

CONTRIBUTION OF TRAFFIC TO ANNUAL AIR POLLUTION WITH NITROGEN DIOXIDE OVER STARA ZAGORA, BULGARIA

Nikolay P. Takuchev

Trakia University, Stara Zagora 6000, Bulgaria

Abstract

Introduction. *Stara Zagora (42,4283° N; 25,6559° E, population 150000) is a densely populated town with developed industry and heavy traffic, subjected to the above-threshold pollution by nitrogen dioxide.*

Aim. *To estimate the contribution of the city traffic to the annual urban air pollution with NO_x.*

Material and methods. *The number of vehicles registered in Stara Zagora municipality in 2012 and the fuel (gasoline, auto gas, natural gas) sold in 2012 in Stara Zagora area, were received through requests for access to public information.*

Results and discussion. *The appraisal for the city traffic emissions of nitrogen oxides into the urban air for 2012 is total 201 t/y. The traffic emits about 2/3 from all annual city emissions of NO_x in Stara Zagora.*

Key words: *Urban air pollution, NO_x, Traffic, Stara Zagora*

1. INTRODUCTION

Stara Zagora is a densely populated town with developed industry, heavy traffic and without centralized heating. The town is located in the foothills of the southern slopes of the Sredna Gora Mountain. The combination between the compact city layout with heavy traffic added to the industrial sources of pollution and the thousands of closely spaced polluting sources – households, determines the local environmental problems associated with urban air pollution. The environmental problems with the urban air pollution of the city have long history. Several events of above-threshold pollution of nitrogen dioxide occur over recent years, mainly in November.

The aim of the paper is to estimate the contribution of city traffic to the annual urban NO_x emission (harmful NO₂ + harmless NO, which converts to NO₂ in the presence of volatile organic compounds in the ambient air).

2. MATERIAL AND METHODS

In a stationary situation the flow leaving the city motor vehicles equals the flow entering the city vehicles, i.e. in average the annual number of vehicles in the city is constant. It slowly changes over the years. Vehicles consume relatively constant amount of fuel and consequently emit relatively constant amount of nitrogen oxides in the air per year. In a stationary situation, fuel burned in the city has purchased from fuel stations in the city, i.e. if the fuel sold in the city is known the air pollution with nitrogen oxides can be evaluated.

From April 2012 the National Revenue Agency (NRA) controls online sales of fuels, in particular those in the territory of Stara Zagora. By request for access to public information the monthly sales from the fuel stations in the territory of Stara Zagora for 2012 by fuel type, were received from the NRA.

Additional data for monthly methane consumption from methane stations in the city for the entire 2012 was received from the supplier OVERGAS AD.

3. RESULTS AND DISCUSSION

The volume of the sold fuels is given in table 1. Since the calculation of the NO_x emissions due to the combustion process in the vehicle engines requires the fuel to be expressed in mass units, in the table are given also the masses of the fuels, calculated by their densities.

The density of gasoline (730 kg/m³) was taken at 15°C. Diesel density (835 kg/m³) was taken at 15°C. The density of autogas is calculated as the average of the densities of propane (510 kg/m³), butane (580 kg/m³) and isobutane (557,3 kg/m³) at 15°C and atmospheric pressure. (Source: Characteristic properties of the gas mixture LPG (LPG), 2013.) Density (416 kg/m³) of the compressed methane (natural gas) is taken at 0°C. (Source: Methane, 2013. Also: Greenhouse Gas Conversion Factors, 2013).

Type of energy source	Sales for April-December 2012	Annual sales for 2012
Gasoline, l (liter)	9346672	12459114
Diesel, l	19888184	26510949
Autogas (LPG), l	10663352	14214248
Methane (CNG), l	6145266	8191640
Gasoline, kg	6823071	9095153
Diesel, kg	16606634	22136642
Autogas, kg	5854180	7803622
Methane, kg	2556431	3407722

Table 1. Sales of fuel stations of Stara Zagora from April to December 2012 and for the year as a whole (the sales for missing months are replaced by the average of the available data). The density of autogas is calculated as average of the densities of propane, butane and isobutane at 15°C and atmospheric pressure.

