

The graphs of each air polluting gas, separated by calendar year, are shown below.

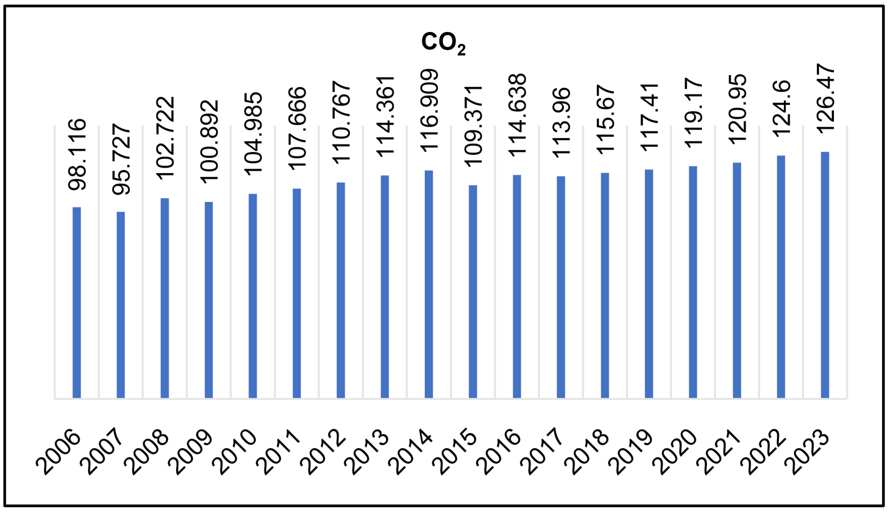

Figure 1. CO_2 emissions in Iran (2006-2023).

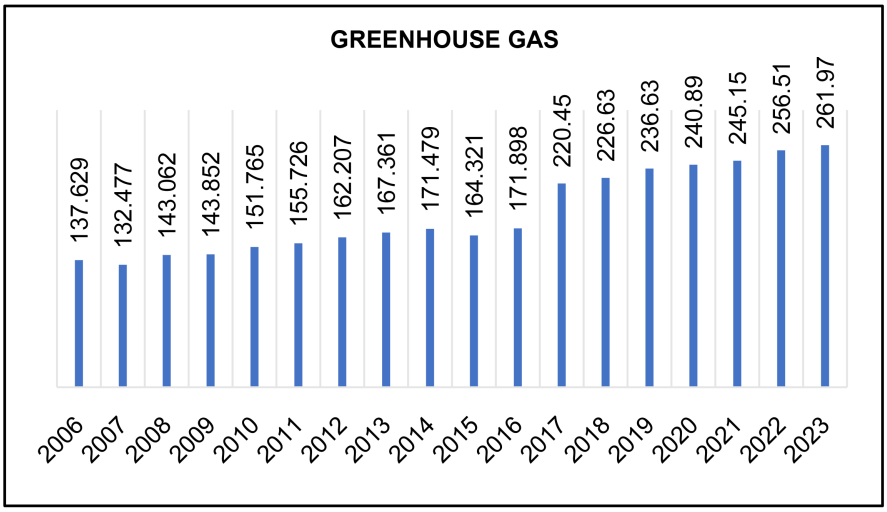

Figure 2. Greenhouse gas emissions in Iran (2006-2023).

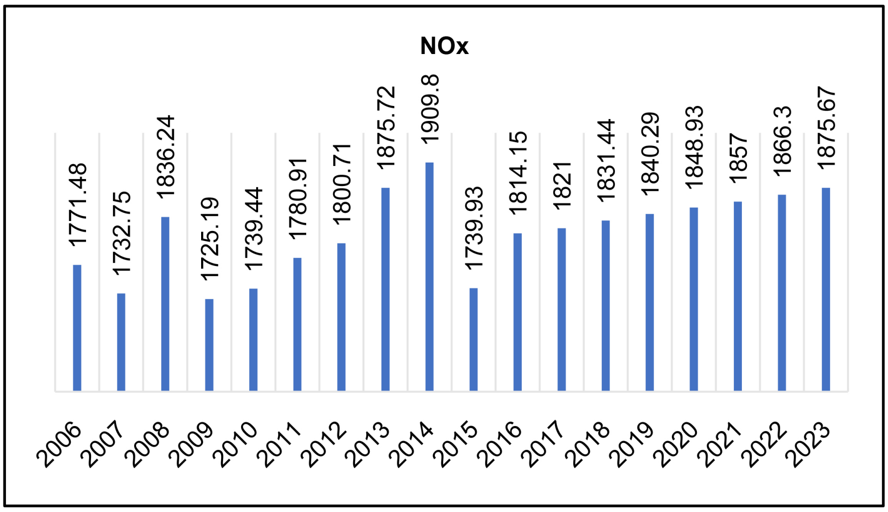

Figure 3. NOx emissions in Iran (2006-2023).

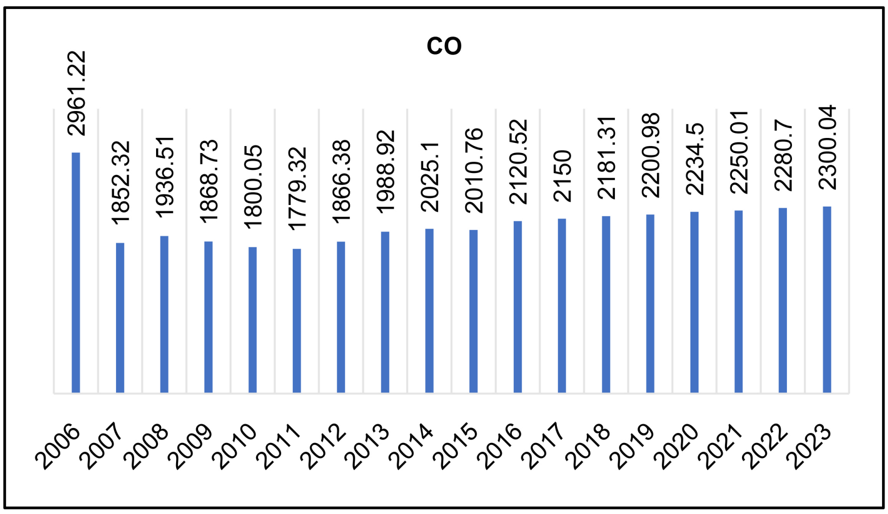

Figure 4. CO emissions in Iran (2006-2023).

