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Forecasting of Primary Air Pollutions: Emission Inventory Sample from Turkey

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Abstract

This study presents an air pollutant emission inventory of primary pollutants for Kayseri, Turkey. Kayseri is one of the largest cities in Turkey which went through industrialization in recent decades together with rapid population growth. Air pollution from residential, industrial, and transportation sources have been a major problem for Kayseri during this period. In this study, emissions of four primary pollutants, namely, particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NOx), and carbon monoxide (CO) were estimate. The sources of air pollutants in Kayseri were classified as point, area, and line sources. The emissions from point and area sources (i.e., industrial and residential areas) were estimated by using the information on types and amounts of fuels used. The emissions from line sources (i.e., transportation) were estimated by using the vehicle count data on major roads. The appropriate emission factors were obtained from the Unites State Environmental Protection Agency or European Environment Agency. The results showed that the annual emission rates for PM, SO_2, NO_X and CO were 2929 tons,5082 tons, 6791 tons and 37094 tons, respectively. Area sources are responsible for 86%, 94%, and 75% of total PM, SO_2, and CO emissions, respectively. Point sources provide about 56% of total NO_X emissions. In order to improve the air quality of our cities, it is envisaged that control measures should be taken especially for reducing the residential emissions caused by heating and the determination of national emission calculation factors in order to achieve more reliable results.

Keywords
Emission Inventory, Primary Air Pollutants, Kayseri, Turkey

Birincil Hava Kirleticilerin Tahmini: Türkiye'den Emisyon Envanteri Örneği

Özet

Bu çalışmada Türkiye'deki hava emisyon envanter açığını kapatmak amacıyla Türkiye'de Orta Anadolu'nun büyük şehirlerinden biri olan Kayseri özelinde endüstriyel tesisler, konut ısınması, ulaştırma ve çizgi kaynaklı kirleticilerin emisyon miktarlarının hesaplanması amaçlanmıştır. Birincil hava kirleticileri olarak PM, SO_2, NO_X ve CO parametrelerinin değerlendirildiği çalışmada Amerika Birleşik Devletleri Çevre Koruma Ajansı (USEPA) ve Avrupa Çevre Ajansından (EEA) elde edilen kütle bazlı ve görev bazlı emisyon faktörleri kullanılarak emisyon miktarları hesaplanmıştır. Ayrıca kullanılan yakıtların miktarı ve kullanılan araç türü/kilometre gibi uygun aktivite bilgileri de emisyon envanteri oluşturulması için hesaplamalarda değerlendirilmiştir. Çalışma sonucunda Kayseri şehrine ait yıllık toplam emisyon miktarları PM, SO_2, NO_X ve CO için sırasıyla 2929 ton, 5082 ton, 6791 ton ve 37094 ton olarak hesaplanmıştır. Konut ısınmasından kaynaklı PM, SO_2 ve CO emisyon miktarlarının şehrin toplam emisyon salınımının sırasıyla %86, %94 ve %75'inden sorumlu olduğu ortaya çıkarılmıştır. Endüstriyel tesislerden salınan emisyon miktarının da NO_X parametresi bazında toplam emisyonun %56'sını karşıladığı sonucuna varılmıştır. Şehirlerimize dair hava kalitesinin iyileştirilmesi adına özellikle ısınmadan kaynaklı kentsel emisyonların azaltılması için kontrol edici önlemlerin alınması gerekliliği ve daha güvenilir sonuçlara ulaşabilmek adına ulusal emisyon hesap faktörlerinin belirlenmesi gerekliliği öngörülmüştür.

Anahtar Sözcükler
Emisyon Envanteri, Birincil Hava Kirleticileri, Kayseri, Türkiye

1. Introduction

Air pollution originating from combustion of biomass and fossil fuels is one of the main environmental problems in metropolitan areas. Establishment of an emission inventory is a crucial step toward control of air pollution. Emission inventories provide the knowledge of the types of pollutants and their emission rates, thus contribute to the development of more efficient emission control strategies. They also help evaluate air quality where sufficient monitoring data are unavailable. Data acquired directly from pollution sources through emission monitors are preferable for estimating emissions. However, this is almost impossible when many sources are involved and when emission rates are variable over time. The use of emission factors with the appropriate activity information provides the best or the most suitable method for estimating emissions (Elbir et al. 2000; Khatami et al. 1998; Zhang and Morawska 2002).