Monthly data are shown graphically in figure 1. It can be seen that the distribution is more or less evenly throughout the year, i.e., is groundless to assert that the November gassing with nitrogen dioxide in 2012 were due to increased traffic, more so in November 2012 the sales of fuels were weakest in the year.

Available data from the NRA show a weak trend of probably decreasing sales of fuel at the beginning of the year (the first three months). An additional argument in favor of such an assumption is the fact that at the beginning of the year sales of methane (the information is available for whole year) were slightly higher. Since the methane is the fuel used of part of public transport and taxis, increased methane sales indicate an increased flow of users of public transport in winter, i.e. reduced flow of personal vehicles and reduced sales of other types of fuel at the beginning of the year. I.e. the missing data on fuel purchased in the first three months of the year can be replaced with monthly averages calculated from the other months, without risk to underestimate the annual emissions of nitrogen oxides originating from traffic (right column of table 1).

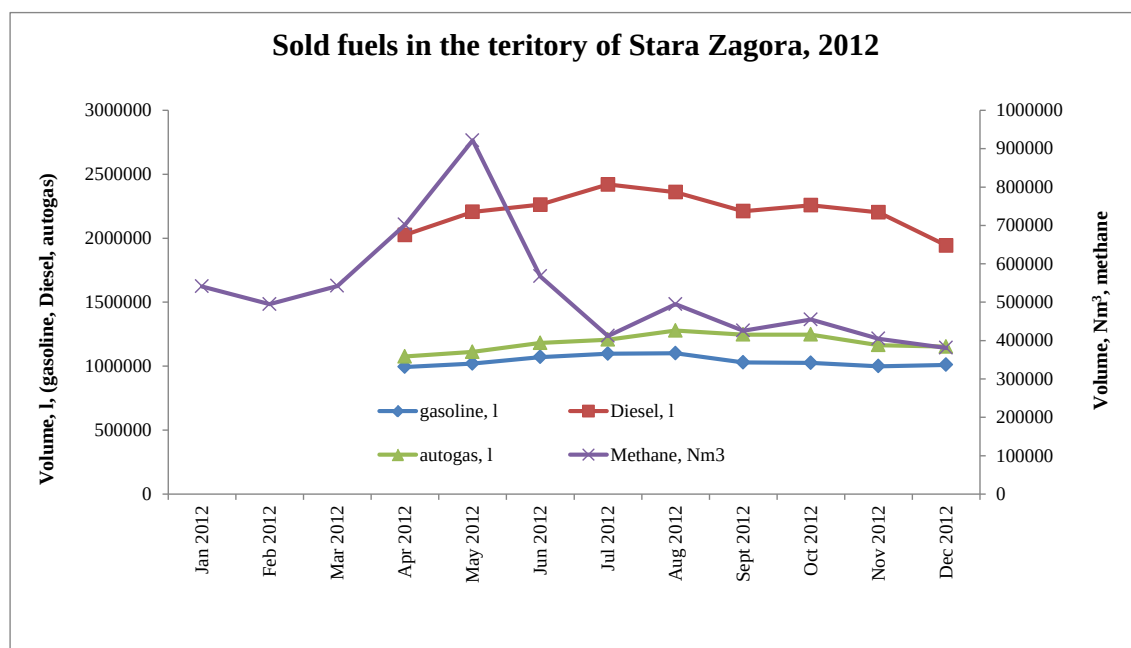


Figure 1. Distribution of fuel stations sales during the year 2012 on the territory of Stara Zagora. In November 2012, when there were above-threshold nitrogen dioxide pollution events and accusations that the traffic is guilty for it, no oversold automotive fuels were observed, by contrast, there is a slight decline in sales.

