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EMISSIONS FROM MUNICIPAL SOLID WASTE TRANSPORT VEHICLES: CASE STUDY BANJA LUKA REGION (B&H)

Abstract: Waste transport is just one of the segments in the solid municipal waste management. Throughout the entire waste life cycle, starting by generation of waste, via storing, collecting, transporting, recycling, treating and depositing, several different polluting substances are emitted. The solid waste transport, apropos, transporting vehicles emit into the air different pollution substances such as CO₂, CO, NO_x, NMVOC, PM, PAHs etc. These substances can present certain problems for human health and environment. The research subject of this study is the analysis of solid waste transportation within the Banja Luka region (B&H), from towns and municipalities belonging to the region and transporting their mixed municipal waste to the Banja Luka landfill. In the analysis, following parameters are included: distance to the landfill, type of vehicle used for the waste transportation, type of the engine, vehicle capacity and the number of tours during a year. The study estimates the emission of CO, NO_x, NMVOC, and PM2.5 during one year using the listed parameters and by applying EMEP/EEA guidelines for estimating the emission of polluting substances into the air. The largest emission of polluting substances (CO, NO_x, NMVOC and PM2.5) is from the oldest vehicles. The newest vehicles had a significantly lesser emission of these polluting substances into the air. The recommendation for decreasing the emission from the transportation vehicles is to organise the transfer-stations, procure new vehicles, optimise the collection routes and decrease the number of tours, as well as to better the usage of the vehicle capacity level.

Keywords: municipal solid waste, waste transport, emission into the air, pollution

Introduction

Municipal solid waste (MSW) is generated daily in the households, schools, commercial and utility objects, industry and healthcare institutions. The waste transport comprehends the transport from one geographic point to the other, apropos, the transport of the full vehicle after concluding the waste collection in one zone or area to the place marked for unloading (transfer stations, treatment facility or landfill). The waste can be transported: by road (vehicles, tractors, etc.), by railroad, by maritime transport or by inner navigable transport routes [1].

The most important polluting substances from the transportation, participating in all segments of the waste management system are: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and hydrofluorocarbons (HFCs).

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The waste transportation emissions can be influenced by vehicle type, fuel used, carrying capacity, and driving behaviour [1]. The fuel used for the vehicles has an important role in the quantity of greenhouse gas (GHG) emission [2, 3]. Perez et al. [4] in the study for waste collection in Madrid (Spain) concluded that vehicles using diesel fuel emit more GHG than the vehicle with natural compounded gas. The type of waste also has a major role in the GHG emission, hence the waste with small density (but large volume) produces greater emission during the transport [5], because it occupies the space, apropos vehicle capacity.

The emissions caused by transport are an important source of non-methane volatile organic compounds (NMVOC) that has a negative impact on human health, as well as contribute to the creation of secondary pollution responsible for photochemical (summer) smog [6]. In Europe in 2019, road transport produced 28.12 % of NO_x, 17.97 % of CO, 7.79 % of particulate matter (PM) with a diameter below 10 µm (PM₁₀) and 9.89 % of PM with a diameter below 2.5 µm (PM_{2.5}) [7].

The European Commission (EC) in 2014 adopted the Strategy for decrease of fuel usage and CO₂ emission for heavy goods vehicles [8]. In this Strategy, it is stated that the betterment of technology can lead to decrease of fuel usage and CO₂ emission for heavy goods vehicles. Significant savings in fuel usage can be achieved by technical betterment of engines, aerodynamics, wheels and additional equipment, as well as by decreasing the vehicle's mass. Besides, the effectiveness can be additionally obtained by better management of the vehicles and by improvement of the working staff.

According to the latest report of the EC for Bosnia and Herzegovina (B&H) [9], it is stated that the transport, entirely, is underdeveloped, and the speed of structural adaptation and reform is slow. The necessary investments are being delayed due to limited capacities for credits, financial limitations, lack of focus on key priorities and coordination, as well as the lack of cooperation between different levels of government. The main sources of emission into the air in B&H, and according to this Report, are thermal power plants, coal-fuel power plants, industry, household heating and transport. On the other hand, the regulations should be adjusted to the European Union (EU) Directive on landfill and close or rehabilitate landfills that do not meet the exact conditions. Significant effort and measures for awareness are necessary, in order to decrease the waste generation and promote recycling and reusing [10].

