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Investigation of Gas Pollutant Emissions from Fossil Fuel Combustion in Iran from 2000 to 2017

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ABSTRACT

Solid fuels such as coal and wood contribute to air pollution by releasing harmful substances into the air during cooking and heating. The burning of coal emits toxins, and industrial activities further degrade air quality. Although natural gas is cleaner compared to coal and oil, it still generates harmful carbon dioxide, with concerns surrounding methane and nitrogen oxides. Tailored policies are essential to decrease emissions in cities like Tehran, Iran, and regions in China, emphasizing the necessity for comprehensive strategies. A search was conducted for keywords related to air pollutants like natural gas, fuel oil, and diesel in online databases such as Google Scholar and Scopus. A review of scientific literature on air pollution caused by these fuels was undertaken, and air pollution production statistics in Iran from 2000 to 2017 were gathered. The One-Sample Kolmogorov-Smirnov Test was used to evaluate the normality of the air pollutant data distribution, and a descriptive study on air pollutant production was carried out using SPSS v27 software, which included statistical tests for correlation analysis. The analysis indicated that from 2000 to 2017, natural gas was the primary producer of CO₂, while diesel was responsible for higher overall pollution despite lower consumption. Significant correlations between pollution levels and fuel types were discovered, with diesel exhibiting the highest emissions, underscoring the necessity for stricter regulations and cleaner fuel alternatives. Strategies to reduce diesel emissions involve increasing natural gas usage, enhancing diesel quality, adopting advanced technologies, promoting electric vehicles, enforcing stringent standards, investing in public transportation.

Introduction

The World Health Organization (WHO) notes that over 80% of urban residents breathe unhealthy air, primarily in low- and middle-income countries. In developing areas, solid fuels such as

coal and wood are key pollution sources, often used for cooking and heating. Burning these fuels emits harmful substances like particulate matter and carbon monoxide. Coal burning releases toxic materials like sulfur and heavy metals, while industrial emissions and vegetation fires worsen outdoor pollution. To

tackle air pollution, policy changes and personal efforts are necessary, especially in the most affected developing countries [1]. Natural gas is primarily composed of methane and forms from decomposed organic matter under high pressure and temperature. It burns cleaner than coal and oil, producing less sulfur dioxide and nitrogen oxides, but still emits carbon dioxide, which contributes to climate change [2]. After extraction, heavy oil is refined into various products, with fuel oil being significant, often referring to diesel fuel. Diesel is mainly produced through the distillation of crude oil and is suitable for compression ignition engines, which ignite the fuel through heat instead of a spark [3]. Refining heavy oil into diesel includes desulfurization to reduce sulfur emissions linked to acid rain. New refining technologies are being developed to improve efficiency and reduce environmental impact. Both natural gas and heavy oil are crucial in the energy sector, necessitating advancements to address environmental concerns [4]. In the United States, the transition from coal to natural gas has significantly improved air quality and reduced emissions. This shift is driven by the lower costs of natural gas and regulations aimed at cutting carbon emissions. A previous study focused on the closing of coal plants and the opening of natural gas plants from 2005 to 2016, examining pollution, air quality, health impacts, and crop production. The shutdown of coal plants significantly lowered pollution levels, especially for particulate matter and sulfur dioxide, aligning with past research linking coal emissions to severe health problems. While natural gas reduces carbon emissions, it also emits methane and nitrogen oxides, raising air quality issues. This emphasizes the need for monitoring environmental effects and developing renewable energy for sustainable growth. Future research should evaluate the impacts of all energy sources to better inform energy policies [5]. A study examines how agriculture, industry, and households contribute to greenhouse gas emissions and pollutants in Iran over time using a descriptive-analytical approach. The analysis utilizes data and statistical tools to uncover relationships between these sectors and pollutants, including

