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Contribution of residential heating to air pollution in an industrial city of Turkey

Türkiye'nin bir sanayi şehrinde konut ısıtmasının hava kirliliğine katkısı

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Abstract

In this study, the contribution of fuels (coal + natural gas) used for residential heating in Kayseri city center to air pollution was investigated. For this reason, the amount of emissions released to the atmosphere was calculated by using the natural gas and coal data used in the residences in the 5 (five) year period between 2015-2019 in the province of Kayseri. In addition, the percentage contribution of both residential heating and industrial point sources to air pollution in terms of emissions was compared. The relationship between annual average emission amounts and National Air Quality Monitoring Network data was also revealed. During the 5 years period, the total amount of emissions originating from the fuels used in residences and industries were 6171 tons for PM, 9049 tons for SO_2, and 14179 tons for NO_x. It has been evaluated that the decrease in PM_{10} concentrations and the increase in NO_X concentrations from 2015 to 2019 may be related to the increase in natural gas use in the city. When evaluated in terms of emission amounts; it has been revealed that PM and SO_2 are mostly released from domestic sources, while NO_Xs are from industrial sources.

Keywords: Natural gas, Coal, Emission, Residential, Industrial

Öz

Bu çalışmada Kayseri il merkezinde konut ısınması amacıyla kullanılan yakıtların (kömür+doğalgaz) hava kirliliğine katkısı araştırılmıştır. Bu nedenle, Kayseri ilinde 2015-2019 yılları arasındaki 5 (beş) yıllık dönemde konutlarda kullanılan doğalgaz ve kömür verileri kullanılarak havaya salınan emisyon miktarları hesaplanmıştır. Ayrıca, hem konut ısınması hem de endüstriyel nokta kaynakların emisyon miktarları açısından hava kirliliğine yüzdesel katkısı karşılaştırılmıştır. Yıllık ortalama emisyon miktarları ile, Ulusal Hava Kalitesi İzleme Ağı verileri arasındaki ilişki ayrıca ortaya çıkarılmıştır. Çalışma süresi olan 2015-2019 yıllarını kapsayan 5 yıllık süre zarfında konut ve endüstrilerde kullanılan yakıtlardan kaynaklı oluşan toplam emisyon miktarları PM için 6171 ton, SO_2 için 9049 ton, NO_x için 14179 ton şeklindedir. 2015 yılından 2019 yılına doğru gerçekleşen PM_{10} konsantrasyonlarında azalma ve NO_X konsantrasyonlarındaki artışın, kentte doğalgaz kullanımının artması ile ilişkili olabileceği değerlendirilmiştir. Emisyon miktarları açısından değerlendirildiğinde; PM'in ve SO_2'nin evsel, NO_x'lerin ise çoğunlukla endüstriyel kaynaklardan salındığı ortaya çıkmıştır.

Anahtar kelimeler: Doğalgaz, Kömür, Emisyon, Konut, Endüstri,

1 Introduction

Air pollution caused by heating increases, especially with the onset of the winter period in Turkey. Air pollutants, which are the main causes of air pollution caused by heating; released into the atmosphere from the chimneys as a result of burning wood, coal, fuel oil, and natural gas in stoves and heaters. Some of these air pollutants have a toxic effect on the atmosphere when they exceed the limit values [1].

In the 2020 World Air Pollution Report, which covers 106 countries, Turkey ranks 46th in terms of air pollution. According to the report, the cities with the most air pollution in Turkey are; Çorum, Erzurum and Düzce. Kayseri ranks 7th in Turkey in terms of air pollution [2]. Kayseri city center has a hollow topographic structure; its east, south and southeast sides are surrounded by mountains. Due to its location and wind strength, air circulation in Kayseri is difficult to achieve, and therefore, air pollution problem arises in the city, especially in winter. Since this situation prevents the airflow in the city, the air quality of the city is adversely affected. There is an intense industrialization, rapid population growth and irregular urbanization in recent years [3]. Kayseri has three organized industrial zones (OIZ) with many industrial facilities, heavy traffic in peak hours and winter inversion that is worsens the air pollution in winter [3]. Air pollution is in the 4th priority when the environmental problems in 2015-2016 are ranked according to their importance and priorities in Kayseri [4].