Several studies processed the segment of waste transportation routes and efficiency achieved due to changing the route, logistics and organisation of waste collection and transportation [11, 12]. Most of the studies processed the optimisation of waste collection and transportation [13, 14], in order to decrease the air emission or decrease the cost. Larsen et al. [15] perceived the initiatives for diesel fuel decrease by optimising the route, as well as decreasing the fuel usage by transporting the waste using the collective lorries. The reloading of waste into the more effective vehicles at the transfer station can make the transport more economical. As for the neighbouring countries and regarding the gas emission occurring during the waste transport, a reduction methodology of GHG emission from the waste collection and transport was done in Republic Serbia [16].

Landfilling of waste in B&H is still the most important segment in waste management. In addition to existing regional and sanitary landfills, waste is still disposed of in illegal and unregulated landfills. Waste management in the Banja Luka region is based on waste disposal at the sanitary regional landfill located in the City of Banja Luka. In addition to waste from the City of Banja Luka, this landfill also disposes of waste from seven local

communities. Waste management in the Banja Luka region is characterised by the following: disposal of mixed municipal waste at the landfill, no system of separate waste collection, no separation and recycling of waste.

In the B&H, there were no studies that process in details a waste transport segment from the stand of negative environmental impact assessment. The largest number of studies, up till now, in B&H included the segment of waste management modelling with the aim to decrease the negative environmental impact [17-19], apropos assessment of environmental pollution from the municipal waste landfills which are still the most dominant manner of waste management in B&H [20]. GHG emissions from the landfills are still more significant than the emission from the waste transportation [21, 22].

The subject of this study is the analysis of waste transportation in Banja Luka region, based on the data of waste quantity transported, number of tours achieved by vehicles during a year and type and number of vehicles transporting the waste. The aim of this study is to estimate the CO, NMVOC, NO_x and PM2.5 emission from the vehicles transporting waste and to recommend the betterment of waste transport in this region.

Materials and methods

Description of the study area

Banja Luka is the second largest city in the Republic of Srpska, B&H. There is a regional sanitary landfill in Ramici, approximately 10 km from the centre of Banja Luka, that serves as a regional landfill for Banja Luka region. This landfill is the second largest landfill in B&H [23]. The waste deposited on this landfill is transported from two towns, one is Banja Luka, and the second is Gradiska, as well as from six municipalities (Laktasi, Srbac, Celinac, Kotor Varos, Knezevo, Prnjavor). The total number of population in the region is 370,329 inhabitants (Table 1).

Table 1
Number of inhabitants per towns and municipalities in Banja Luka region, distance of towns and municipalities and the quantity of deposited waste

Towns and municipalities in Banja Luka region	Number of inhabitants	Quantity of deposited waste [Mg]	Quantity of waste [kg/ year] per a resident	Distance from the landfill [km]
Banja Luka	185,042	67,915.72	367	-
Laktasi	34,966	10,290.21	294	19
Gradiska	51,727	11,257.02	218	48
Srbac	17,587	282.64	16	53
Celinac	15,548	2,315.64	149	16
Kotor Varos	19,710	2,183.68	111	34
Knezevo	9,793	1,063.20	109	51
Prnjavor	35,956	6,210.58	173	62
Total	370,329	101,518.69	274	-

In Table 1 and on Figure 1, the position and distance of the towns and municipalities compared to the position of the landfill, is presented. Compared to the overall number of inhabitants encompassing this region, the town of Banja Luka is the largest and inhabited by 50 % of the total number of stated inhabitants. In respect to the overall quantity of collected municipal waste in the region, the town Banja Luka generates about 67 % of

waste. The largest quantity of waste per a resident is in Banja Luka (367 kg). The smallest quantity of collected and deposited waste during a year is in municipality Srbac (16 kg), because this local community still uses a dump site. In regard to the quantity of deposited waste during a year in Banja Luka region, one resident, in average generates 274 kg of waste. In the EU countries, in the year 2019, the average quantity of waste generated by a resident was 502 kg of mixed municipal waste [24]. According to the official statistics of EU, during the year 2019 the smallest quantity of waste was generated in Romania, apropos, in average 280 kg of mixed municipal waste was generated per a resident.

The landfill in Banja Luka is about 10 km from the town centre. It was built in 1976 and used for depositing waste generated in the town Banja Luka. Due to the civil war (1992-1996) and poor socio-economic circumstances this landfill became an open dump site after the war. From 2002, thanks to the World Bank Project, this landfill became the regional landfill and from 2004 the waste generated in other municipalities was deposited here. Celinac and Laktasi are the closest municipalities, while Prnjavor is the furthest municipality. In 2008 a transfer station was built in Gradiska. This is the only local community in the region that has improved the waste collection and decreased the transportation cost by buying 25 Mg (tonne = 10^6 g) vehicle. By building the reloading station and buying the semi-trailer the municipality Gradiska decreased the cost of transporting the municipal waste to the regional landfill for 3.7 times on the yearly level [25].