nitrogen oxides, sulfur dioxide, carbon dioxide, sulfur trioxide, carbon monoxide, methane, suspended particulate matter, and nitrous oxide [6]. Many large cities struggle to meet clean air targets, but setting zero greenhouse gas emissions goals may help improve air quality. The benefits of electrification depend on the source of electricity. Tehran's emission inventory used a detailed method to analyze emissions from power plants and vehicles. The study aimed to improve policymaking, analyze emissions over a four-year period, and evaluate inventory methods. Findings showed annual emissions of 478 kt CO, 103 kt NO_x, 91 kt VOCs, and 19 kt SO_x, highlighting the need for targeted policies on greenhouse gases and air quality [7]. The relationship between natural gas use, economic growth, and PM_{2.5} emissions in China was explored. It found that increased natural gas consumption raises PM_{2.5} emissions nationwide, but in regions with high natural gas use, emissions decrease. The study supported the Environmental Kuznets Curve concept, suggesting emissions initially rise with economic growth before declining due to regulations. It called for tailored policies for different regions, suggesting investment in natural gas where feasible while enforcing stricter measures where needed [8]. The effects of China's "coal-to-gas" policy on regional air quality showed significant PM_{2.5} reductions in targeted northern areas but increases in southern regions due to natural gas shortages from energy transitions. Around 60% of PM_{2.5} reductions in pilot cities were attributed to coal control measures, indicating their success but also pointing out the complexities in energy and environmental policy. This stresses the need for integrated strategies for cleaner air and better health outcomes [9]. An analysis of air pollutants in Tehran from 2005 to 2016 showed that CO and SO₂ levels decreased by approximately 50% due to improved fuel quality and vehicle standards. However, NO₂ levels increased by over 50%, influenced by an increase in the number of vehicles and changes in heating fuels. O₃ formation shifted from being NO_x-limited to NO_x-saturated around 2012-2013. PM_{2.5} levels slightly decreased by around 30% from 2011 to 2015 but increased from 2015 to 2016, partially due to a drought

causing more dust. Asbestos fibers in the air declined by more than 60% between 2012 and 2015 [10]. Due to the growing trend of using natural gas as a fuel in our country, Iran is experiencing a shift in the quantity and type of pollution. We conducted a study on air pollution emissions from natural gas, fuel oil, and diesel sources in Iran from 2000 to 2017.

Materials and Methods

Literature review

Initially, a search of keywords related to our study such as natural gas, fuel oil, and diesel was conducted using online databases like Scholar and Scopus. Scientific literature and databases focusing on air pollution caused by these fuels were reviewed.

Data collection

Initially, data on air pollution statistics were gathered, specifically focusing on pollutants and greenhouse gas emissions from natural gas, fuel oil, and diesel in Iran. This data included annual emissions in tons of air pollutants like NO_x , SO_2 , CO_2 , SO_3 , CO , CH_4 , SPM, and N_2O from natural gas, fuel oil, and diesel between 2000 and 2017. The information was sourced from the Statistical Center of Iran's database, available at <https://amar.org.ir> [11,12].

Data distribution analysis

The One-Sample Kolmogorov-Smirnov Test was utilized to analyze the normality of data distribution, consisting of the annual production of air pollutants and greenhouse gas emissions from natural gas, fuel oil, and diesel fuels in Iran during 2000-2017 [13].

Descriptive and analytical study

A descriptive study and comparison of the annual production of air pollutants and greenhouse gases from natural gas, fuel oil, and diesel fuels from 2000 to 2017 was conducted using SPSS v27 software. The correlation between the annual production of air pollutants

and greenhouse gases was investigated using the Spearman's correlation test in SPSS v27 software. The difference in the annual production of air pollutants among the three fuels - natural gas, fuel oil, and diesel in Iran was investigated using the Kruskal-Wallis H test. However, for the variable SO_3 , the comparison between fuel oil and diesel was done using the Independent Samples Test in SPSS v27 software [13].