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There are many studies about air quality (Akkoyunlu and Ertürk 2002; Dadaser-Celik and Kirmaci 2011; Demirayak et al. 2011; Menteşe et al. 2009; Onat and Sahin 2012; Özdemir et al. 2010) but only a few emission inventories available in the literature for Turkish metropolitan areas. Elbir and Muezzinoglu (2004) prepared air pollutant emission inventory of primary pollutants for Izmir. Cetin et al. (2007) developed emission inventory for the primary air pollutants for the Kocaeli city center, which is a highly industrialized area situated in the western part of Turkey. Özden et al. (2008) presented an assessment of air quality of the city Eskişehir for five major pollutants. As can be seen from the previous literature, Turkey emission inventories were developed for large and the most industrialized cities. Information regarding the medium-scale cities in Turkey is not available. In this study, we developed an inventory of primary air pollutants in the city of Kayseri, in Turkey.

In this study, with an emission inventory, we aim to evaluate the air pollution levels in Kayseri and evaluate the contribution of different sources (residential heating, industrial activities, and transportation) to air pollution. The pollutants considered in this study include PM, SO_2, nitrogen oxides (NO_X), and carbon monoxide (CO). With this study, we will be able to obtain the first estimates of NO_X and CO pollution caused by various sources. A qualitative assessment of the uncertainties will be given to discuss the possible errors in estimations. The methods used in this study can be used for estimating emissions in other metropolitan areas. The results produced provide insights regarding the contributions of various combustion sources to air pollution in metropolitan areas.

2. Material and Methods

Kayseri is a medium-scale metropolitan city, located at the center of Anatolia. Continental climate with cold winters and hot summers is prevalent in Kayseri; therefore, energy consumption for residential heating is quite high during the heating season. Kayseri has also undergone a dense industrialization in recent decades, which was followed by a rapid population growth and an irregular urbanization in recent decades (Figure 1). The population in Kayseri has increased at rate of about 7.1% per year in the last 5 years and it reached to about 1.389 million in 2018 (TUİK 2018). Although there are no power plants or large-scale factories in the city, busy traffic arteries, three organized industrial zones (OIZ) with over 1200 industrial facilities, and residential heating constitute the potential sources of air pollutants. Due to its climatological and topographical setting, air pollution has been a major problem for Kayseri for decades. Annual average concentrations of sulfur dioxide (SO_2) and particulate matter (PM), which are two air pollutants routinely monitored in Turkey, reached up to 157 $\mu g/m^3$ and 98 $\mu g/m^3$ in early 1990s, respectively (Dadaser-Celik and Kirmaci 2011). A recent analysis of the trends in SO_2 and PM levels in Kayseri showed that a gradual improvement in SO_2 levels was realized since 1990s (Dadaser-Celik and Kirmaci 2011). This improvement is speculated to be related to the availability and use of natural gas and precautions taken to control the use of low-quality coal to the city. However, no formal studies were conducted to evaluate the contributions of different sources (i.e., residential heating, industrial activities, and transportation) to air pollution in the city. PM concentrations are still high, which poses significant health risks. During the 2016-2017 heating season, average concentration of PM10 was 103.5 $\mu g/m^3$ (URL-1 2017). This value is much higher than the standards set by World Health Organization and European Commission (EEA 2010).