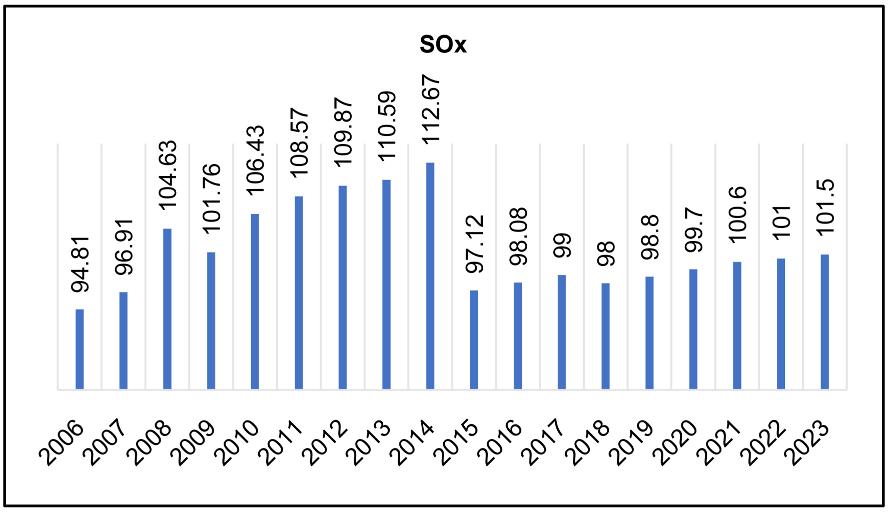

Figure 5. SOx emissions in Iran (2006-2023)

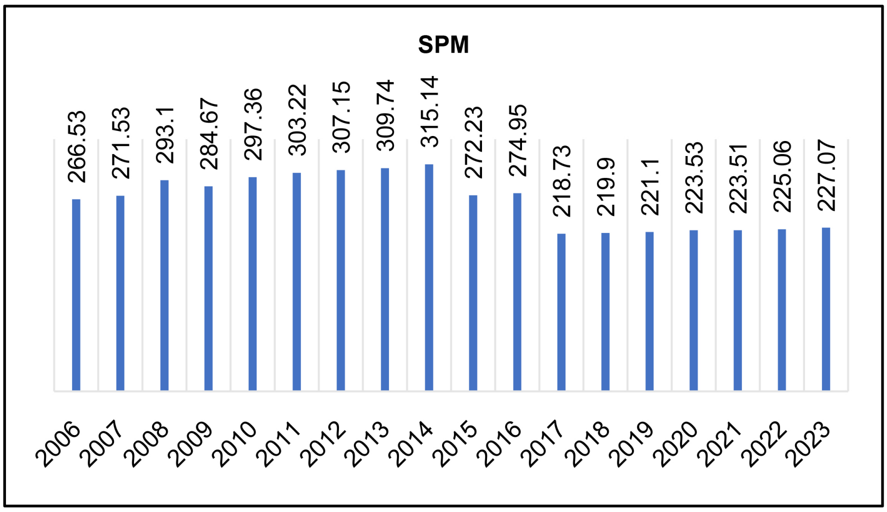

Figure 6. SPM emissions in Iran (2006-2023).

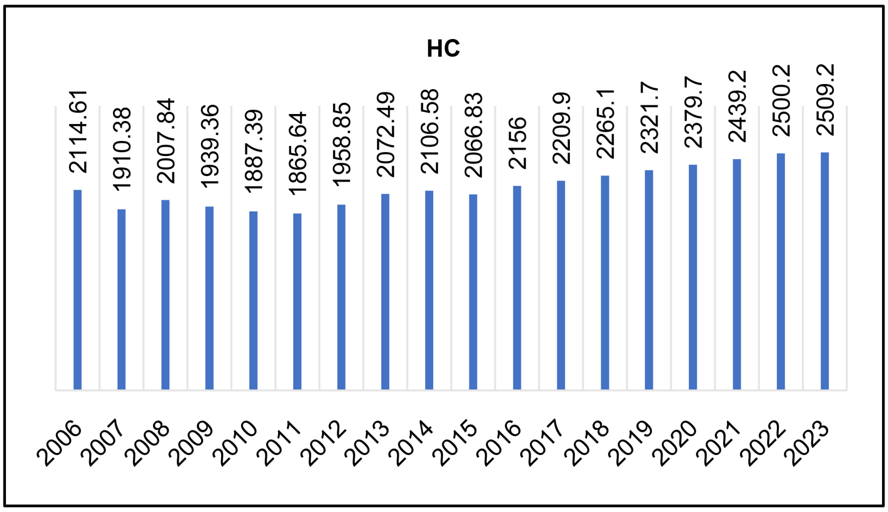

Figure 7. Annual HC emissions in Iran (2006-2023).

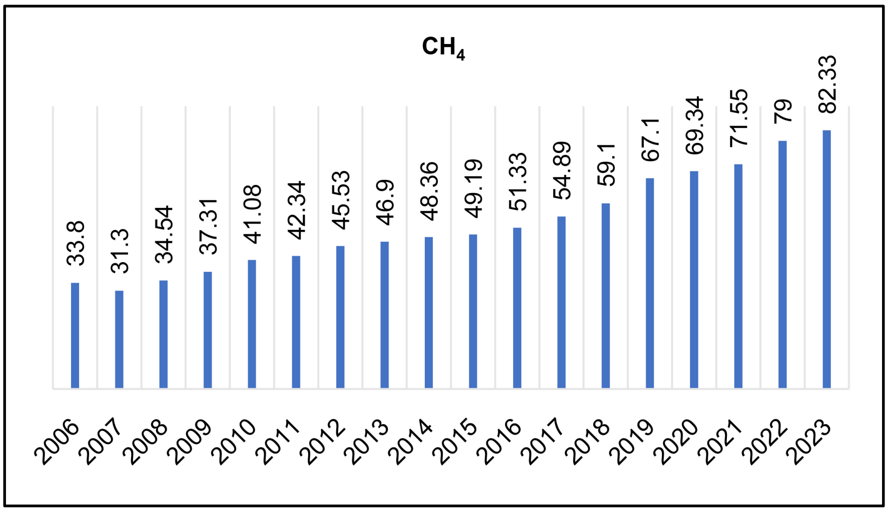

Figure 8. Annual CH_4 emissions in Iran (2006-2023).