Results and Discussion

The annual mean production of air pollutant gases resulting from the consumption of natural gas, fuel oil, and diesel fuels in Iran from 2000 to 2017 was analyzed

The annual mean amount of carbon dioxide (CO_2) produced from natural gas was 251,188,400 tons, significantly higher than that from fuel oil at 51,600,121 tons and diesel at 87,033,449 tons. This disparity is due to natural gas being the predominant fuel used in the country. Despite diesel fuel producing the most air pollutants, its share in total fuel consumption is lower compared to natural gas. Overall, natural gas is a cleaner fuel (Figures 1 and 2). The annual mean production of air pollutants from diesel for NO_x was 644,507 tons, CO was 143,405 tons, CH_4 was 151,836 tons, SPM was 272,343 tons, and N_2O was 7,514 tons. However, diesel's share in total fuel consumption is lower compared to natural gas. To assess pollution levels, we calculated the ratio of the annual mean production of carbon dioxide to the annual mean production of each pollutant studied. Natural gas had the highest ratios, such as CO_2/SO_2 at 419,234.262, CO_2/CO at 3,940.529, CO_2/CH_4 at 19,207.853, CO_2/SPM at 9,980.863, and $\text{CO}_2/\text{N}_2\text{O}$ at 441,107.034. The CO_2/NO_x ratio was highest for natural gas at 578.031. Sulfur pollutants were higher during diesel and fuel oil consumption, with fuel oil producing more SO_2 and SO_3 annually compared to diesel. The annual mean production of SO_2 was 664,238 tons from fuel oil and 488,161 tons from diesel, while the annual mean production of SO_3 was 6,915 tons from fuel oil and 6,461 tons from diesel.

Table 1. The emissions of air pollutants from natural gas, fuel oil, and diesel fuels in Iran from 2000 to 2017

	the study year								
	2007	2006	2005	2004	2003	2002	2001	2000	
	283701	251849	227317	211573	190387	186858	168203	170356	NO_x
	131339	118673	113214	108721	111318	116266	118545	114895	Fuel Oil
	607460	575166	553482	519721	525115	498757	477234	461203	Diesel
	745	670	592	551	492	480	423	411	SO₂
	814387	245018	226632	214965	638347	692960	715940	691605	fuel Oil
	535992	514916	470570	433890	436054	425099	411939	398738	Diesel
	245452905	200675413	179578763	167293323	150045885	145938712	129915662	126690292	CO₂
	58322366	46637228	43138882	40918140	40502790	43967942	45425997	43881905	Fuel Oil
	92632989	83223992	75817271	69821935	69972579	68498914	66422254	64293618	Diesel
	8409	3743	3462	3284	9752	10586	10936	10564	SO₃
	6306	6060	5458	5000	4975	4895	4717	4531	Diesel
	15521	13700	11874	10887	9561	9451	8157	7495	CO
	64	58	54	50	50	54	57	54	Fuel Oil
	145804	137241	134860	127402	129222	121612	115808	111887	Diesel
	6820	5550	4967	4628	4150	4037	3584	3505	CH₄
	2148	6264	5794	5495	5440	5906	6102	5894	Fuel Oil
	4481	419989	412024	389400	394557	371096	353477	341440	Diesel
	24078	21347	19199	17840	16018	15747	14220	14231	SPM
	17351	15662	14486	13740	13601	14764	15253	14736	Fuel Oil
	279529	263774	256844	241720	244813	231407	220782	213289	Diesel
	441	-	-	-	-	-	-	-	N₂O
	429	-	-	-	-	-	-	-	Fuel Oil
	7642	-	-	-	-	-	-	-	Diesel