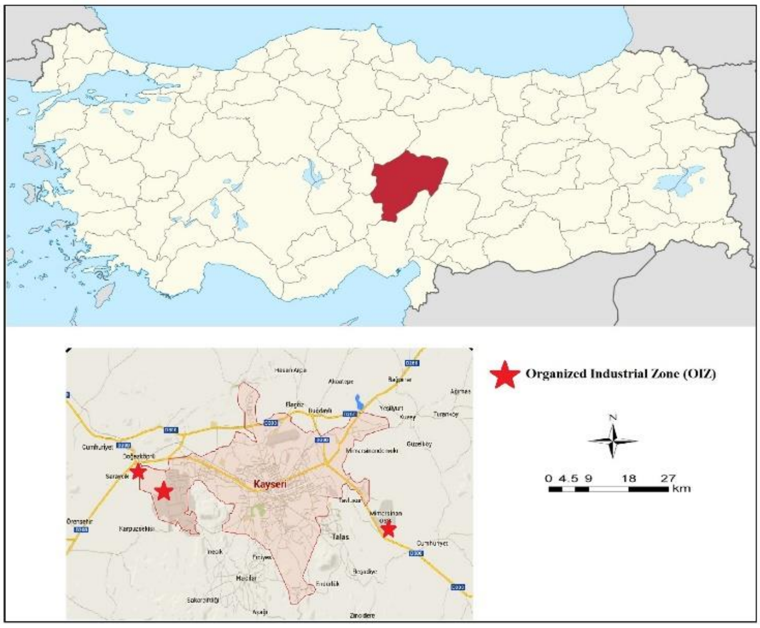

Figure 1: The location of Kayseri in Turkey and Kayseri city center (URL-2 2018)

An emission inventory was prepared for Kayseri by taking into account all possible emission sources. The pollutant sources were classified into three groups as point sources (industries), area sources (residential heating), and line sources (transportation on urban roads) to cover all possible sources. Emissions from these sources were estimated by using appropriate emission factors depending upon the types and amounts of fuels used (EPA 1996a; EPA 1996b; EPA 1998; EEA 2009; Liberti et al. 2009). Emission factors are not readily available in Turkey so, previous studies used emission factors (Elbir et al. 2000; Elbir and Muezzinoglu 2004; Kunzli et al. 2000) developed by international institutions (such as European Environmental Agency-EEA or United States Environmental Protection Agency-USEPA) An emission factor is typically defined as the amount of a concerned pollutant emitted per unit mass of fuel burned (mass-based) or per a defined task performed (task-based) (Liberti et al. 2009). The unit of task-based emission factor depends on the definition of tasks. For example, for road transportation, the task will be certain distance driven by a motor vehicle and thus the unit of the emission factor will be kilograms of pollutant emitted per kilometer driven (i.e., kg/km) (Gertler et al. 1998; Winebrake and Deaton 1999). Mass-based emission factors are preferable, when quantities of the fuels consumed are available (Gertler et al. 1998; Winebrake and Deaton 1999). These emission factors will have a unit such as kilograms of pollutant emitted per kilogram of fuel burned (i.e., kg/kg).

In general, Equation 1 can be used to calculate emissions. In Equation 1, EF is the emission factor, activity is the activity in consideration, and *a* and *b* represent the fuel type and sector-activity, respectively. For example, for estimating PM emissions from residential heating, EF will be mass of PM emitted per unit of fuel consumed and the activity data will be mass of fuel consumed during a specific period. For estimating NOx emissions from road transport, EF will be mass of NOx emitted per kilometers traveled and activity data will be total kilometers traveled during a specific period. Below, the details about emission calculations were provided.

$$\text{Emissions} = \sum(\text{EF}_{\text{ab}} \text{ x Activity}_{\text{ab}}) \quad (1)$$

2.1 Point Sources

Point sources represent the emissions from industrial plants. To estimate the emissions from point sources, we used the information on the total amount of fuels used by industries. In Kayseri, there are three separate OIZs (Figure 1). Recently established two OIZs, Mimarsinan and Incesu, are located outside of the city center and include only a few basic industrial facilities. The third industrial complex, Kayseri OIZ, is located within the boundaries of the city center and includes over 1200 industrial facilities. There are also a few industrial plants distributed randomly in and around the city center. Major industrial activities in these plants are furniture and home textile (Figure 2).

Natural gas is one of the major combustion fuel used in industries. A few individual plants use some other fuels, such as wood and coal. The fuels are mainly used to produce industrial process steam and heat the industrial plant. To estimate emissions from natural gas use, we obtained the total amount of natural gas used by the Kayseri OIZ for the year 2018 from KAYSERIGAZ, the company responsible for the distribution of natural gas in Kayseri. In our calculations, we assumed that the heating capacity of 20% of the plants is higher than 29 MW, while that of 80% of the plants is lower than 29 MW (KAYSERIGAZ 2018). We were not able to reach the amount of wood used by the industries, as wood is the by-products of production processes and no data are recorded by the companies. As the amount of wood used is estimated to be very minor compared to other fuels, we did not include the emissions from it. Coal is used only by a large plant and a few small plants. In our calculations, we used the data on coal used by the largest industrial installation in the study area for the year 2018 (Kayseri Seker A.S). To calculate the emissions from coal consumptions, we assumed that sulfur content is 2%, which is the average of the sulfur content in lignite produced in Turkey (URL-3 2018). The emission factors used in the calculations were obtained from USEPA. Emission factors given in Table 1 show that the emissions from natural gas are lower than the emissions from coal per unit of fuel consumed.