Many researchers are studying on the effect of emissions resulting from the use of fuels for residential heating in the world. In the study by Khot and Chitre [5], higher levels of particulate matter were measured, especially in winter, due to seasonal conditions, as India is the third country with low quality fuel consumption, after China and the USA. In the study conducted by Kerimray et al. [6], when PM concentrations in households using coal in Ireland, Mongolia

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and China were compared; it was observed that there are significant differences in the pollution levels of the countries due to differences in ventilation, fuel quality, stove maintenance, and operation. In the study by Cichowicz [7], air pollution in Poland in terms of seasonality is high in winter and heating season, and low in summer. Higher air pollution levels during the winter months, together with emissions from household fuel consumption, is a common phenomenon due to inversion events during these periods. Yun et al. [8] stated that the housing sector in China contributed only 7.5% of the total energy consumption in 2014 but contributed 27% of $PM_{2.5}$ emissions. They determined that the contribution of coal and biomass fuels used in residential heating was high in indoor and outdoor exposure.

One of the worst air pollution levels in Turkey was experienced in Ankara in the 1970s [9]. Özşahin et al. [10] revealed that the main cause of air pollution in Keşan district of Edirne province is poor quality fuels used for heating purposes. It has been determined that the annual average concentration of pollution consists of the most SO_2 and the least NO gases. Dadaşer-Çelik and Apaydın [1] conducted a study in 105 neighborhoods selected for Kayseri province in Kocasinan, Melikgazi and Talas districts, domestic coal has a share of 1.68% in total fuel consumption, while imported coal and natural gas are 47.9% and 50%, respectively. For Kayseri, annual total SO_2 emissions are calculated as 3023 tons, total NO_x emissions as 1251 tons, total CO emissions as 9193 tons, and total PM emissions as 844 tons. Morcalı and Akan [11] stated that the biggest reason for the high amount of SO_2 pollutant in Kahramanmaraş during the 3-month winter period, when compared to other periods, is the use of different types of solid fuels during the winter months. There are other studies conducted by Hamit et. al. [12] and Buldur and Sarı [13] stating increasing air pollution levels in winter months. Lastly, Dadaşer-Çelik and Azgın [14] showed that residential heating by coal, is the main air pollutant source in Kayseri. They found that the largest contributor to total emissions was residential heating, with lignite and anthracite burning as the main source of pollution for primary pollutants including PM, SO_2 and CO. In the literature, no study has been found in an industrial city where the use of domestic coal and natural gas is proportionally compared.

In this study, the amount of emissions resulting from the use of natural gas and coal used for residential heating in the province of Kayseri for the years 2015-2019 was calculated. In addition, the contribution of residential heating and industrial emission rates were compared. Graphical and statistical relationship between the emission values calculated and the air pollution parameters in the city center was revealed.

2 Materials and methods

2.1 Study area and data used

In this study, between 2015-2019; coal and natural gas data, that is used in residences and industries in the central districts of Kayseri, and data from the air quality monitoring station were evaluated. Details about the data are given in Table 1.

Table 1. Air quality and residential fuel data used in the study

Data	Data gathered	Type of data	Data content
Air quality	havaizleme.gov.tr	Yearly average	-PM_{10} ($\mu g/m^3$) -SO_2 ($\mu g/m^3$) -NO_x ($\mu g/m^3$)
Fuel	KAYSERİGAZ	Yearly consumption	-Natural gas (Sm^3)
	KMM (Coal sales)	Yearly sales	-Coal (kg)
	KMM (social fund)	Yearly distribution	-Coal (kg)

KMM: Kayseri Metropolitan Municipality
Social fund: Fund for social cooperation and solidarity

Natural gas consumption data (between 2015-2019) was obtained from Kayseri Natural Gas Distribution Marketing and Trade Inc. (KAYSERİGAZ). Within the scope of natural gas data received from KAYSERİGAZ, the amount of natural gas used in residences for the years 2015-2019 was determined by the data obtained from the Kayseri Provincial Environmental Status Reports [15-16]. The amount of coal used in the residences in the central districts (Melikgazi, Kocasinan, Talas, Hacılar) in Kayseri Province between 2015-2019 was obtained from Kayseri Metropolitan Municipality.