2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
777612	739307	685318	628723	515092	549021	555804	573935	555900	551099
45631	60555	125405	156219	178424	182660	156589	147114	208509	192317
666176	664589	672510	801472	864950	775123	794552	738650	709369	695605
730	741	694	685	658	615	642	574	554	528
252767	348049	685030	871594	971782	945354	824463	756334	1069079	991986
463961	456072	477738	538092	569461	526577	533291	528863	533820	531825
391765354	374921434	353832342	340203516	304924289	295299378	294631867	287662171	272355300	260204611
18919888	26531425	48523986	63888402	74171027	72047085	62732655	57406735	74000356	67785381
85999696	86239415	87410946	103634771	114314426	100957553	104847926	99264915	96988789	96260105
1724	2650	7320	7405	6237	6387	5906	6874	10123	9112
5958	6016	12907	7305	8103	6981	7297	6735	6553	6504
129644	119688	110782	102441	71782	89463	102254	106353	108542	119812
45087	59671	69228	91248	105333	86651	60778	45582	56791	60430
148327	142330	139564	164700	165021	162370	160015	160946	158139	156049
25030	24659	23574	22657	21079	21449	19883	18100	12811	8910
633	825	1656	1732	2389	2398	2027	1983	2196	2283
4243	4216	4180	4889	5302	4801	4937	4756	4641	4629
39102	37323	34132	32980	28799	28706	28779	27952	26675	25878
4861	6687	17739	17177	18875	18539	16251	275995	19453	18649
278973	268292	275574	310468	312846	305754	301718	303580	298177	294634
726	696	641	632	566	545	544	528	485	460
127	166	331	346	477	481	405	397	439	464
6609	6701	7027	7303	7694	7632	7585	8219	8176	8072

Source: Energy Balance Sheet, Ministry of Energy, Deputy for Electricity and Energy Affairs [11,12]
 "-": This line indicates that no data is available for the corresponding category.



Figure 1: Comparison of the average production of air pollutant gases resulting from the consumption of natural gas, fuel oil, and diesel fuels in Iran from 2000 to 2017



Figure 2: Comparative charts of air pollutant emissions from natural gas, fuel oil, and diesel fuels in Iran from 2000 to 2017.

Table 2: A descriptive overview of air pollutants emitted by natural gas, fuel oil, and diesel fuel

Variables	N	Nature Gas		Fuel Oil		Diesel	
		Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
NO _x	18	434558.61	217430.49	132577.44	42326.65	644507.44	123016.26
SO ₂	18	599.16	105.06	664238.44	285774.86	488161	52437
CO ₂	18	251188400.9	86899699	51600121.6	15793551.8	87033449.6	15168100.1
SO ₃	18	-	-	6915.22	2978.61	6461.16	1897.63
CO	18	63744.83	50181.6	37846.66	37715.39	143405.38	17295.03
CH ₄	18	13077.38	8671.13	3398.05	2066.25	151836.55	190658.59
SPM	18	25167	7857.62	29656.61	61600.25	272343	31777.4
N ₂ O	11	569.45	93.88	369.27	120.64	7514.54	554.62
CO ₂ /NO _x	18	578.031	-	389.207	-	135.038	-
CO ₂ /SO ₂	18	419234.262	-	77.683	-	178.288	-
CO ₂ /SO ₃	18	-	-	7461.819	-	13470.251	-
CO ₂ /CO	18	3940.529	-	1363.399	-	606.905	-
CO ₂ /CH ₄	18	19207.853	-	15185.215	-	573.204	-
CO ₂ /SPM	18	9980.863	-	1739.919	-	319.572	-
CO ₂ /N ₂ O	11	441107.034	-	139735.482	-	11582.006	-

Among the fuels studied, diesel had the highest pollution levels based on the lowest ratio between CO₂ production and other air pollutants: CO₂/CO at 606.905, CO₂/CH₄ at 573.204, and CO₂/SPM at 319.572. During the study period, CO production from diesel was higher than from natural gas and fuel oil. There was a sudden increase in CO production from natural gas and fuel oil in 2008. Methane production from diesel increased suddenly after 2007, dropping significantly in 2007 due to technological advancements. The majority of N₂O production is from diesel fuel (Tables 1 and 2).

Data distribution

When analyzing emissions of air pollutants from natural gas fuel, it was found that the variables for annual CO and CH₄ emissions do not follow a normal distribution. However, the variables for annual SPM, N₂O, NO_x, SO₂, and CO₂ emissions do exhibit a normal distribution. In the case of fuel oil, the variables for CO, CH₄, and SPM emissions do not adhere to a normal distribution. On the other hand, for diesel fuel, the variables for SO₂, SO₃, and CH₄ emissions do not conform to a normal distribution. Among all the samples, only the variable for SO₃ emissions conforms to a normal distribution, while the other air pollutants do not (see Supplement 1).