Table 1: Emissions factors used to calculate the emission rates for the fuel combustion in industries (EPA 1996b; EPA 1998)

Fuel	Heating capacity of the boiler, (MW)	PM[a] (kg t^{-1})	SO_2 (kg t^{-1})	NO_x (kg t^{-1})	CO (kg t^{-1})
Natural Gas	<29MW	0.174	0.014	4.34	1.91
	>29MW	0.174	0.014	2.28	1.91
Coal (Lignite)	-	2	19.44S[b]	8.42	0.161

[a] *To calculate PM emissions from natural gas, total (filterable + condensable) PM emission factors were used.*
[b] *S=sulfur content of coal (% by weight)*

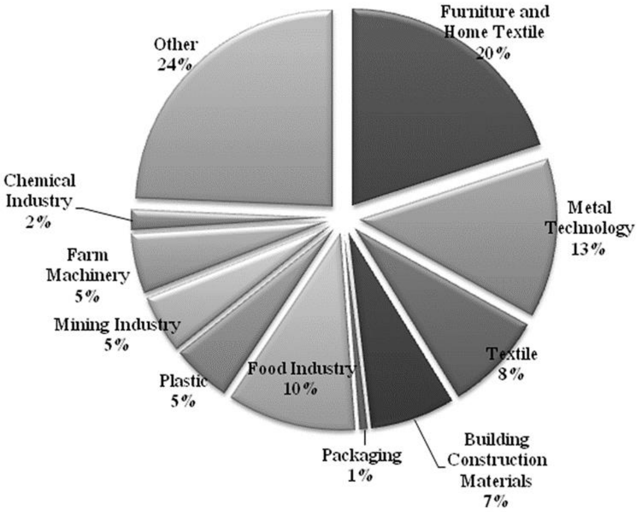

Figure 2: Distribution of industrial sectors in Kayseri

2.2 Area Sources

Residential heating was considered as the area sources. The pollutant emission rates from these sources were calculated based on the amounts of different fuels consumed for residential heating in Kayseri. In residential heating, natural gas and coal (anthracite and lignite) are used. The data on amount of coal (anthracite or lignite) use in the year 2016 were obtained from the General Directorate of Environment in Kayseri (URL-4 2015). Similar to other cities in Turkey, we assumed that 80% of the coal is burned with stove and 20% by medium-size boilers (Odabaş 2009). The data on amount of natural gas use in residential heating were obtained from KAYSERIGAZ. To calculate emissions from natural gas use, based on the data received from KAYSERIGAZ, we assumed that 42% of the natural gas is burned in stove (combi boiler) and the remaining 58% is burned in the small/medium size boilers (KAYSERIGAZ 2018).

The annual emission rates were calculated by multiplying the amounts of fuels with the corresponding emission factors given in Table 2. The emission factors were obtained from EEA. From the emission factors, we can see that the rates of pollutant emissions are significantly variable for different fuels and combustors. The emissions from natural gas combustion are comparatively lower than emissions from coal combustion per unit of fuel used. Anthracite has much lower sulfur content (0.6-0.77%) than lignite coal, thus has lower emissions (USGS 2006). The combustion with small/medium size boilers instead of stove (combi boiler) produces fewer pollutants with the same fuel.

Table 2: Emissions factors used to calculate emission rates for residential heating (EEA 2006)

Fuel	Heating type	PM (kg t^{-1})	SO_2 (kg t^{-1})	NO_x (kg t^{-1})	CO (kg t^{-1})
Natural Gas	Stove (combi boiler)	0.02	0.02	2.46	1.48
	Small size boiler ≤50 kW	0.02	0.02	3.45	1.48
Coal (Anthracite)	Stove	12.08	17.98	2.68	133.76
	Medium size boiler 50 kW-1 MW	5.04	17.98	4.28	53.5
Coal (Lignite)	Stove	9.03	35.93	2.01	100.32