The air pollution data of the city, measured at the Air Quality Monitoring Stations, were obtained from the website of the National Air Quality Monitoring Network [17]. Since 2007, air quality measurement stations have been operating in 3 regions that will represent the province, in order to measure pollutant emissions originating from fuels for heating and industrial purposes and traffic. These are the air quality measurement stations located in the Organized Industrial Zone, in the garden of the Private Melikgazi Hospital and in the Hürriyet neighborhood. PM_{10} (particulate matter), SO_2 (sulfur dioxide), CO (carbon monoxide), NO_x (nitrogen oxides) parameters are measured in these stations [18]. Air quality measurement results can be viewed online at www.havaizleme.gov.tr and historical data can be accessed [17]. Natural gas and coal data and emission amounts in industries are taken from our previous study [19]. Quality Assurance vs. Quality Control (QA/QC) of this data is periodically checked and there is a detailed procedure about reporting [20].

2.2 Calculation of emission amounts

Based on the pollutants released to the air from coal and natural gas used in Kayseri city center between 2015-2019, PM, SO_2 and NO_x emission amounts resulting from the use of fuel in the residences were calculated. The emission factor expresses the mass of the pollutant released into the air per unit of fuel, which helps to estimate the amount of fuel consumed annually and the average amount of emissions according to the type of fuel. Emission amounts are calculated with the help of the following equation.

Emission Amount = Fuel Amount x EF (emission factor) (1)

Since there are no special emission factors created in Türkiye, emission factors published by the EEA, which is the common database of European countries, are used. The emission factors, used to calculate the amount of emissions from fuels, are taken from CORINAIR [21] and the source emission factors catalog of the US Environmental Protection Agency (USEPA) [21-22]. Emission factors, used to calculate pollutant emissions from residences in this study, are summarized in Table 2.

Table 2. Industrial and residential heating emission factors [21-22].

Fuel type	PM	SO_2	NO_x
Lignite (kg/ton)	2	19.44*S	8.42
Petroleum coke (g/GJ)		500*S	300
Natural gas (kg/ton) <29 MW	0.174	0.014	4.34
Natural gas (kg/ton) >29 MW	0.174	0.014	2.28
Imported lignite (g/GJ)	404	675	110
Local lignite (g/GJ)	404	1200	110
Natural gas (residential) (kg/ton)	0.02	0.02	1.85

S:Percentage of S in fuel (%)

Two types of data were used for the amount of coal consumed by the residential heating of houses in Kayseri city center. These data are the amount of coal sold by the coal sales companies in the city and the distribution amounts of the social fund coals. Using these data, the amount of coal used for residential heating in the central districts has been reached. Ash, sulfur percentages and calorific values of the fuels needed to calculate the emission amounts are given in Table 3 and these values are taken from the fuel analysis results found in the 2015-2019 Environmental Status Reports prepared for Kayseri Province [15].

Table 3. Coal analysis results

Year	Fuel type	Lower calorific value (kcal/kg)	Lower calorific value (Gj/g)	Percentage of S (%)	Ash content (%)
2015	Imported	7336	30.71	0.32	6.98
	Local	4327	18.12	1.75	40.52
2016	Imported	6400	26.80	0.7	11
	Local	4678	19.59	1.65	28.76
2017	Imported	7690	32.20	0.45	5.3
	Local	4678	19.59	1.65	28.76
2018	Imported	7623	31.92	0.31	8.16
	Local	5030	21.06	1.56	17
2019	Imported	7262	30.40	0.45	7.86
	Local	4678	19.59	1.65	28.76

With this data, the annual emission amounts of fuels were calculated with Equation 1, using the emission factors given in Table 2. The amount of emissions caused by fuel use and the measurement results, obtained from air quality measurement stations, are shown on tables and graphics, and the relationship between fuel use and air pollution is revealed.