Data for the vehicle fleet of Stara Zagora District received from the District Police Directorate, are shown in table 2.

to 1.1.2012	<i>Type of vehicle</i>				
<i>First registration:</i>	<i>Passenger cars</i>	<i>Light duty</i>	<i>Haevy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>to 1990</i>	24747	1416	2014	354	1509
<i>between 1991 and 1995</i>	31717	1773	1074	240	871
<i>between 1996 and 2000</i>	28352	1782	865	184	945
<i>after 2000</i>	12383	1878	901	191	1749
<i>Total</i>	97199	6849	4854	969	5074
<i>Shares,%</i>	85	6	4	1	4

Table 2. Vehicles registered in Stara Zagora district.

In Stara Zagora municipality "Program of reducing levels of nitrogen dioxide and reaching the established norms in Stara Zagora for the period 2013-2015", are given the total number of vehicles, registered in the municipality in 2010 and shares of vehicles by type divided into three groups. The number of vehicles in the municipality of Stara Zagora was calculated on these data where the missing data from the municipality information on the distribution of light duty, heavy duty vehicles and busses is calculated according to their share as it is shown in table 2. The final data is shown in table 3.

<i>Number: 80914</i> <i>at the end of 2010</i>	<i>Type of vehicle</i>				
	<i>Passenger cars</i>	<i>Light duty</i>	<i>Haevy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>Shares,%</i>	87	Total 10			3
<i>Number</i>	70395	4413	2942	736	2427

Table 3. Vehicles registered in Stara Zagora municipality.

The approximate ratios of the number of vehicles registered in the municipality by type of fuel, are given in the same source: gasoline: diesel: auto gas = 50:30:20. It can be assumed that the heavy duty trucks and buses use 100% diesel. The motorcycles use gasoline. This gives the data in a table 4.

	<i>Type of vehicle</i>				
	<i>Passenger cars</i>	<i>Light duty</i>	<i>Haevy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>Shares,%</i>					
<i>Gasoline</i>	50	50			100
<i>Diesel</i>	30	30	100	100	
<i>Auto gas</i>	20	20			
<i>Number</i>					
<i>Gasoline</i>	35198	2207			2427
<i>Diesel</i>	21119	1324	2942	736	
<i>Auto gas</i>	14079	883			

Table 4. Distribution of motor vehicles registered in the municipality of Stara Zagora by type and by fuel used.

The result of vehicles counting per day in a city street with heavy traffic (November 2010) is shown in table 5.

<i>Number: 11985</i> November 12, 2010	<i>Type of vehicle</i>				
	<i>Passenger cars</i>	<i>Light duty</i>	<i>Haevy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>Shares,%</i>	89,9	7,6	2,0	0,3	0,2
<i>Number</i>	10773	910	236	39	27

Table 5. Distribution by type of the vehicles passed per day along the counting point in November 12, 2010.

Shares of vehicles types in the municipality derived from the above mentioned three independent sources (table 3, table 4 and table 5), are close in value, which confirms the reliability of the data in table 4 used in the calculations below.

Tier 1 method (recommended by European Environmental Agency (EEA), EMEP/EEA emission inventory guidebook 2013 1.A.3.b Road transport) was used to estimate the emissions of nitrogen oxides from the vehicles in Stara Zagora. The method is consistent with the legal and technical requirements for the vehicle fleet of Europe in 1995, which corresponds to the specificity of the vehicle fleet of Bulgaria at the time. As shown in table 1, in Stara Zagora prevail cars manufactured between 1991 and 1995. The number of more new cars gradually increases which reduces the emissions and the real input of the traffic to the air pollution of the city is probably smaller than the obtained by the above mentioned method.

A typical fuel consumption in grams per kilometer by vehicle type and by fuel used, is shown in table 6.