2.3 Line Sources

Pollution caused by road transportation is covered under line sources. The emission rates from road transportation were estimated by using the data on number and type of vehicles (i.e., automobile, light-duty vehicles, etc.) registered in traffic in Kayseri (TUIK 2017; URL-4 2015). We calculated the emissions by automobiles with diesel, gasoline, and liquefied petroleum gas (LPG) engines. According to Turkish Statistical Institute (TUIK) about 40% of the cars in Turkey use LPG, 35% use gasoline, and 25% use diesel fuel in Turkey (TUIK 2017). We assumed that these numbers are also valid for Kayseri. The emission factors used to compute the emission rates from vehicles were given in Table 3. In selecting the emission factors, we assumed that the vehicles move at an average rate of 50 km h^{-1} (EEA 2009).

Also, the annual distance of whole vehicles selected 7500 km (Ağçayak 2007). The emissions factors show that larger vehicles produce larger amounts of pollutants.

Table 3: Emission factors used to calculate emission rates for different vehicle types (EEA 2009)

Fuel/Vehicle Type		PM ($g\ km^{-1}$)	NO_x ($g\ km^{-1}$)	CO ($g\ km^{-1}$)
Automobile	Gasoline	ND[a]	1.35	7.52
	LPG	ND[a]	2.16	7.1
	Diesel	0.20	0.66	0.71
Light Duty Vehicles		0.29	1.43	1.58
Bus		$7.86xV^{-0.736b}$	$89.174xV^{-0.5185b}$	$59.003xV^{-0.7447b}$
Diesel Heavy Duty Vehicle 7.5 t < W < 16		$9.6xV^{-0.72b}$	$92.58xV^{-0.73b}$	$37.28xV^{-0.6945b}$
Diesel Heavy Duty Vehicle W >32t		$11.02xV^{-0.696b}$	$132.88xV^{-0.55b}$	$37.28xV^{-0.6945b}$

[a] *ND: No data*
[b] *Based on the velocity of $V=50\ km\ h^{-1}$*

3. Results

Annual emission rates of the pollutants from point, area, and line sources were evaluated for Kayseri and the results are provided under separate sections below. Comparisons of pollutant emissions from different sources are also given.

3.1 Emissions from Point Sources

The emissions from point sources are due to the use of natural gas or coal for energy production at the industrial plants. As mentioned above, except for a few industrial plants, natural gas is dominantly used by industries in Kayseri. To calculate the emissions from coal use, we obtained the amount of coal used by the largest plant in Kayseri, which was 30600 tons in 2010. Natural gas use in the same year at the all other industrial plants was about 2 million tons. The emission rates calculated for point sources were summarized in Table 4. Total annual emissions from point sources were calculated as 103 tons, 284 tons, 1373 tons and 611 tons for PM, SO_2, NOx, and CO, respectively. Combustion of coal (lignite) by the largest industrial process is responsible for 98% of total amount of SO_2 emissions from point sources, while natural gas combustion in the industrial plants is the most significant source for PM, NOx and CO emissions (Table 4).

Table 4: Total annual emissions from point sources

Fuel	Heating capacity of the boiler	PM ($t\ yr^{-1}$)	SO_2 ($t\ yr^{-1}$)	NO_x ($t\ yr^{-1}$)	CO ($t\ yr^{-1}$)
Natural Gas	<29MW	44.37	3.57	1106.79	487.09
	>29MW	11.09	0.89	145.36	121.77
Coal (Lignite)	-	48.00	279.94	121.25	2.32
Total		103.47	284.40	1373.40	611.18

3.2 Emissions from Area Sources

The emissions from area sources are due to the use of natural gas or coal for residential heating. These emissions depend on many factors such as severity of winter, population density type, and amount of fuel used. In Kayseri, total amount of anthracite, lignite coal in 2016 and natural gas used in 2018 were 214000 tons, 26350 tons, 202659 tons, respectively. Coal is the dominant fuel type used for residential heating, constituting about 65% of fuel use. Majority of coal used in Kayseri is anthracite, due to the restrictions related to sulfur content of the coal sold in Kayseri. There is an increasing tendency to use natural gas in residential heating. Therefore, the contribution of natural gas is expected to be much higher in near future (Figure 3).