2.3 Statistical analysis

Emission amounts of domestic and industrial point sources were analyzed statistically with air pollution data between 2015-2019. For this, SPSS 10.0 program was used. Since some of the data are in the form of annual averages, annual average data were introduced to the program and variables with negative or positive high or low correlation were determined using the "Pearson Correlation" tool.

3 Results and discussion

3.1 Fuel consumption for residential heating

The amount of coal distributed to all Districts of Kayseri from the municipality for social fund for the years of 2015-2019 is given in Table 4. It has been determined that the amount of coal distribution, made in the central districts, constitutes 44 percent of the total distribution. Almost half of the total coal distribution in Kayseri is made to the central districts. Since 44% of coal distribution belongs to central districts by social fund, it has been accepted that 44% of total sales made in coal sales companies in Kayseri are made to central districts.

Table 4. Social fund coal amounts.

Municipality	Amount of coal (tons)				
	2015	2016	2017	2018	2019
City Center	15135	16246	16458	15301	11992
Municipalities Others	19707	22646	20704	20498	14293

The values accepted as the amount of coal sales made by the private companies to the central districts are given in Table 5. By taking the sum of the coal distributed by the social fund for the central districts and the coal sales by the coal sales companies, the total amount of coal used for residential heating in the central districts has been obtained. In addition, data on the amount of domestic natural gas consumption in Kayseri Province in the 2015-2019 periods are given in Table 5.

Table 5. Coal sales and total coal and natural gas amounts in the central districts of Kayseri Province

Parameter	2015	2016	2017	2018	2019
Coal Sales (Ton)	85350	81683	63305	52876	47623
Total Coal (Ton)	100485	97929	79763	68177	59615
Natural gas (Sm^3, million)	303.9	361.9	375.8	362.7	396.4

3.2 Emissions from domestic heating and total emissions

Emission calculations were made with this assumption: 80% of the coal used in Kayseri is imported coal and 20% is domestic coal [15]. In Table 6, the total emission amounts of natural gas used in residences and coal sources used for domestic heating are given.

Between 2015 and 2019, the total PM emission amount due to coal use in residential heating was 4603 tons, SO_2 emission amount was 8521 tons, NO_x amount was 1253 tons. The total amount of natural gas emissions from residential

heating is 28 tons for PM, 28 tons for SO_2 and 2598 tons for NO_x. According to these data, it was seen that PM and SO_2 emissions were caused by coal, while NOx emissions were mostly caused by natural gas.

Table 6. Emissions from fuels used for residential heating

Year	Natural gas (tonnes)			Coal (tonnes)		
	PM	SO_2	NO_x	PM	SO_2	NO_x
2015	4.7	4.7	438.6	1144	2103	311
2016	5.6	5.6	522.2	1003	1877	273
2017	5.8	5.9	542.3	956	1761	260
2018	5.6	5.7	523.4	819	1519	223
2019	6.2	6.2	572.0	680	1258	185

In Table 7, the emission amounts of the fuels used for energy production in residences and industries in the five-year period between 2015-2019 are given. According to this; a total of 4631 tons of PM, 8549 tons of SO_2 and 1256 tons of NO_x emissions were generated. The total amount of these emissions originating from solid fuels used for energy production in residences and industries was 6171 tons for PM, 9049 tons for SO_2, and 14179 tons for NO_x. It is also illustrated in Figure 1.