	<i>Fuel Consumption , g/km, by type of vehicle</i>				
	<i>Passenger cars</i>	<i>Light duty</i>	<i>Haevy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>Gasoline</i>	70	100			35
<i>Diesel</i>	60	80	240	240	
<i>Auto gas</i>	57,5				

Table 6. Fuel consumption per kilometer for vehicle type. (Source : EMEP / EEA emission inventory guidebook 2013 1.A.3.b Road transport, Tier 1 method , page 29 , table 3-14).

The fuel in kilograms, which all vehicles in the city would burn covering 1 km of city streets can be calculated by multiplication of relevant data from tables 4 and 6, divided by 1000. The result is given in table 7.

	<i>Burned fuel in kg per 1 km mileage by type of vehicle</i>				
	<i>Passenger cars</i>	<i>Light duty</i>	<i>Haevy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>Gasoline</i>	2464	221			85
<i>Diesel</i>	1267	106	706	177	
<i>Auto gas</i>	810				

Table 7. Fuel burnt by all vehicles in the city of Stara Zagora, in kilograms per kilometer.

If the distribution of vehicles on their annual mileage in city conditions is known, equivalent kilometers run in the city of vehicles of a given type can be calculated from fuel data burnt per kilometer of a given type vehicles (table 7), and data on fuel purchased from the fuel stations (table 1).

Data on the average mileage of the vehicles in urban conditions for the country (Bulgaria) by category, is presented in a report to the Metropolitan municipality on "Inventory of emissions of CO₂, released into the atmosphere as a result of energy consumption on the territory of Sofia Municipality", 2012, page 19, table 19. The data are given in table 8. The calculations below are based on the assumption that these data are representative for Stara Zagora as a proportion between the annual mileage of different types of vehicles.

Average mileage in city conditions: 3393 km	Average mileage in the city, km/y, per vehicle					Total
	Passenger cars	Light duty	Heavy duty	Buses	Motorcycles	
Gasoline	2693	3151			686	6530
Diesel	3895	4193	4410	4410		16908
Auto gas	2693					2693

Table 8. Average mileage of a vehicle in an urban environment in Bulgaria in 2011 (Source: "Inventory of emissions of CO₂, released into the atmosphere as a result of energy consumption on the territory of Sofia Municipality" prepared by the international consulting company in the field of ecology "Denkstatt" p.19, table 19)

The absolute average annual mileage of a motor vehicle for Stara Zagora, probably differs from the values in table 8. It depends mostly on the size of the settlement on which depend the distances to work, shops, medical facilities, etc. All these distances are proportional to the size of the settlement and determine the absolute value of the average annual mileage of different types vehicles in the settlement – the mileage is longer in larger settlements and vice versa.

For each type of vehicle was calculated the relative average mileage in city conditions as a percentage of the mileage for a given type of vehicle compared to the cumulative absolute mileage of all types of vehicles using a particular fuel type. The result is given in table 9.

	Relative average annual mileage by type of vehicle				
	Passenger cars	Light duty	Heavy duty	Buses	Motorcycles
Gasoline	0,412	0,483			0,105
Diesel	0,230	0,248	0,261	0,261	
Auto gas	1,000				

Table 9. Relative average mileage per a vehicle type by fuel type for urban conditions in Bulgaria.

Unlike the average mileage in absolute terms, the relative average mileage of a vehicle (for a given fuel type) does not depend on the size of the settlement, if other conditions like economy, population density, distribution of jobs, etc being equal. Below this independence is used to evaluate the absolute value of the average annual mileage per type of vehicle for Stara Zagora. As far as the above mentioned conditions are not the same for all locations in the country, the independence of the relative average mileage of a vehicle for a particular fuel type on the size of the settlement is rather approximate.

The total mass of fuel of a particular type sold by the fuel stations on the territory of Stara Zagora per year is known (table 1). The same mass is proportional on a function (polynomial) calculated as a sum of multiplications between the fuel of the same type burnt per year by all vehicles of a given type in the city of Stara Zagora (table 7) and the relative average mileage per a vehicle type by fuel type for urban conditions in Bulgaria (table 9). For the three above mentioned types of fuel three such functions were calculated.