Correlation between study year and annual production of air pollutants from natural gas fuel

There is a direct and significant correlation between the annual productions of the studied air pollutants ($p < 0.01$). However, it is important to note that these pollutants are lower compared to the other studied fuels. Furthermore, the direct and significant correlation between the study year and the annual production of air pollutants ($p < 0.01$) suggests that there has been an increase in natural gas consumption in our country, Iran (Supplements 2 and 3). The correlation between natural gas use and air pollutants is complex and involves several scientific principles. Natural gas has a higher hydrogen-to-carbon ratio than coal and oil, leading to less carbon monoxide (CO) emission since more hydrogen promotes complete oxidation of carbon during combustion. Furthermore, natural gas has lower sulfur content, resulting in reduced emissions of sulfur dioxide (SO₂), which is harmful to health and contributes to acid rain [14]. Nitrogen oxides (NO_x) form during high-temperature combustion, with their amount depending on conditions rather than just fuel composition. Although natural gas typically burns at lower temperatures and thus produces fewer nitrogen oxides, the specific outcomes depend on the combustion process and other nitrogen compounds present. Natural gas combustion also leads to fewer particulate matters (PM) and volatile organic compounds (VOCs) compared to coal and oil, though emissions rely on other gas compounds and technology used [15]. While methane (CH₄) is a significant component of natural gas and a potent greenhouse gas, its combustion primarily releases carbon dioxide (CO₂) and water vapor. However, unburned methane can escape during production and distribution, adding to global warming. The temperature of combustion impacts nitrogen oxide formation; properly managing combustion can help reduce these emissions [16]. To reduce environmental impacts from natural gas use, strategies include improving combustion efficiency, adopting cleaner technologies, and implementing emission control systems. In addition, capturing methane emissions through leak detection and infrastructure upgrades is essential. Finally, transitioning to renewable energy sources like wind, solar, and hydroelectric power is crucial

for decreasing greenhouse gas emissions further. Overall, the use of natural gas must be managed alongside environmental considerations [17]. Advanced pollution control technologies can greatly reduce nitrogen oxides and other emissions. Furthermore, shifting from higher-emission fuels to natural gas can lower the emissions of pollutants like SO₂ and PM, explaining reduced pollutant levels in areas with increased natural gas use [18].

Correlation between the study year and the annual production of air pollutants from fuel oil

The inverse correlation observed between the study year index and the annual production of sulfur trioxide (SO₃), methane (CH₄), and nitrous oxide (N₂O) pollutants implies that, despite an increase in fuel oil consumption, efforts to mitigate these specific emissions have been somewhat successful over time. This success could be attributed to the implementation of stricter environmental regulations, technological advancements, or a shift in industrial practices aimed at reducing these pollutants. The direct and significant correlations between the annual production of nitrogen oxides (NO_x) and other pollutants such as N₂O, suspended particulate matter (SPM), carbon monoxide (CO), CO₂, and SO₂ suggest that the formation of these pollutants may be interconnected. This indicates that the combustion processes involved in fuel oil flaring contribute to the production of these gases in a way that is not entirely independent. For example, high-temperature combustion, typical in flaring, can lead to the formation of both NO_x and CO, which are known to be produced during incomplete combustion. In addition, the oxidation of sulfur compounds in fuel oil can result in the formation of SO₂, which may further react to form SO₃ in the presence of atmospheric oxygen [19]. The direct and significant correlation between the annual production of CO₂ index and N₂O, SPM, and CO indices suggests that burning fuel oil is associated with the production of these pollutants. The direct correlation between the annual production of CO and SPM may also indicate incomplete combustion or other

combustion processes contributing to particle formation [20].

The direct and significant correlation between CH₄ and N₂O is expected, as both are greenhouse gases produced during flaring. While CH₄ is a potent greenhouse gas, N₂O is even more potent and can result from the reaction of nitrogen and oxygen in high-temperature combustion environments [16,20]. The absence of a significant correlation between the study year index and SO₂ and CO₂ emission rates may suggest that control measures for these pollutants have been less effective compared to those for CH₄ and SO₃. This could be due to various factors, such as the stability of these gases in the atmosphere, natural sinks, or the effectiveness of control technologies used for their reduction. However, a lack of significant correlation does not necessarily mean emissions have not changed; rather, it indicates that observed changes are not statistically correlated with the timeframe considered in the study [19-20] (Supplements 4 and 5).