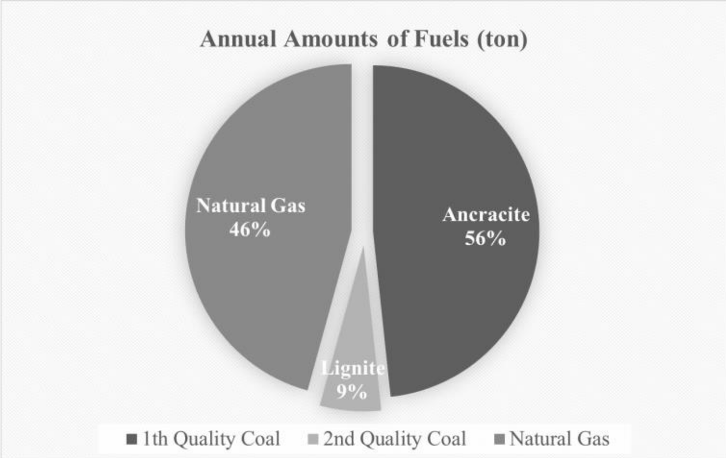

Figure 3: Fuel types used for residential heating activities in Kayseri (URL-3 2018)

The emission rates calculated for area sources were summarized in Table 5. Total emissions from area sources were calculated as 2527 tons, 4798 tons, 1268 tons, and 28115 tons for PM, SO_2, NOx and CO, respectively. The most significant emissions from area sources were SO_2 and CO. More than 90% of the SO_2 emissions from residential heating results from the lignite and anthracite combustion in the residential areas. For CO emissions, the major contributor is coal combustion in stoves. Natural gas combustion contributes most to NOx emissions and coal combustion contributes most to PM emissions.

Table 5: Total annual emission from area sources

Fuel	Heating type	PM (t yr^{-1})	SO_2 (t yr^{-1})	NO_x (t yr^{-1})	CO (t yr^{-1})
Natural Gas	Stove	1.70	1.70	209	126
	Small size boiler ≤50 kW	2.11	2.11	364	156
Coal Anthracite	Stove	2068	3078	459	22900
	Medium size boiler 50 kW-1 MW	217	770	183	2290
Coal Lignite	Stove	238	947	53	2643
Total		2527	4798	1268	28115

3.3 Emissions from Line Sources

The emissions from line sources are created by combustion of fuels by vehicles. The data related to the number of vehicle types in Kayseri city center in 2016 were summarized in Figure 4. Automobiles were the major vehicle types on roads. About 40% of all vehicles consist of automobiles. Table 6 presents the contribution to total emissions from road transportation according to different vehicle types. Automobiles provide the largest amount of CO and NOx emissions. Heavy duty trucks are responsible for the largest amounts of PM. Results showed that about 86% of all CO emissions and 46% of all NOx emissions were provided by the automobiles.

4. Discussion

4.1 Total emissions

Figure 5 shows the contribution of various sources to the total PM, SO_2, NOx, and CO emissions in Kayseri. Total annual emission rates were 2929 tons, 5082 tons, 6791 tons, 37094 tons for PM, SO_2, NOx, and CO, respectively. Areal sources are largest contributor in the pollution load for PM and SO_2 emissions in Kayseri. About 86% of all PM emissions and 94% of all SO_2 emissions were provided by areal sources. This is caused by the use of high amounts of coal in residential heating. About 21% of coal used in Kayseri was lignite in 2010, which has high sulfur content and lower calorific value compared to anthracite. PM emissions from coal were also significant. Point sources constituted the other source for PM and SO_2, but their contribution was comparatively lower, as coal was used by only a few industrial plants in Kayseri. For PM, a minor amount (10%) of emissions was caused by road transmission.

Table 6: Total annual emissions from line sources

Vehicle Type		PM ($t\ y^{-1}$)	NO_x ($t\ y^{-1}$)	CO ($t\ y^{-1}$)
Automobile	Gasoline	-	602	3356
	LPG	-	1102	3621
	Diesel	64	210	226
Automobile Total		64	1914	7203
Light Duty Vehicles		94	461	510
Bus		14	374	122
Diesel Heavy Duty	7.5<weight<16t	110	1023	473
Diesel Heavy Duty	>32t	18	377	60
Total		299	4150	8368