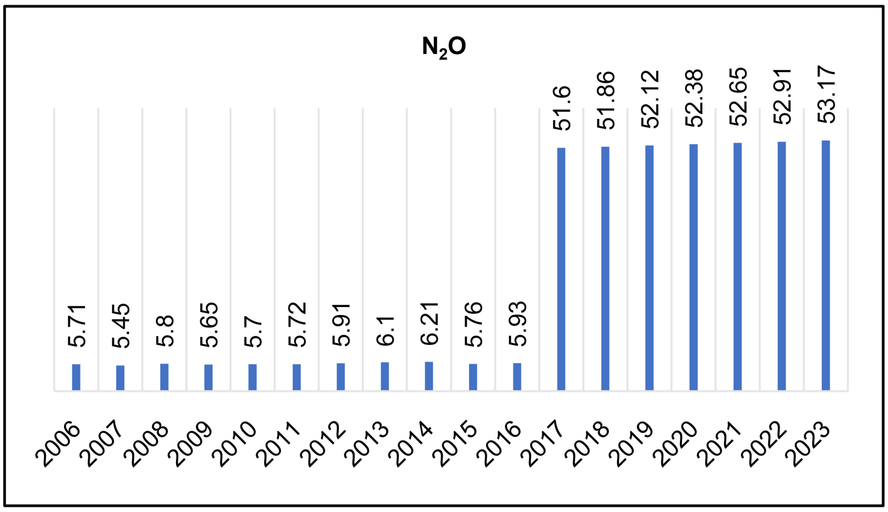

Figure 9. Annual N_2O emissions in Iran (2006-2023).

3.2. Comparison of Individual Pollutant Trends in Iran (2006-2014 vs. 2015-2023)

For each individual air pollutant, a comparison was performed between two distinct time periods: 2006 to 2014 and 2015 to 2023. Normality of data was confirmed by the Kolmogorov-Smirnov test. Homogeneity of variances was assessed using Levene's test, and if violated (sig < 0.05), the Brown-Forsythe test and Dunnett's T3 test were applied. If variances were equal (sig > 0.05), an independent samples t-test was used.

3.2.1. Greenhouse Gas Emissions

Null Hypothesis (H0): The production of greenhouse gases was the same in the two time periods: 2006 to 2014 and 2015 to 2023.

Alternative Hypothesis (H1): The production of greenhouse gases was not the same in the two time periods: 2006 to 2014 and 2015 to 2023.

As shown in **Table 3**, the test statistic is significant ($p < 0.001$). This indicates that the null hypothesis is rejected, and the alternative hypothesis is accepted, confirming with 95% confidence that the production of greenhouse gases was not the same in the two time periods. Furthermore, it was higher in the second 9-year period (**Figure 10**).

Table 3. Comparison of greenhouse gas emissions over two time periods (2006-2014 vs. 2015-2023).

Years Studied	Number	Mean	Statistic t	Significance of the Test
2006 to 2014	9	151.73	−5.88	<0.001
2015 to 2023	9	224.94		

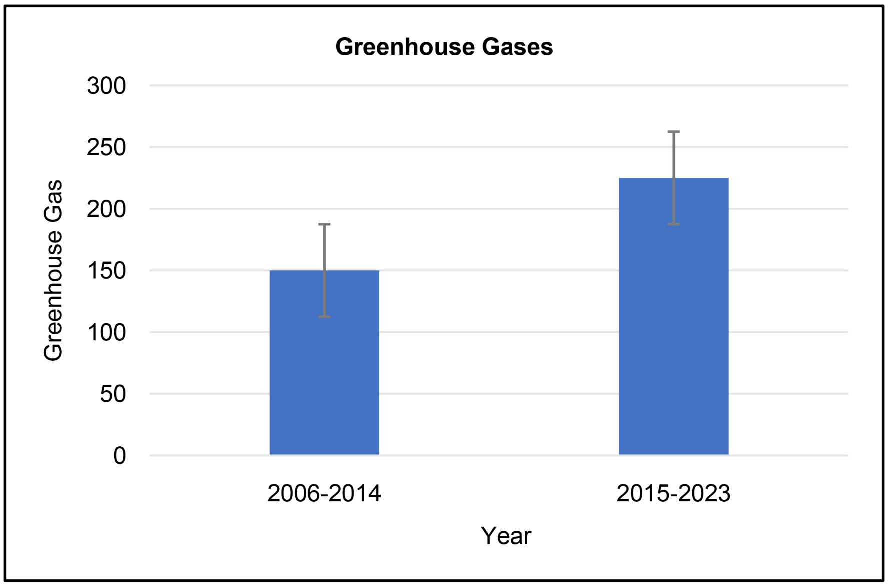

Figure 10. Comparison of greenhouse gas emissions between 2006-2014 and 2015-2023 in Iran.

3.2.2. Suspended Particulate Matter (SPM) Emissions

Null Hypothesis: The production of SPM was the same in the two time periods: 2006 to 2014 and 2015 to 2023.

Alternative Hypothesis: The production of SPM was not the same in the two time periods: 2006 to 2014 and 2015 to 2023.

Table 4. Comparison of SPM emissions over two time periods (2006-2014 vs. 2015-2023).

Years Studied	Number	Mean	Statistic t	Significance of the Test
2006 to 2014	9	294.24	6.40	<0.001
2015 to 2023	9	234.00		

As shown in **Table 4**, the test statistic is significant ($p < 0.001$), leading to the rejection of the null hypothesis. This indicates that SPM production was not the same between 2006-2014 and 2015-2023, with significantly higher production observed in the earlier period (**Figure 11**).