Correlation between the study year and the annual production of air pollutants from Diesel Fuel

There is a direct correlation between the study year and the annual production of pollutants such as nitrogen oxides (NO_x), sulfur dioxide (SO₂), SO₃, carbon monoxide (CO), carbon dioxide (CO₂), and suspended particulate matter (SPM). The increase in these pollutants may be due to heightened industrial activities, energy consumption, or a higher number of diesel vehicles, often associated with economic growth and urban expansion [21,22]. In contrast, there is an inverse correlation between the study year and emissions of methane (CH₄) and nitrous oxide (N₂O). This decline may result from environmental regulations aimed at reducing emissions from specific sources. Advances in diesel engine technology or changes in industrial processes could also lead to decreased emissions [23]. The direct correlations among the annual production of pollutants like NO_x, CO, SO₃, CO₂, and SPM suggest that they may have similar sources or creation processes. For example,

fossil fuel combustion, especially in diesel engines, is a significant source of these pollutants. The correlation between the annual production of CO₂ and SPM indicates that vehicle emissions contribute to both types of pollution [24]. An inverse correlation between NO_x and CH₄ emissions may indicate different sources or effective regulatory measures for one pollutant over another. Efforts to reduce NO_x through technology like catalytic converters may not significantly impact methane emissions, which are often linked to landfills, agriculture, and natural gas systems. Moreover, a correlation exists between the annual production of CO and SPM, likely due to shared emission sources such as incomplete fossil fuel combustion [25].

Different pollutants stem from distinct chemical processes in diesel combustion. Emission control technologies also influence the correlation between the annual production of methane and other emissions. Changes in diesel fuel quality over the study year, particularly regarding sulfur content due to regulations, are significant. Adopting ultra-low-sulfur diesel (ULSD) reduces SO₂ and SPM but may have little effect on methane emissions [26] (Supplements 6 and 7).

Mean comparison among three groups (representing the type of fuel studied)

According to Kendall's correlation test, a direct and significant correlation was found between the group type index (representing the type of fuel studied ordered by pollution ratio) and the annual production of air pollutants such as SO₂, CO, SPM, and N₂O. This highlights the importance of fuel selection in environmental policy. The findings suggest that transitioning to cleaner fuels like natural gas and fuel oil could have significant environmental benefits by reducing harmful pollutants. These pollutants are known to contribute to respiratory diseases, acid rain, and the formation of photochemical smog, emphasizing the urgency of reducing their emissions [27].

In contrast, there was an inverse and significant correlation between the group type index and the annual production of CO₂.

Table 3: The results of a correlation test conducted between the group type index (representing the type of fuel studied) and other air pollution indices. In this study, fuel groups were ranked based on the degree of pollutant emissions (ratios of CO₂/SPM, CO₂/SO₂, CO₂/SP, CO₂/CO, CO₂/N₂O) for the fuels under study

Kendall's tau Correlations									Spearman's rho		
Variables		NO _x	SO ₂	CO ₂	CO	CH ₄	SPM	N ₂ O	Variables		SO ₃
Groups	Correlation Coefficient	0.161 1	0.427 **	- .304* *	.408* *	- 0.023 7	.370* *	.304*	Groups	Correlation Coefficient	- 0.144 3
	Sig. (2-tailed)	0.131 5	0.000	0.004 4	0.000 1	0.824 1	0.000 5	0.028 1		Sig. (2-tailed)	0.400 7
N		54	54	54	54	54	54	33	N		36

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

Table 4: The mean comparison among three groups in tests representing the type of fuel

Kruskal-Wallis Test								Independent Samples Test	
Variables	NO _x	SO ₂	CO ₂	CO	CH ₄	SPM	N ₂ O	Variables	SO ₃
Kruskal-Wallis H	36.33 2	37.673	44.78 4	36.253	13.46 8	37.25	27.12 9	t-test for Equality of Means (t)	0.545
df	2	2	2	2	2	2	2	df	28.848
Asymp. Sig.	0.000	0.000	0.000	0.000	0.001	0.000	0.000	Sig. (2-tailed)	0.59

When the asymptotic significance is less than 0.05 in the Kruskal-Wallis Test, it indicates a significant difference. When the significance (2-tailed) is less than 0.05 in the Independent Samples Test, it also indicates a significant difference.