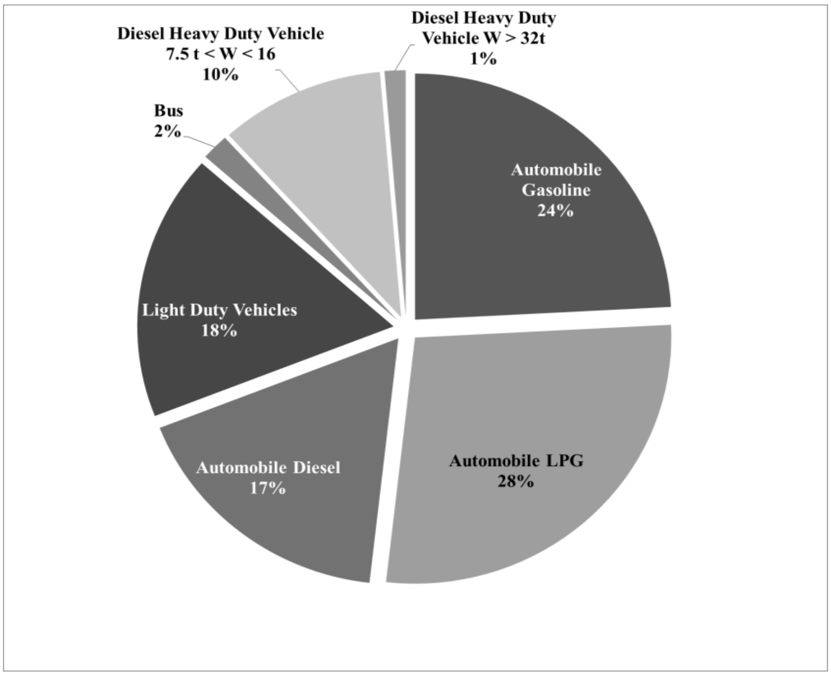

Figure 4: Average number of vehicles on major roads in Kayseri (TUIK 2017)

The contribution of transportation was largest (61%) to total NOx emissions in Kayseri. On the other hand, natural gas is the major fuel type used in industrial plants. About 20% of NOx emissions are provided by point sources and the remaining 18% are provided by area sources. For CO, majority of the emissions (75%) are provided by area sources. Contributions of point and line sources were about 2% and 22%, respectively.

4.2 Uncertainties in emission estimations

An uncertainty analysis should be conducted to evaluate the reliability of the results in an emission inventory (Ho and Dinh 2008; Zheng et al. 2009). Qualitative, semi-quantitative, and quantitative approaches can be employed for this purpose (Miller et al. 2005). In this study, we conducted a qualitative assessment of uncertainties. Qualitative assessment does not provide explicit quantitative comparison of uncertainties for different emission factors or inventories, however, it presents a quick and less data-intensive approach (EPA 1997). In this study, we evaluated the uncertainties by assessing the reliability and accuracy of data sources, estimation methods, and uncertainty in emission factors for different source categories.