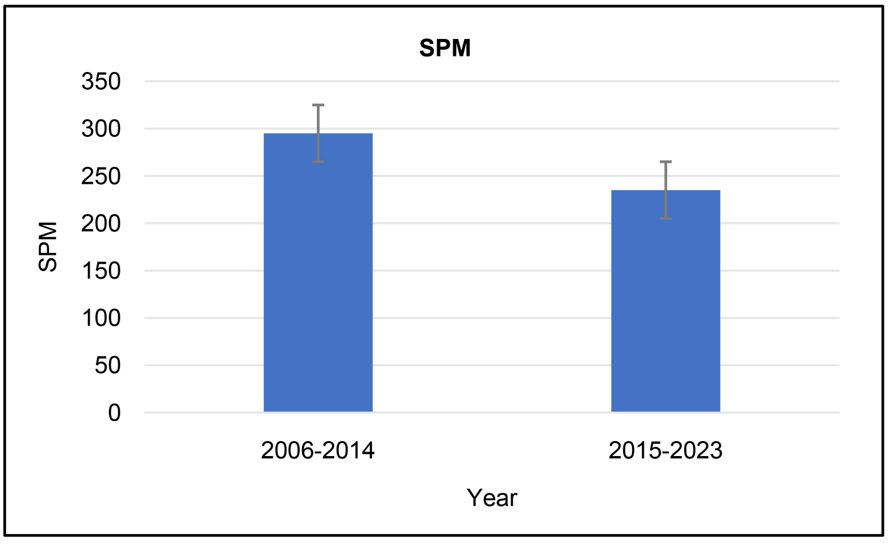

Figure 11. Comparison of SPM emissions between 2006-2014 and 2015-2023 in Iran.

3.2.3. Methane (CH_4) Emissions

Table 5. Comparison of CH_4 emissions over two time periods (2006-2014 vs. 2015-2023).

Years Studied	Number	Mean	Statistic t	Significance of the Test
2006 to 2014	9	40.13	−5.53	<0.001
2015 to 2023	9	64.87		

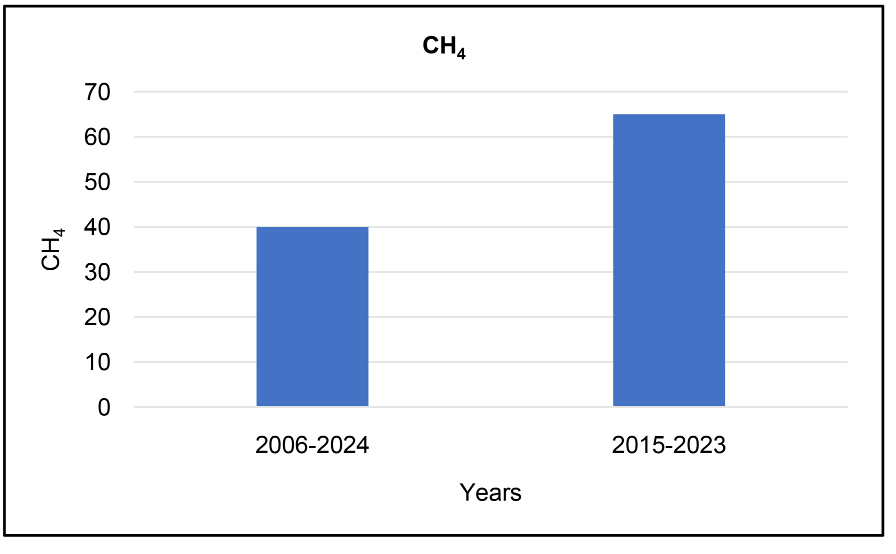

Figure 12. Comparison of CH_4 emissions between 2006-2014 and 2015-2023 in Iran.

Null Hypothesis: CH_4 production was the same in the two time periods of 2006-2014 and 2015-2023.

Alternative Hypothesis: CH_4 production was not the same in the two time periods of 2006-2014 and 2015-2023.

As shown in Table 5, the test statistic is significant ($p < 0.001$). This indicates that the null hypothesis is rejected, and the alternative hypothesis is accepted, confirming with 95% confidence that CH_4 production was not the same in the two time periods. Furthermore, it was higher in the second nine-year period (Figure 12).

3.2.4. Nitrous Oxide (N_2O) Emissions

Null Hypothesis: N_2O production was the same in the two time periods of 2006-2014 and 2015-2023.

Alternative Hypothesis: N_2O production was not the same in the two time periods of 2006-2014 and 2015-2023.

As shown in Table 6, the test statistic is significant ($p < 0.001$). This indicates that the null hypothesis is rejected, and the alternative hypothesis is accepted, confirming with 95% confidence that N_2O production was not the same in the two time periods. Furthermore, it was higher in the second nine-year period (Figure 13).

Table 6. Comparison of N_2O emissions over two time periods (2006-2014 vs. 2015-2023).

Years Studied	Number	Mean	Statistic t	Significance of the Test
2006 to 2014	9	5.80	−5.30	<0.001
2015 to 2023	9	42.04		

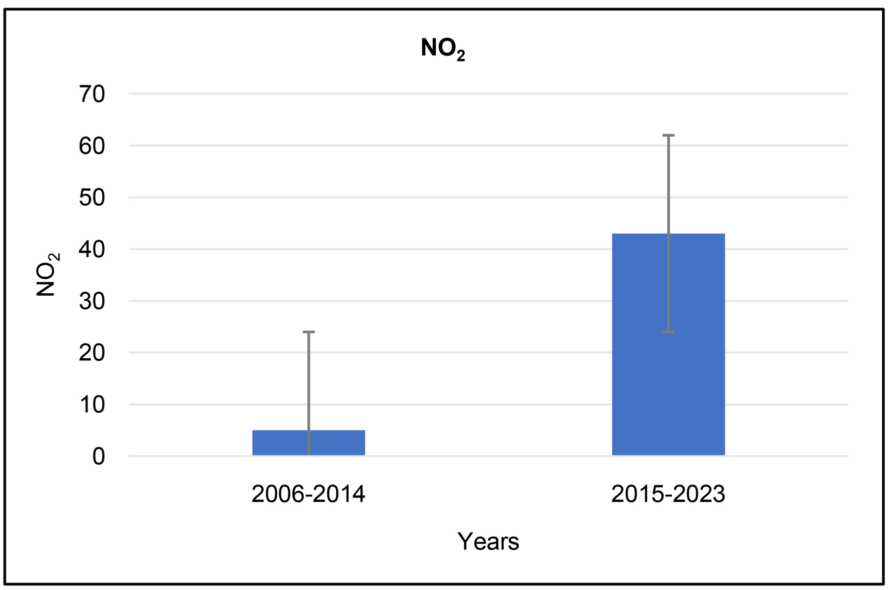

Figure 13. Comparison of N_2O emissions between 2006-2014 and 2015-2023 in Iran.