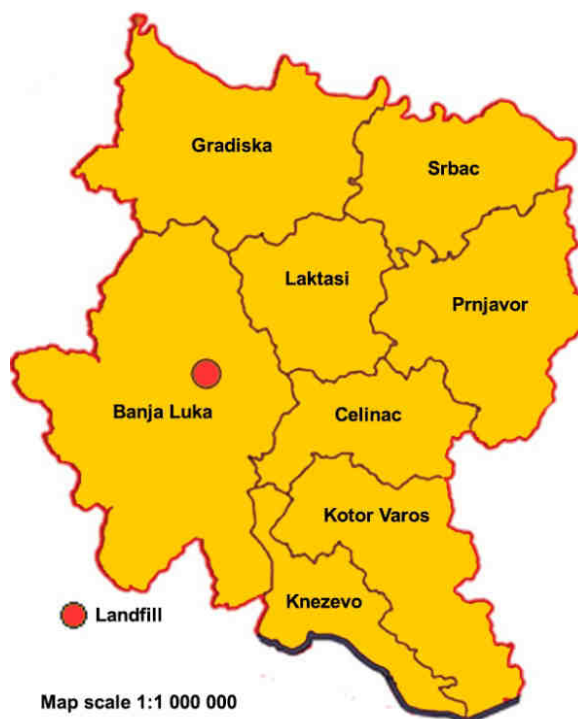


Fig. 1. Position of towns and municipalities in regard to the Banja Luka landfill

Waste transport in Banja Luka region

In Table 2 a number of vehicles that transfer the waste to the Banja Luka regional landfill regarding the type of engine and vehicle capacity is presented. Out of the total number of vehicles that transport the waste (73 vehicles), most of them have Euro III engine. Meaning, that 40 vehicles (55 %) are with the Euro III engine, capacity of < 7.5 Mg, and 8 vehicles (11 %) with Euro III engine and capacity of (7.5-16) Mg. A very few, just 6 vehicles (8 %) with the engine Euro V and Euro VI are present in the Banja Luka region. About 53 vehicles have the capacity of less than 7.5 Mg or about 73 % of vehicles, while 19 vehicles (26 %) have capacity of (7.5-16) Mg. Only one vehicle has a capacity bigger than 16 Mg. The largest number of vehicles transporting the waste are from Banja Luka town or 48 vehicles (66 %) out of the total number of vehicles transporting the waste to the landfill. Knezevo and Srbac have only one vehicle per a municipality. The town Gradiska that has a reloading station, at the beginning of 2020 transferred the waste to the landfill with several vehicle of smaller capacity, even though they possess a vehicle with the capacity of 16 Mg, as this vehicle was being repaired.

Table 2
Type of vehicle per engine and number of vehicles transporting the waste to the Banja Luka regional landfill

Number of vehicles														Total
Type of engine	Euro I		Euro II		Euro III		Euro IV			Euro V		Euro VI		
Vehicles capacity	< 7.5 Mg	(7.5-16) Mg	< 7.5 Mg	(7.5-16) Mg	< 7.5 Mg	(7.5-16) Mg	< 7.5 Mg	(7.5-16) Mg	(16-32) Mg	< 7.5 Mg	(7.5-16) Mg	< 7.5 Mg	(7.5-16) Mg	
Banja Luka	2	-	5	1	26	6	3	2	-	-	2	-	1	48
Knezevo	-	-	-	-	-	-	-	-	-	-	1	-	-	1
Laktasi	2	-	-	-	3	-	-	-	-	1	-	-	-	6
Gradiska	-	-	-	-	5	-	-	-	1	-	-	-	-	6
Prnjavor	-	-	-	-	6	-	-	1	-	-	-	-	-	7
Kotor Varos	-	-	-	-	-	2	-	-	-	-	-	-	-	1
Celinac	-	-	-	-	-	-	-	2	-	-	-	-	-	2
Srbac	-	-	-	-	-	-	-	-	-	-	1	-	-	1
Total	4	-	5	1	40	8	3	5	1	1	4	-	1	73

In Table 3 the data on average age of vehicles owned by the communal company transporting waste and the number of tours those vehicles performed in 2020 on the territory of their local community are presented. The average age of vehicles that transported waste to the Banja Luka landfill was approximately 15 years of age. This fact is also confirmed by the data on 58 vehicles (about 80 %) having Euro I, Euro II and Euro III engines.