Table 7. Emission amounts due to fuel consumption for residential heating and energy generation in industries

	Residential heating			Industrial energy generation		
Year	PM (tonnes)	SO_2 (tonnes)	NO_x (tonnes)	PM (tonnes)	SO_2 (tonnes)	NO_x (tonnes)
2015	1,149	2,108	750	307	100	1,969
2016	1009	1,883	795	306	100	2,032
2017	962	1,768	803	317	101	2,132
2018	825	1,525	746	307	100	2,079
2019	686	1,265	757	303	99	2,116

While the contribution of fuel use in residences to PM and SO_2 emissions is high, the contribution of fuel use in industries is high for NO_x. In this case, it can be said that point sources caused by residential heating affect PM and SO_2 more than industrial fuel use for energy generation, while industrial point sources affect NO_x parameter more.

3.3 The relationship between fuel use and air pollution in residences

On the website of the National Air Quality Monitoring Network, annual average measurement results of PM_{10}, SO_2 and NO_x pollutants between 2015 and 2019 were obtained from three stations in Kayseri [17]. By taking the average of the annual measurement results of the three stations, the measurement results for that year were obtained for Kayseri.

The relationship between the annual amount of emissions caused by the use of i) coal and natural gas (total) in residences and total coal and natural gas use (residential and industrial) of Kayseri between the years 2015-2019 and the annual average measurement results obtained from air quality measurement stations are examined and presented in Figure 2 to 4 for these three pollutants.

When the PM_{10} measurement results recorded in Kayseri and the amount of PM emissions resulting from the use of fuel in the residences are examined, it is seen that increases and decreases are in similar trend (Figure 2-a, b). While the annual average measurement result of the parameter was 80.5 $\mu g/m^3$ in 2015, the average measurement result was 79.4 $\mu g/m^3$ in 2016. The same decrease occurred in the amount of emissions as seen in the graph. Since 2017, it is seen that the measurement values have decreased in parallel with the decrease in the amount of coal use. It has been determined that the effect of the increase in the amount of natural gas usage on the PM parameter is realized at a very low rate compared to coal. With the decrease in the use of coal in the city and the increase in the use of natural gas, it has been determined that the PM_{10} concentration has decreased in general every year during the period covering the 2015-2019 year. Similarly, in another study, it was determined that there was a decrease in PM_{10} values between 2005 and 2015 in Turkey, and the effect of the transition from coal use to natural gas use in cities over the years was high [23]. When the graph related to the total emission amounts originating from coal and natural gas use in industry and residences is analyzed, it is seen that there are increases and decreases in a similar trend to the amount of residential emissions. This shows that the use of natural gas and coal for residential heating has a high contribution to the total amount of emissions.

When the emission amounts resulting from the use of fuel in residences and the annual average measurement results for the SO_2 parameter are evaluated, increases and decreases are in agreement with the years; 2016, 2017 and 2018 (Figure 3). Again, correspondence is expected between the emission amounts resulting from the amount of coal use in the industries and the measurement values, while there has been an increase in SO_2 measurement results, despite the decrease in coal use between the years 2015-2016. In 2019, while there was a decrease in the amount of emissions, the average measurement result of the parameter increased compared to the previous year. Since there will be no traffic-related interference in this situation, it can be mentioned that there is unknown source of fuel with high sulfur content. This increase in SO_2 concentration may be due to the illegal trade or displacement of social fund coals or quality change, like change in sulfur content. The total emission amount graph was also the same with the residential emission amount, as in PM.

For the NO_x parameter, there was both an increase and decrease in the concentration in similar trend with the emission amount (Figure 4-a). It was seen that the measured NO_x concentration increased with the increase in the amount of NO_x emission except for the year 2018 which has decreasing trend. Considering that NO_x emissions contribute to ozone formation, it is thought that this situation may provide a basis for measuring high ozone concentrations for Kayseri Province in the future. In Figure 4-b, it is seen that total emissions do not fluctuate. However, it is clearly seen that there is an uptrend both in NO_x emissions and yearly average concentrations.