3.2.5. Hydrocarbon (HC) Emissions

Null Hypothesis: HC production was the same in the two time periods of 2006-2014 and 2015-2023.

Alternative Hypothesis: HC production was not the same in the two time periods of 2006-2014 and 2015-2023.

As shown in Table 7, the test statistic is significant ($p < 0.001$). This indicates that the null hypothesis is rejected, and the alternative hypothesis is accepted, confirming with 95% confidence that HC production was not the same in the two time periods. Furthermore, it was higher in the second nine-year period (Figure 14).

Table 7. Comparison of HC emissions over two time periods (2006-2014 vs. 2015-2023).

Years Studied	Number	Mean	Statistic t	Significance of the Test
2006 to 2014	9	1984.79	−5.48	0.00
2015 to 2023	9	2316.43		

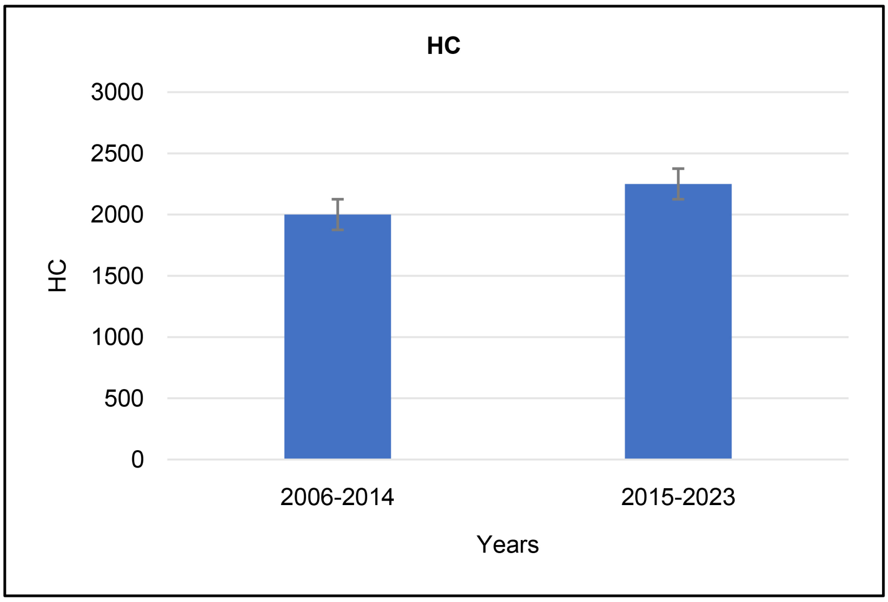

Figure 14. Comparison of HC emissions between 2006-2014 and 2015-2023 in Iran.

3.2.6. Sulfur Oxide (SOx) Emissions

Null Hypothesis: SOX production was the same in the two time periods 2006-2014 and 2015-2023.

Alternative Hypothesis: SOX production was not the same in the two time periods of 2006-2014 and 2015-2023.

As shown in Table 8, the test statistic is significant ($p = 0.015$), leading to the rejection of the null hypothesis. This indicates that SOx production was not the same in the two time periods (Figure 15).

Table 8. Comparison of SOx emissions over two time periods (2006-2014 vs. 2015-2023).

Years Studied	Number	Mean	Statistic t	Significance of the Test
2006 to 2014	9	105.14	2.74	0.015
2015 to 2023	9	99.31		

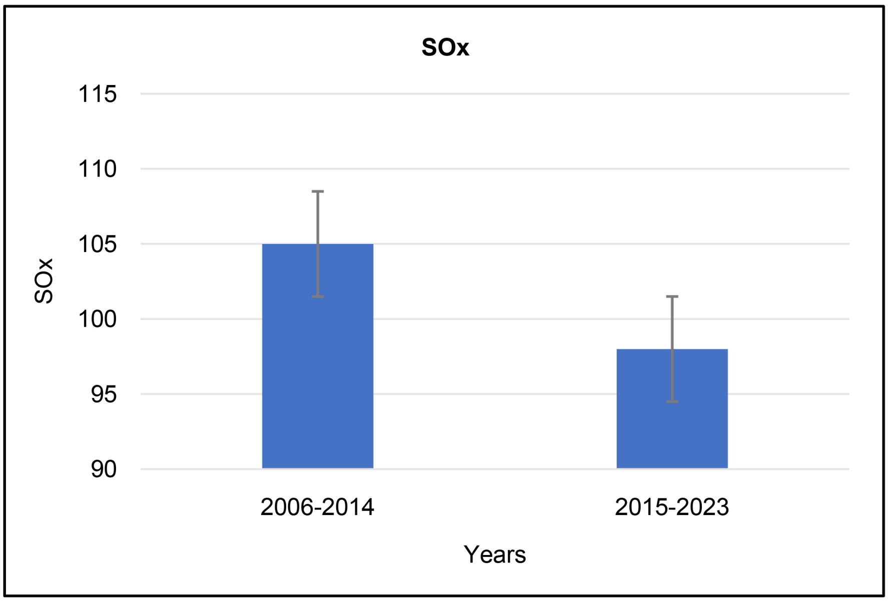

Figure 15. Comparison of SOx emissions between 2006-2014 and 2015-2023 in Iran.

3.2.7. Nitrogen Oxide (NOx) Emissions

Null Hypothesis: NOX production was the same in the two time periods of 2006-2014 and 2015-2023.

Alternative Hypothesis: NOx production was not the same in the two time periods of 2006-2014 and 2015-2023.

As shown in Table 9, the calculated test statistic is not significant ($p = 0.18$). Therefore, there is insufficient statistical evidence to reject the null hypothesis, suggesting that NOx levels remained relatively consistent between the two time periods (Figure 16).

3.2.8. Carbon Monoxide (CO) Emissions

Null Hypothesis: CO production was the same in the two time periods of 2006-2014 and 2015-2023.

Alternative Hypothesis: CO production was not the same in the two time periods of 2006-2014 and 2015-2023.

As shown in Table 10, the test statistic is significant ($p < 0.001$), leading to the rejection of the null hypothesis. This indicates that CO production was not the same in the two time periods, with significantly higher production observed in the latter period (Figure 17).

Table 9. Comparison of NOx emissions over two time periods (2006-2014 vs. 2015-2023).