The quantity of waste collected and transported by vehicle of < 7.5 Mg capacity was 61,046.39 Mg, apropos compared to the total quantity of waste collected in this region these vehicles collected and transported about 60 % of waste. The number of tours that the vehicles performed during the transport was 14,451. The average mass of waste per a vehicle of < 7.5 Mg was 4.22 Mg. The vehicles having capacity of (7.5-16) Mg collected and transported about 34,041.64 Mg (34 %) of waste in this region and made 6,397 tours. The average waste mass per a vehicle of this capacity was 5.32 Mg. Regarding the average

waste mass per a vehicle, the level of fulfilling the vehicle capacity was rather small by comparison with the vehicle capacity.

The vehicle from Gradiska having capacity of 25 Mg made 274 tours from transfer station to the landfill in total. The average mass of waste per a tour in this case was 23.47 Mg, apropos the vehicle capacity was well used.

The quantity of transported waste from Laktasi and Gradiska was 10,290.21 Mg, apropos 11,257.02, and the number of tours during the year from Laktasi was 3,037 and from Gradiska 496 tours. The construction of transfer stations and procurement of vehicle with bigger capacity enabled the town Gradiska to make a lesser number of tours to the landfill.

Table 3

Average years of vehicles and number of tours in 2020 done by the vehicles for waste transport

Towns and municipalities in Banja Luka region	Average age of vehicles	Quantity of waste [Mg] / number of tours (vehicles < 7.5 Mg)	Quantity of waste [Mg] / number of tours (vehicles (7.5-16) Mg)	Quantity of waste [Mg]/ number of tours (vehicles (16-32) Mg)	Number of tours in total
Banja Luka	15	39,959.04 / 10,415	27,956.68 / 5,547	-	15,962
Knezevo	8	-	1,063.20 / 118	-	118
Laktasi	17.5	10,290.21 / 3,037	-	-	3,037
Gradiska	14	4,826.36 / 222	-	6,430.66 / 274	496
Prnjavor	17	5,688.14 / 724	522.44 / 73	-	797
Kotor Varos	19	-	2,183.68 / 329	-	329
Celinac	14	-	2,315.64 / 330	-	330
Srbac	18	282.64 / 53	-	-	53
In total	-	61,046.39 / 14,451	34,041.64 / 6,397	6,430.66 / 274	21,122
Average quantity of waste per vehicle [Mg]	-	4.22	5.32	23.47	-

Methodology for estimating the air emission from transport vehicle

EMEP/EEA guidelines for estimating the emission of polluting substances into the air is applied for calculating the emission for each sub-sector of road transport [26]. The input data that are needed for the model are divided per: (1) type of vehicle (personal vehicle, light field vehicles, heavy cargo vehicles, buses, motor scooter, motorcycles), (2) type of engine (four stroke gasoline engine, two stroke gasoline engine, diesel engine, rotation engine, electric-engine), (3) cylinder capacity (< 0.8 L, (0.8-1.4) L, (1.4-2.0) L, > 2.0 L), (4) weight class (rigid < 7.5 Mg, (7.5-12) Mg, (12-14) Mg, (14-20) Mg, (20-26) Mg, (26-28) Mg, (28-32) Mg, > 32 Mg, hinged (14-20) Mg, (20-28) Mg, (28-34) Mg, (34-40) Mg, (40-50) Mg, (50-60) Mg) and (5) age of vehicle.

Vehicle number data and annual mileage per technology (the number of vehicle-km per technology) is required to use the Tier 2 method.

Tier 2 method is based on the fuel consumption used by different vehicle categories and their emissions:

$$E_{i,j} = \sum_k (< M_{j,k} > \times EF_{i,j,k})$$

$$E_{i,j} = \sum_k (N_{j,k} \times M_{j,k} \times EF_{i,j,k})$$

where: $EF_{i,j,k}$ - technology-specific emission factor of pollutant i for vehicle category j and technology k [g/veh-km], $M_{j,k}$ - total annual distance driven by all vehicles of category j and technology k [veh km], $M_{j,k}$ - average annual distance driven per vehicle of category j and technology k [km/veh], $N_{j,k}$ - number of vehicles in nation's fleet of category j and technology k .

The emission estimation methodology in this study covers exhaust emission of CO, NO_x, NMVOC and PM2.5.