Each of the terms of each of the three functions has to be multiplied by the same unknown coefficient, to coincide with the annual sales of the corresponding type of fuel. Goal Seek function of MS Excel was used to obtain the coefficient for each of the functions. The results are given in table 10.

<i>Fuel type</i>	<i>Coefficient, $y^{-1} \cdot km^{-1}$</i>
<i>Gasoline</i>	8043
<i>Diesel</i>	40383
<i>Auto gas</i>	9634

Table 10. Values of the unknown coefficient in the above mentioned functions.

The annual mileage of each type of vehicle and type of used fuel is obtained by multiplying the appropriate fuel type coefficient (table 10) to the relative average mileage per a vehicle type for urban conditions in Bulgaria, taken from table 9. The results are given in table 11.

	<i>Average annual mileage , km, by type of vehicle</i>				
	<i>Passenger cars</i>	<i>Light duty</i>	<i>Heavy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>Gasoline</i>	3314	3885			845
<i>Diesel</i>	9288	10015	10540	10540	
<i>Auto gas</i>	9634				

Table 11. Average mileage per vehicle per year in the city of Stara Zagora.

Part of the fuel purchased from the stations in Stara Zagora is spent out of town and does not contribute to pollution in the city. The part of the fuel burned in the city boundary can be assessed by comparing the average mileage in the city streets for Bulgaria (table 8) with the average mileage, regardless of the type of road for Bulgaria. The average annual mileage of vehicles in the country for all types of roads, is given in table 12.

Type of Vehicle	Fuel	Technology	Average annual mileage , km	Number of cars
Passenger cars, from 0.8 to > 2l, three gasoline classes	gasoline	PC Euro 2 и 4	5976	499433
Passenger cars, from 1.4 to > 2l, two diesel classes	Diesel	PC Euro 4 - 98/69/EC Stage2005	11738	457104
Passenger cars	LPG	PC Euro 2 - 94/12/EEC	66348	26768
Passenger cars	CNG	PC Euro 4 - 98/69/EC Stage2005	60178	15183
Light duty <3,5 t	gasoline	LD Euro 4 - 98/69/EC Stage2005	8645	7274
Light duty <3,5 t	Diesel	LD Euro 4 - 98/69/EC Stage2005	12522	101604
Heavy duty Rigid <=7,5 t	Diesel	HD Euro II - 91/542/EEC Stage II	15597	4546
Bus City Standard, 15 - 18 t	Diesel	HD Euro III - 2000 Standards	30878	1119
City Bus	CNG	HD Euro III - 2000 Standards	122748	0
Motorcycles, from under 50 to under 250 cm ³	gasoline	Mop - Euro II, Mot - Euro I	1545	58720

Table 12. Average mileage per vehicle for Bulgaria, 2011 (Source: United Nation Framework Convention of Climate Change, 2013).

The ratio between the data in table 8 and those in table 12 shows the proportion of the fuel, burned in urban environments. The values of the ratio are shown in table 13.

	<i>Average annual mileage , share by type of vehicle</i>				
	<i>Passenger cars</i>	<i>Light duty</i>	<i>Haevy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>Gasoline</i>	0,451	0,364			0,444
<i>Diesel</i>	0,332	0,335	0,283	0,143	
<i>Auto gas</i>	0,041				

Table 13. Share of average city mileage for vehicles by type in Bulgaria for 2011 compared with the average total mileage.

To obtain the average city mileage of a vehicle for Stara Zagora, the data in table 11 were multiplied by those in table 13. The result is shown in table 14.

	<i>Average annual mileage, km, by type of vehicle</i>				
	<i>Passenger cars</i>	<i>Light duty</i>	<i>Haevy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>Gasoline</i>	1493	1416			375
<i>Diesel</i>	3082	3354	2980	1505	
<i>Auto gas</i>	391				

Table 14. Average annual city mileage for vehicles in Stara Zagora.