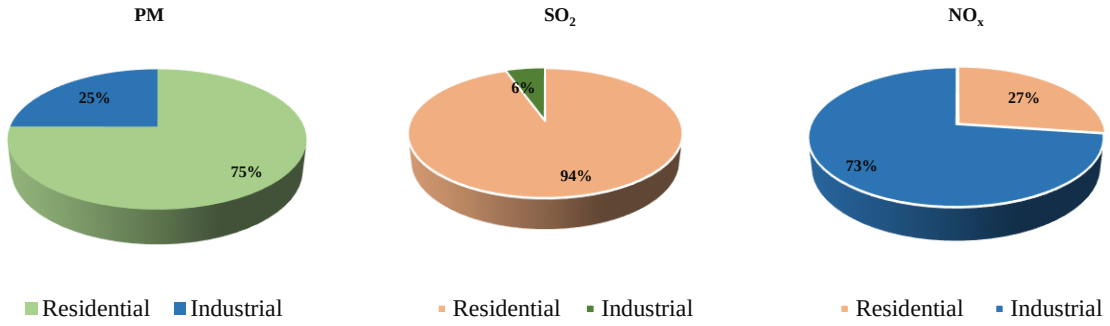
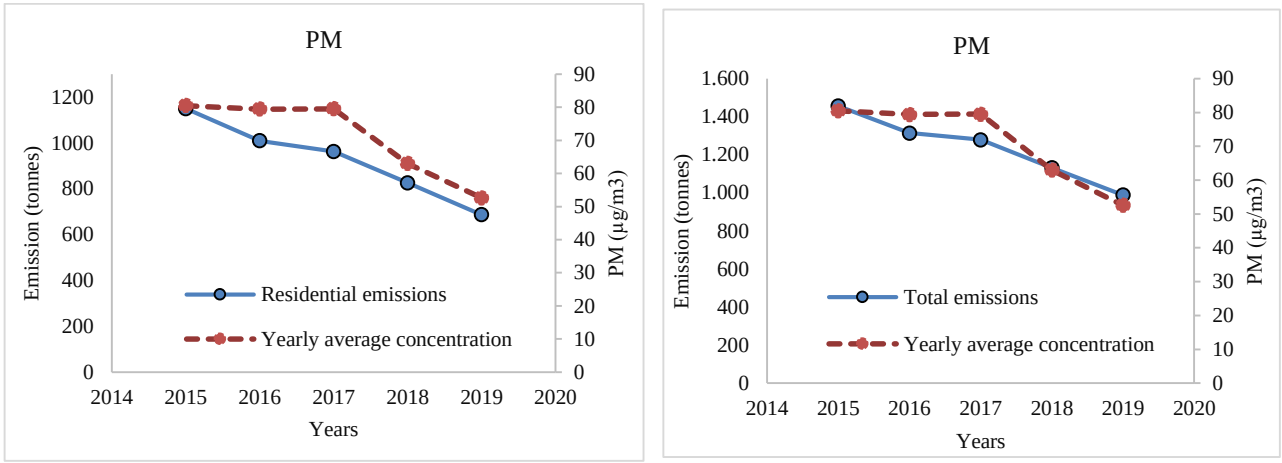
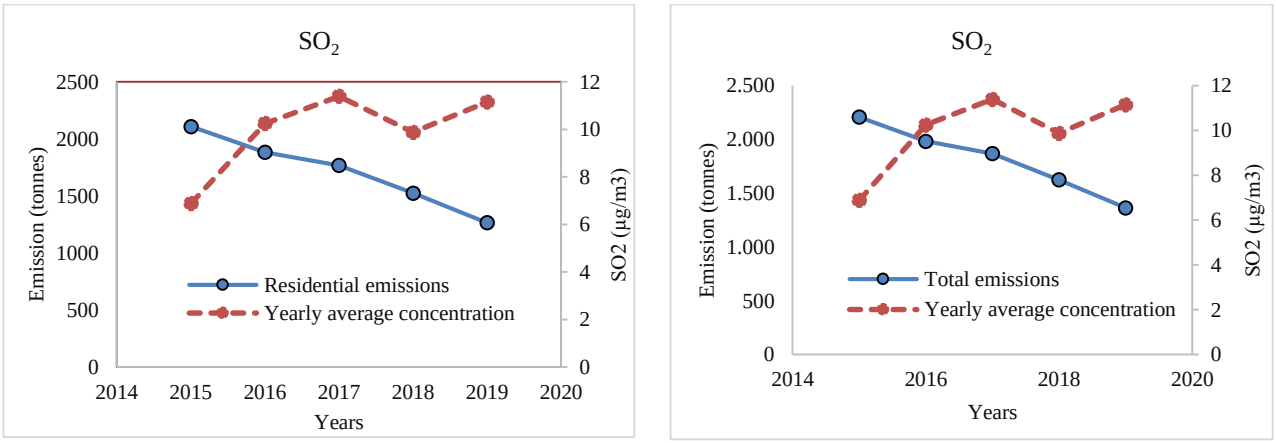