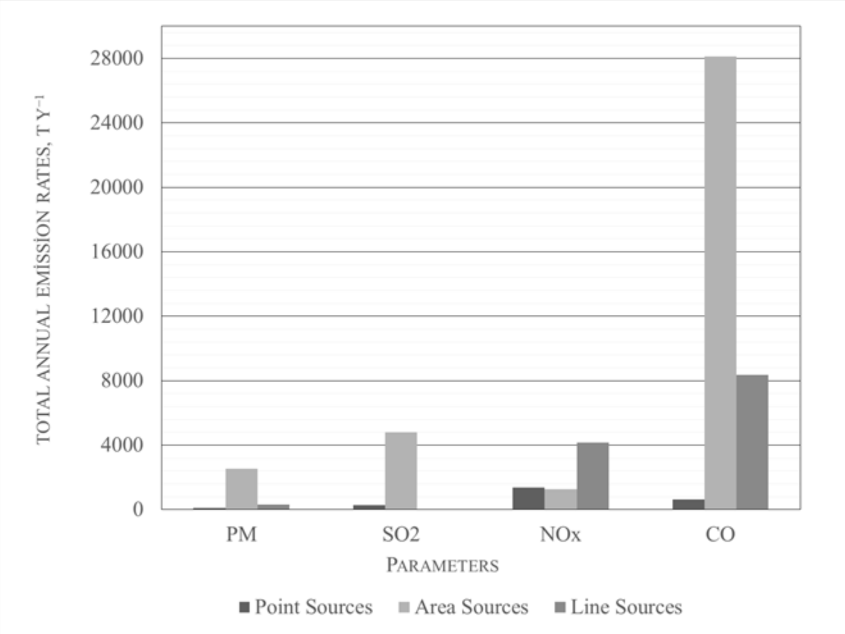

Figure 5: Total annual emission rates from point, area, and line sources

The uncertainties in emissions estimated for point (industrial facilities), area (residential heating) and line (road transportation) sources originate from uncertainties in activity data and emission factors. Major activity data used for the calculation of point and area emissions is fuel use as natural gas and coal. The data on natural gas use can be accepted as almost accurate as the data were provided by the single natural gas supplier. No errors other than measurement errors are expected. The data on coal consumption can also be accepted as reasonably accurate because it is based on the statistics provided by the local state agency. One major problem in calculation of point and area sources is not inclusion of some types of fuels (wood) used by the residential and industrial sources. The emissions from wood burning are very low compared to coal burning and the amount of wood burned is very small compared to other fuels. Therefore, neglect of emissions from wood use adds only a small error to the calculations. Major activity data used for the calculation of line sources is the number of vehicles and average mileage taken by them. Data on number of vehicles are again based on state statistics and not much error is expected. However, the average mileage taken was selected based on our best judgment. Overall, we can say that activity data of area and point sources include low level uncertainty and activity data of line sources include medium level uncertainty. The uncertainty associated with emission factors can be much higher due to substantial variations among emission factors for different types of processes. In this study, emission factors developed by USEPA and EEA were used due to unavailability of Turkish emission factors, which adds the largest uncertainty to the results.

There are only a few studies in the literature that provided a quantitative assessment of uncertainty levels for emission inventory studies. Zhao et al. (2011) estimated the uncertainties in emission inventory for China. They showed that the uncertainties in estimations of SO_2, NOx and PM were in the range of -14 to 38% at the 95% confidence interval. Fu et al. (Fu et al. 2013) found that the total uncertainty for the emissions of SO_2, NO_X, PM_{10} were in the range of−12% to 40% at the 95% confidence interval. Based on previous studies and evaluation of the sources of errors in the data used in this study, we see that the uncertainty in emission inventory studies seems to be almost inevitable. This should be considered while using the results of the analysis.

5. Conclusion

Emission inventories provide information about contributions of individual source categories to total emissions for one or more pollutants for a given time period and geographic area. Hence, inventories can be used for a wide variety of decision-making purposes (EPA 1996b; EPA 1998). Examples include development of control strategies for reducing emissions, generation of strategies for emissions permits, projections of future emissions, real-time air quality forecasting and simulation, risk analysis, accountability assessments, and prioritization of data needs, among others (EPA 1997). Also emission inventory for developing countries such as Turkey help urban land designers prepare better air pollution control programs.

In this study, the emission inventory for Kayseri showed that residential heating, where significant amount of coal is used, is the major pollutant source. Although state agencies try to restrict the use of low quality coal in the city center, it can be seen that about 10-20% of the coal used in Kayseri was still lignite. This situation contributes most to SO_2 and PM pollution.

The problem with residential heating can be solved by promoting natural gas; however, the cost of natural gas use is much higher than coal. This is a major drawback from natural gas use for the low-income population of Kayseri. Some mechanisms such as subsidies can be applied for making natural gas attainable by a large population. All possible sources (i.e., industrial, residential heating and transportation sources) were included in to provide an inventory of pollutants for Kayseri. The values of emission rates vary largely, by nature, from one type of combustion source to another, from one type of fuel to another. Due to large variations in fuel types and burning conditions, emissions can be very different throughout the world. The emission inventory, which has been prepared for the first time for Kayseri, has shown some important results. The total annual emissions from rates were 2929 tons, 5082 tons, 6791 tons, 37094 for SO_2, PM, NOx, and CO, respectively. Residential heating was found to be the major contributor in total emissions from region, combustion of lignite and anthracite was the major pollution source for the primary pollutants including PM, SO_2 and CO, while the natural gas combustion in the industrial plants is the most significant source for NOx. Major uncertainties in estimations originate from the use of emission factors from other sources and data availability. For improving the air quality in Kayseri, the use of coal in residential heating should be reduced and the use of much cleaner alternatives (e.g., natural gas) should be promoted.

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