The product of relevant data from tables 4, 6 and 14, divided into 1000 gives annual fuel consumption in kilograms of the vehicles on the territory of Stara Zagora. The result is given in table 15.

	<i>Fuel consumption, kg, by type of vehicle</i>				
	<i>Passenger cars</i>	<i>Light duty</i>	<i>Haevy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>Gasoline</i>	3679546	312519			31862
<i>Diesel</i>	3905369	355206	2104224	265900	
<i>Auto gas</i>	316559				

Table 15. Fuel consumption in urban conditions from the vehicles of Stara Zagora.

The emission factors for NO_x by fuel and vehicle type are given in table 16.

	<i>Emission factor for NO_x, g/kg, by type of vehicle</i>				
	<i>Passenger cars</i>	<i>Light duty</i>	<i>Haevy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>Gasoline</i>	29,89	25,46			10,73
<i>Diesel</i>	13,88	18,43	38,29	38,29	
<i>Auto gas</i>	34,30				

Table 16. Emission factors for nitrogen oxides in g/kg by fuel and vehicle type according to the method Tier 1. (Source: EMEP/EEA emission inventory guidebook 2013 1.A.3.b Road transport, Tier 1 method , p.26 table 3-6)

The product of relevant data from tables 15 and 16, divided by 1,000,000 gives in Mg the emitted nitrogen oxides from the traffic in the city of all vehicles per year. The result is given in table 17.

General issue:	<i>Emissions of NO_x, Mg/y, by type of vehicle</i>				
280,6 t/y	<i>Passenger cars</i>	<i>Light duty</i>	<i>Haevy duty</i>	<i>Buses</i>	<i>Motorcycles</i>
<i>Gasoline</i>	110,0	8,0			0,3
<i>Diesel</i>	54,2	6,5	80,6	10,2	
<i>Auto gas</i>	10,9				

Table 17. NO_x emissions from all vehicles in the city of Stara Zagora in Mg per year.

4. CONCLUSIONS

Regulation of traffic in the city of Stara Zagora deviates the trucks from the central part of Stara Zagora, so their contribution to the emission of nitrogen oxides can be ignored, i.e. the above calculations show that for the year traffic in Stara Zagora emits 201 Mg of NO_x, which is about 2/3 of all NO_x emissions from the city.

REFERENCES

- Characteristic properties of the gas mixture LPG (LPG), 2013. Last visited: 14.1.2014 r. (Bulgarian). <http://www.gastradebg.com/pagebg.php?P=2&SP=33>
- EMEP/EEA emission inventory guidebook 2013 1.A.3.b Road transport, method Tier 1, p.26, table 3-6. Last visited: 14.1.2014 r. <http://www.eea.europa.eu/publications/emep-eea-guidebook-2013>
- EMEP / EEA emission inventory guidebook 2013 1.A.3.b Road transport, Tier 1 method, page 29, table 3-14. Last visited: 14.1.2014 r. <http://www.eea.europa.eu/publications/emep-eea-guidebook-2013>
- Greenhouse Gas Conversion Factors, 2013. Pb13773-ghg-conversionfactors2012.xls, Fuel Properties. Last visited: 14.1.2014 r. <https://www.gov.uk/government/publications/2012-greenhouse-gas-conversion-factors-for-company-reporting>
- Inventory of emissions of CO₂, released into the atmosphere as a result of energy consumption on the territory of Sofia Municipality", 2012, page 19, table 19. Last visited: 14.1.2014 r. <http://www.sofia.bg/strategii.asp>
- Methane, 2013. Last visited: 14.1.2014 r. (Bulgarian). <http://bg.wikipedia.org>
- Program of reducing levels of nitrogen dioxide and reaching the established norms in Stara Zagora for the period 2013-2015. last visited: 15.1.2013 r. (Bulgarian). <http://www.starazagora.bg/bg/administrativni-aktove/programi>
- United Nation Framework Convention of Climate Change, 2013. Page. 533, table 262, page 549, table 264. http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/7383.php