Figure 1. Rates of emissions resulting from fuel use for residential heating and industrial energy generation between 2015-2019



(a) (b)

Figure 2. Comparison of PM emission amount and PM_{10} average measurement results (a) Residential emissions (b) Total emissions



(a) (b)

Figure 3. Comparison of SO_2 emission amount and SO_2 average measurement results (a) Residential emissions (b) Total emissions

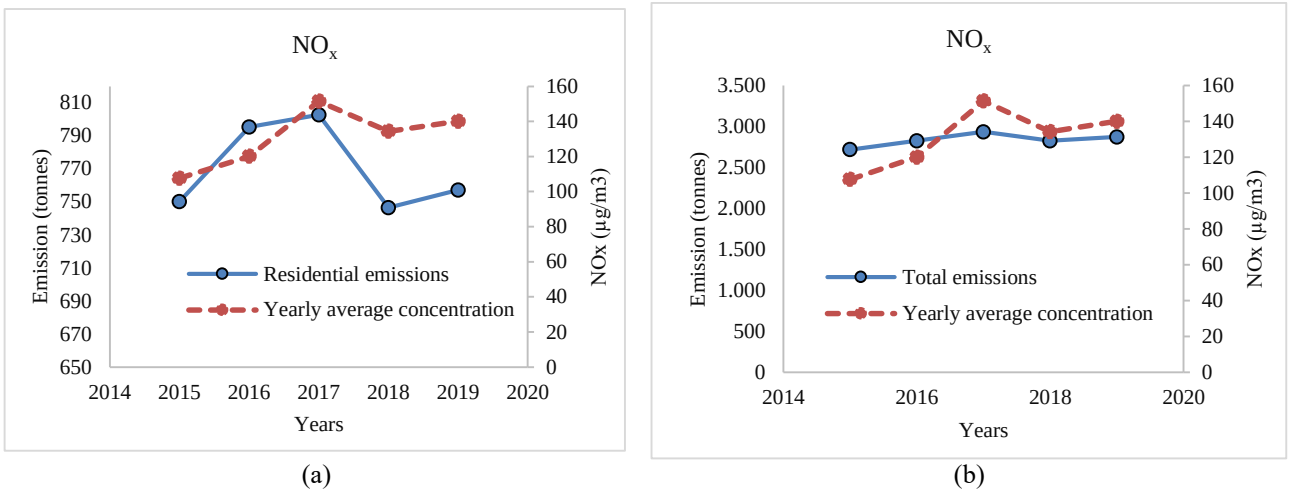


Figure 4. Comparison of NO_x emission amount and NO_x average measurement results (a) Residential emissions (b) Total emissions