Years Studied	Number	Mean	Statistic t	Significance of the Test
2006 to 2014	9	1796.92	−1.41	0.18
2015 to 2023	9	1832.97		

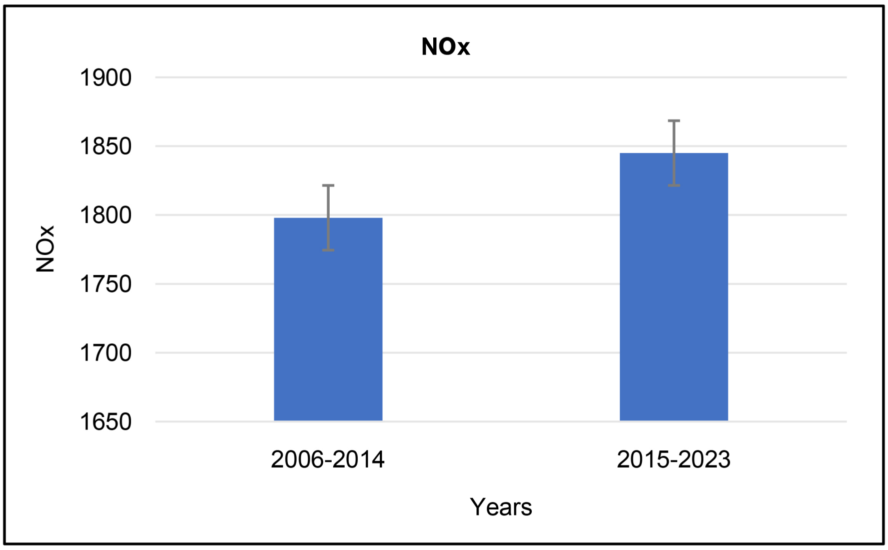

Figure 16. Comparison of NOx emissions between 2006-2014 and 2015-2023 in Iran.

Table 10. Comparison of CO emissions over two time periods (2006-2014 vs. 2015-2023).

Years Studied	Number	Mean	Statistic t	Significance of the Test
2006 to 2014	9	1908.74	−6.34	0.00
2015 to 2023	9	2191.98		

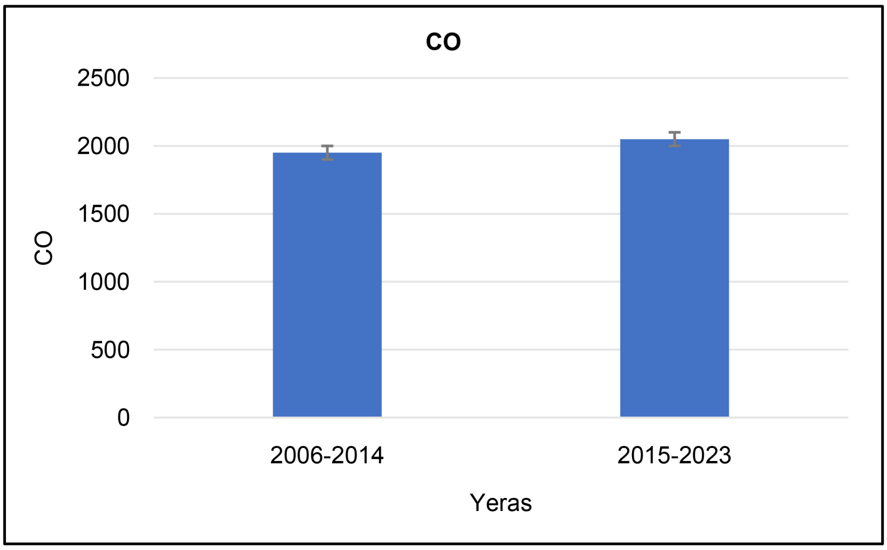

Figure 17. Comparison of CO emissions between 2006-2014 and 2015-2023 in Iran.

3.2.9. Carbon Dioxide (CO_2) Emissions

Null Hypothesis: CO_2 production was the same in the two time periods of 2006-2014 and 2015-2023.

Alternative Hypothesis: CO_2 production was not the same in the two time periods of 2006-2014 and 2015-2023.

As shown in Table 11, the test statistic is significant ($p = 0.001$), leading to the rejection of the null hypothesis. This indicates that CO_2 production was not the same in the two time periods, with significantly higher production observed in the latter period (Figure 18).

Table 11. Comparison of CO_2 emissions over two time periods (2006-2014 vs. 2015-2023).

Years Studied	Number	Mean	Statistic t	Significance of the Test
2006 to 2014	9	105.79	−4.06	0.001
2015 to 2023	9	118.03		

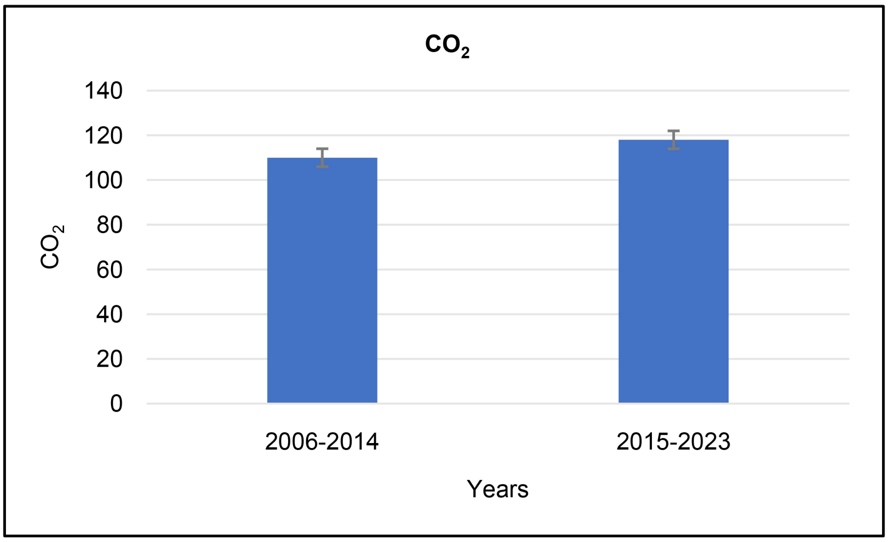

Figure 18. Comparison of CO_2 emissions between 2006-2014 and 2015-2023 in Iran.