No significant correlation was found between the group type index and the annual production of methane (CH₄) as an air pollutant. Diesel engines, for example, are generally more efficient than gasoline-powered engines, resulting in lower CO₂ emissions per unit of energy produced. However, it is crucial to consider the environmental impact of diesel exhaust, which includes higher emissions of other pollutants like NO_x and particulates that are harmful to human health and the environment [28]. Diesel fuel had the highest mean annual production of air pollutants, with NO_x at 644,507 tons, CO at 143,405 tons, CH₄ at 151,836 tons, SPM at 272,343 tons, and N₂O at 7,514 tons. Despite this, its contribution to total fuel consumption in Iran is low. The Kruskal-Wallis H test showed significant differences in pollutant emissions among different fuel types Table 3 and 4. The high levels of NO_x, CO, CH₄, SPM, and N₂O associated with diesel consumption are particularly concerning due to their impact on ozone formation, respiratory health, and global warming potential [29]. The

implications of these findings for Iranian environmental policy are twofold. Firstly, while diesel may emit less CO₂, its high levels of other pollutants indicate a significant overall environmental impact that requires attention in terms of public health and environmental degradation. For example, policymakers could consider implementing stricter emissions standards for diesel vehicles or promoting cleaner fuels and vehicles with lower emissions [22-28]. Investing in public transportation systems powered by cleaner energy sources could also help reduce reliance on diesel-powered transport, thereby decreasing associated health risks [22-29].

Conclusion

Strategies to reduce the environmental impact of diesel-related air pollution emissions in Iran focus on improving air quality and protecting health. Each strategy is important and understanding them helps clarify their principles. One key strategy is increasing the

use of natural gas, which results in lower emissions of nitrogen oxides, sulfur dioxide, and carbon dioxide compared to diesel. Natural gas is cleaner and more efficient, producing less particulate matter and minimizing smog formation. Improving diesel fuel quality is also important. Using low-sulfur diesel and meeting stricter standards, like Euro 5 or Euro 6, can lower the emissions of harmful gases. Low-sulfur diesel supports advanced technologies that effectively reduce emissions, and adding bio-components to diesel can help cut greenhouse gas emissions. Investing in advanced emission control technologies is critical. Technologies such as selective catalytic reduction (SCR) and diesel particulate filters (DPF) can significantly lower emissions by converting nitrogen oxides and capturing particulate matter from exhaust. Promoting alternative fuels and vehicles is another necessary step. Electric and hybrid vehicles produce no tailpipe emissions, while biofuels, like biodiesel, have a smaller carbon footprint. Policies that support these options through subsidies and infrastructure can encourage their adoption, depending on sustainable electricity sources for EVs and biofuel production. Enforcing strict emission standards ensures compliance with environmental rules, involving inspections and penalties. Scientific studies establish these limits and how to achieve them. Investing in public transportation can decrease the number of diesel vehicles, reducing fuel consumption and emissions. Successful public transport systems need to be accessible, affordable, and efficient. Implementing emissions trading schemes offers financial incentives to lower emissions through cap-and-trade systems, promoting cost-effective emission reductions. Regular monitoring and reporting of fuel consumption and emissions are necessary for informed policymaking. This includes identifying trends and evaluating the success of strategies. These approaches are supported by scientific principles related to air quality and health. Considerations of Iran's unique context, including economic conditions and collaboration opportunities, are essential for effective strategy implementation. In addition,

public education can encourage cleaner transportation choices.

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Reference

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