Table 8. Statistical evaluation for concentrations and emissions

		C_{PM}	C_{SO2}	C_{NOX}	$PM_{emission}$	$SO2_{emission}$	TNOX
	Pearson Correlation	1	-,394	-,386	**,941***	**,938***	-,236
C_{PM}	Sig. (2-tailed)		,512	,521	,017	,018	,702
	N	5	5	5	5	5	5
	Pearson Correlation	-,394	1	,877	-,680	-,683	**,953***
C_{SO2}	Sig. (2-tailed)	,512		,051	,207	,204	,012
	N	5	5	5	5	5	5
	Pearson Correlation	-,386	,877	1	-,627	-,656	**,950***
C_{NOX}	Sig. (2-tailed)	,521	,051		,257	,230	,013
	N	5	5	5	5	5	5
	Pearson Correlation	,941*	-,680	-,627	1	**,998****	-,533
PM emission	Sig. (2-tailed)	,017	,207	,257		,000	,355
	N	5	5	5	5	5	5
	Pearson Correlation	,938*	-,683	-,656	,998**	1	-,552
TSO2	Sig. (2-tailed)	,018	,204	,230	,000		,335
	N	5	5	5	5	5	5
	Pearson Correlation	-,236	,953*	,950*	-,533	-,552	1
TNOX	Sig. (2-tailed)	,702	,012	,013	,355	,335	
	N	5	5	5	5	5	5

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

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

Air pollution has been an important problem for Kayseri Province due to its climatological and topographic structure [14]. It has been also concluded that the NO_X parameter is largely composed of emissions from industries. According to the studies conducted at the end of 2015 in Kayseri Province, it has been determined that the primary sources causing air pollution are emissions from heating with a rate of 40%. This is followed by emissions from traffic with a rate of 30%, other factors with a rate of 20%, and topography and meteorological factors with a rate of 10% [4]. More studies are needed, like multivariate analysis, to investigate all factors affecting the air pollution [24]. In this study, air pollution trends follow the residential sourced emissions in PM and NO_x. Therefore, traffic induced air pollution may have low impact on air pollution trend. This may be due to

the ubiquitousness of the traffic effect on air quality monitoring stations.

Again, in a study conducted in Kayseri, it was stated that residential heating, in which a significant amount of coal is used in the city, is the main source of air pollutants [14]. In addition, studies conducted in the provinces of Kütahya, Erzurum, Batman and Isparta in our country have concluded that the effect of fuels used for heating housing on air pollution is high [12-13]. In a study conducted in Erzurum, it was emphasized that with the widespread use of natural gas for heating purposes in the city, the PM_{10} concentration decreased compared to the period before the use of natural gas [25]. In a study conducted in China, it was reported that PM_{10} concentration is mainly contributed from domestic heating [26].

3.4 Statistical evaluation

Statistical analysis of all emission amounts and air pollution concentrations was made and it was determined whether there was a significant correlation. The correlation of the total emission of each parameter revealed by the coals burned and the natural gas used for energy production in the industries and the average concentration of the pollutant parameters taken from the air pollution measurement stations in Kayseri province were investigated. According to the results in Table 8, there is a significant correlation between the amount of PM emission and the amount of SO_2 emission. Also, PM concentration is highly correlated to both PM and SO_2 emissions. For this reason, it can be said that coals burned for industrial energy production affect both SO_2 emissions and PM_{10} emissions. Other emission sources should not be overlooked here. Therefore, it cannot be said that only coals burned in power plants affect SO_2 emissions. In addition, NOx emissions were also found to be correlated to SO_2 and NOx concentrations.

4 Conclusion

In this study, annual emission amounts of PM, SO_2 and NO_x parameters were calculated over the coal and natural gas consumption amounts used in the houses located in the areas covering the central districts of Kayseri Province between 2015-2019. Also, annual average air quality measurement parameters of PM_{10}, SO_2 and NO_x and the amount of emissions caused by fuel use are compared. It has been concluded that the effect of coal use in residences on pollutant emissions except for NO_x in Kayseri is higher than the use of natural gas. In addition, when the emission amounts due to fuel use and the emission measurement results are evaluated, it has been determined that the increase in the use of natural gas in the city and the decrease in the amount of coal use cause a decrease in the amount of PM_{10}, especially due to the change in the amount of emissions. It is thought that factors other than natural gas and coal use (use of other low quality fuels, etc.) have a significant effect on the reason for the increase and decrease in SO_2 amount. It has been concluded that the contribution of natural gas use to the increase in NOx emission is high.

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Conflict of Interest

There is no conflict of interest.

Similarity Rate (Turnitin): 12%

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