3.3. Comparison of CO_2 Emissions across Countries (2000-2022)

This section compares the average CO_2 production among Iran, the USA, Canada, and the United Kingdom between 2000 and 2022. Normality of data was confirmed by the Kolmogorov-Smirnov test. Levene's test indicated unequal variances ($sig < 0.05$), thus the Brown-Forsythe test and Dunnett's T3 test were applied.

- Null Hypothesis (H0): There is no difference in the amount of carbon dioxide produced in the years 2000 to 2022 among Iran, the USA, Canada, and the United Kingdom.
- Alternative Hypothesis (H1): There is a difference in the amount of carbon dioxide produced in the years 2000 to 2022 among Iran, the USA, Canada, and the United Kingdom.

As shown in Table 12, the test statistic is significant ($p < 0.001$), leading to the rejection of the null hypothesis. This indicates that there is a statistically significant difference in the amount of carbon dioxide produced among Iran, the USA, Canada, and the United Kingdom between 2000 and 2022.

The mean comparison was performed using the Dunnett T3 test, as presented in Table 13.

Table 12. Brown-Forsythe test results for CO_2 emissions comparison across countries (2000-2022).

Type of Test	Statistical value	Test Significance
Brown-Forsythe	6537.35	<00.001

Table 13. Mean CO_2 emissions comparison across countries using Dunnett T3 test (2000-2022).

Mean comparison	CO_2/Million tons	Country
d	111.91	Iran
a	1855.50	USA
b	167.98	Canada
c	124.49	United Kingdom

Countries sharing the same letter in the "Mean Comparison Category" column do not have a statistically significant difference in their mean CO_2 emission values. Countries with different letters, however, show a statistically significant difference (Figure 19). For example, the USA (Category "a") has the highest average CO_2 emissions, differing significantly from Iran, Canada, and the United Kingdom.

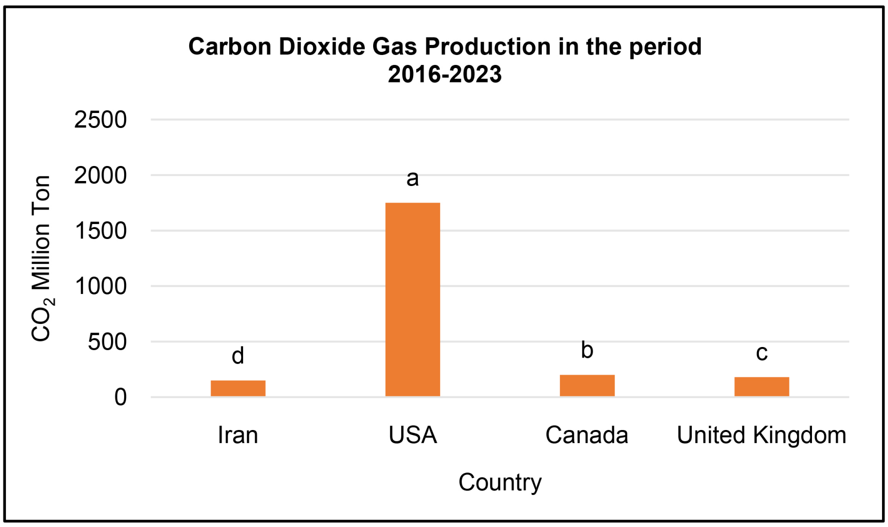

Figure 19. Average CO_2 emissions across Iran, USA, Canada, and UK (2016-2023) (Million tons).

3.4. Comparison of CO_2 Emissions between Two Periods across Countries (2006-2014 vs. 2015-2023)

This section presents a comparative analysis of CO_2 production between two distinct time periods (2006-2014 and 2015-2023) across Iran, the USA, Canada, and the United Kingdom (Table 14). Data normality was confirmed by the Kolmogorov-Smirnov test. Levene's test for equality of variances showed a significant difference (sig < 0.05), indicating unequal variances. Consequently, the Brown-Forsythe test was employed, and the Dunnett T3 test was utilized for mean comparisons.

- Null Hypothesis (H0): There is no difference in the amount of carbon dioxide produced in the two periods of 2006-2014 and 2015-2023 across Iran, the USA, Canada, and the United Kingdom.
- Alternative Hypothesis (H1): There is a difference in the amount of carbon dioxide produced in the two periods of 2006-2014 and 2015-2023 across Iran, the USA, Canada, and the United Kingdom.

Table 14. Brown-Forsythe test results for CO_2 emissions comparison between two periods across countries.

Type of Test	Statistical value	Test Significance
Brown-Forsythe	2724.77	0.00

The mean comparison was performed using the Dunnett T3 test (Table 15).

Table 15. Mean CO_2 emissions comparison between 2006-2014 and 2015-2023 for Iran, USA, Canada, and UK using Dunnett T3 test.

Country	CO_2/Million tons		CO_2/Million tons	
	2006-2014	Mean comparison	2015-2023	Mean comparison
Iran	105.79	c	118.026	d
USA	1869.11	a	1841.89	a
Canada	168.23	b	167.72	b
United Kingdom	129.48	c	119.5	c

Countries sharing the same letter in the "Mean Comparison Category" columns for a given period do not have a statistically significant difference in their mean CO_2 emission values for that period. Countries with different letters, however, show a statistically significant difference. For example, the USA (Category "a") consistently has the highest average CO_2 emissions in both periods (Figure 20).

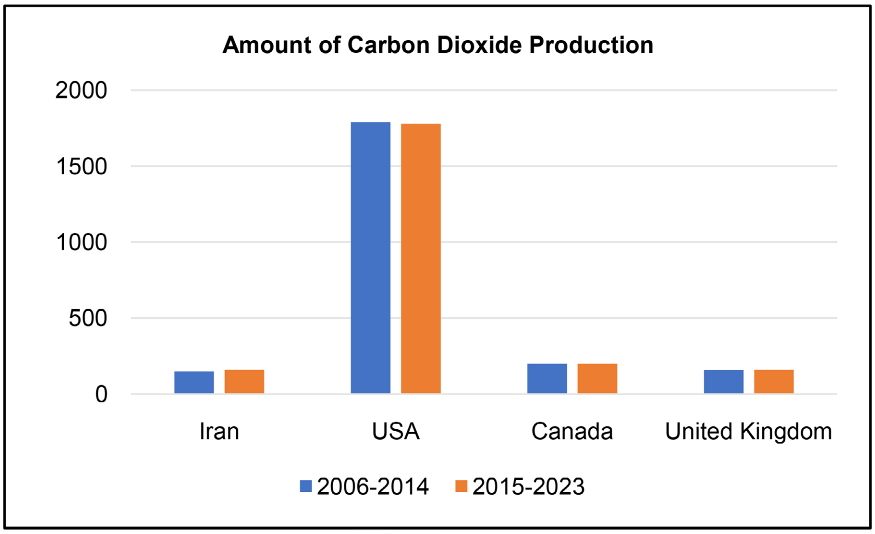

Figure 20. Comparison of average CO_2 emissions between 2006-2014 and 2015-2023 across Iran, USA, Canada, and UK (Million tons).

4. Discussion

This study provides an updated analysis of air pollutant trends in Iran from 2006 to 2023 and a comparative examination of CO_2 emissions across Iran, the USA, Canada, and the UK from 2000 to 2022. The findings reveal critical shifts in pollutant concentrations and offer insights into both local and global environmental challenges.

Our updated analysis for Iran (2006-2023) indicates a significant increase in the average production of all measured pollutants when comparing the periods of 2006-2014 and 2015-2023, apart from NO_x. Specifically, greenhouse gases (GHGs), CH_4, N_2O, HC, CO, and CO_2 all showed a statistically significant rise in the latter period (2015-2023) compared to 2006-2014, with higher average concentrations. Notably, SPM and SOx also showed a statistically significant difference between the two periods; SPM production was significantly higher in the earlier period (2006-2014), while SOx levels also differed significantly. In contrast, NOx production showed no statistically significant difference between 2006-2014 and 2015-2023, suggesting levels remained relatively consistent across the timeframes, with insufficient evidence to conclude a statistically significant change.

The observed sharp rise in CO_2 in Iran, particularly from 2015 onwards, mirrors global industrialization and urban growth [1]. This surge is strongly driven by the transportation sector, including often overlooked factors such as Tehran's waste fleet, which contributes significantly to national emissions [6]. While Iran's road transport CO_2 emissions are lower than those of larger economies like the USA or China, the trajectory suggests a pattern akin to emerging economies [5]. The significant increases in CH_4 and N_2O highlight a growing concern in waste and agricultural management practices in Iran, pointing to areas requiring urgent attention and revised strategies [1]. Similarly, the rising trends in HC and CO may indicate an increase in vehicle activity, a greater reliance on older vehicle technologies, or inadequate fuel quality and emission control standards within the transportation sector. These findings underscore the need for targeted interventions beyond traditional CO_2 reduction efforts to manage a broader spectrum of air pollutants.

The contrasting behavior of SPM and SOx, which exhibited significant differences between the two periods, might suggest the influence of specific local controls, industrial shifts, or variations in fuel composition. Conversely, the stability in NOx levels could imply that existing emission control measures for this pollutant have been relatively consistent or that its primary sources have not seen substantial changes over the analyzed periods.

Globally, the United States continues to show the highest CO_2 emissions among the comparative countries, with transportation being a dominant contributor [4]. Canada's lower GHG share, despite its large landmass and reliance on vehicle transport, reflects different factors, including policies designed to spur innovation in GHG mitigation and green technologies [3]. The European Union's pronounced road transport GHG dominance (72% of its sector's emissions) highlights challenges that resonate with Iran's situation [1]. The comparison of CO_2 emissions across these nations between 2006-2014 and 2015-2023 confirms a statistically significant difference in CO_2 production among countries and across these time periods. This multi-national perspective contextualizes Iran's emission trends within broader global patterns, demonstrating that while local factors are paramount, global trends and varied national responses provide crucial lessons.

Mitigation strategies are urgently needed to address these trends. Successful approaches, such as the impact of U.S. fuel standards on CO_2 reductions (though susceptible to policy rollbacks), offer valuable lessons [4]. For Iran, promising avenues include biogas swap initiatives, which could significantly reduce waste-related CO_2 emissions [6]. Furthermore, transit solutions that have led to projected GHG reductions, like Russia's 12.7% cut by 2030 through transport optimization, provide robust statistical affirmation for these paths [7]. Power sector upgrades, such as natural gas combined cycles cutting Canada's emissions by 59% and Iran's by 32%, or CO_2 capture achieving 94% and 90% reductions, provide proven paths forward for reducing greenhouse gas emissions [8]. Policy recommendations must extend beyond the transportation sector to include comprehensive strategies for industrial emissions, waste management, and agricultural practices, particularly to curb the rising CH_4 and N_2O levels. Implementing stricter vehicle emission standards, promoting public transportation, encouraging electric vehicle adoption, and investing in renewable energy sources for both transportation and the broader energy sector are crucial. These targeted interventions, informed by the observed trends and comparative insights, are essential for balancing rising GHG emissions with effective pollutant controls, paving the way for a cleaner future. Future research should focus on probing the specific drivers behind the observed changes in pollutant levels and assessing the health and environmental impacts of these trends. Exploring sustainable alternatives, such as rail and marine transport, and refining emission estimation tools are also crucial next steps.

5. Conclusions

This study provided an updated analysis of air pollutant trends in Iran from 2006 to 2023 and a comparative examination of CO_2 emissions across Iran, the USA, Canada, and the UK from 2000 to 2022. Our findings reveal significant increases in most Iranian air pollutants, including GHGs, CH_4, N_2O, HC, CO, CO_2, SPM, and SOx, between the periods of 2006-2014 and 2015-2023, with only NOx showing no statistically significant change. These trends underscore the complex impacts of industrialization, urbanization, and specific sectoral activities, particularly transportation and waste management, on Iran's air quality [1].

The global CO_2 comparison highlighted the USA as the highest emitter, contextualizing Iran's emission trajectory within broader international patterns and emphasizing the universal need for proactive strategies [4] [6].

The robustness of these findings is supported by a rigorous statistical methodology. This research establishes a critical foundation for developing and implementing targeted interventions, such as enhancing vehicle emission standards, promoting public transport, optimizing waste management, and fostering sustainable energy transitions across all sectors, to achieve a cleaner and more sustainable future. Future research should delve deeper into the specific drivers of these changes and their precise health and environmental impacts, while also exploring sustainable transport alternatives.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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