Results and discussion

The results of estimating the emission of CO, NO_x, NMVOC and PM2.5 from vehicles transporting the waste to the Banja Luka regional landfill are presented in Tables 4-7 and on Figures 2-5. When estimating the emission, the transportation distance, number of tours during a year, vehicle capacity and type of engine was included.

Table 4 shows emission of CO from vehicles transporting the waste to the Banja Luka region. The total estimated CO emission from all vehicles transporting the waste to the Banja Luka regional landfill is 1.38 Mg of CO. The emission of CO is the highest from the Euro I-III engines, while somewhat lesser from the new vehicles (Euro IV-VI). It is expected that the emission from older vehicles will be higher, because 80 % of vehicles have Euro I-III engines. Nevertheless, if we estimate the emission from vehicles according to the quantity of transported waste, the values of these emissions per a Mg from the vehicles Euro IV-Euro VI are even lesser.

About 80 % of all CO emissions is from the vehicles transporting the waste, happening after collection on the town Banja Luka territory until arriving to the landfill located some 10 km from the town centre. All other municipalities participate with just 20 % in regard to the overall CO emission during a year. From Banja Luka town the total emission from vehicles with Euro III engine is 1.10 Mg of CO or considering the total emission of CO generated during the waste transportation from the town to the landfill, 90 % of CO emission is made by the Euro III engine vehicles.

On Figure 2 the CO emissions from the vehicle transporting the waste and estimated per a Mg of transported waste are presented. The CO emission per a Mg of waste are the highest from the vehicles with Euro I, II and III engine. The transport of waste by the oldest vehicles (Euro I engine), vehicles with capacity less than 7.5 Mg generated 4.92 g/Mg CO from Banja Luka, 14.36 g/Mg from Laktasi. The waste transport to the landfill with the Euro III engine vehicles with the capacity less than 7.5 Mg from Banja Luka, Gradiska, Laktasi, Prnjavora and Srbac produced the CO emission of 28.14 g/Mg, 6.45 g/Mg, 6.23 g/Mg, 27.65 g/Mg and 5.80 g/Mg, respectively. The newest vehicles with Euro IV-Euro VI engine produced far less CO emission per a Mg of waste, apropos the values varied in volume from (0.15-0.620) g/Mg of CO. The smallest emission of CO is from the only vehicle that has the newest engine Euro VI and is only two years old. The CO emission during the transport of waste from Gradiska during a year is 31,116 g of CO from the vehicle with Euro III engine (< 7.5 Mg) or 6.45 g/Mg of waste. When the waste was transported by the Euro IV (25 Mg capacity) the CO emission was 1,380 g, apropos 0.21 g/Mg of waste.

In the Table 5 the emission of NO_x from the vehicles transporting the waste in the Banja Luka region is presented.

The total estimated NO_x emission from all vehicles transporting the waste to the Banja Luka regional landfill is 6.41 Mg. The NO_x emission is the highest from the vehicles with Euro I, II and III engine, while lesser from the vehicles of newer generations (Euro IV, V, VI). It is expected to have a much higher emission from the older vehicles, because there are approximately 80% of vehicles with Euro I-III engines. Nevertheless, if we estimate the emission from the vehicles according to the waste quantity, the values of these emissions are far lesser per a Mg of transported waste from the vehicles of Euro IV - Euro VI engines.

About 82 % of all NO_x emission is just from the vehicles transporting the waste collected on the town Banja Luka territory, and afterwards driven to the landfill approximately 10 km from the town. All other municipalities participate with only 18 % in regard to the overall NO_x generated emission during a year. As for the town Banja Luka, the total emission from the vehicles with Euro III engines is 4.41 Mg of NO_x, or if regarding the total NO_x emission generated during the waste transport from the town to the landfill it is 85 % of NO_x emission generated by the vehicles with Euro III engine.

Table 4

Emission of CO [g] from vehicles transporting the waste to Banja Luka landfill

Type of engine	Euro I	Euro II		Euro III		Euro IV			Euro V		Euro VI	Total
Vehicles capacity	< 7.5	< 7.5	7.5-16	< 7.5	7.5-16	< 7.5	7.5-16	15-32	< 7.5	7.5-16	7.5-16	
Banja Luka	9,894	97,520	5,601	757,226	224,940	1,470	388	-	-	870	130	1,098,039
Gradiska	-	-	-	31,116	-	-	-	1,380	-	-	-	32,496
Laktasi	36,793	-	-	32,955	-	-	-	-	470	-	-	70,218
Prnjavor	-	-	-	157,287	-	-	321	-	-	-	-	157,608
Srbac	-	-	-	1,640	-	-	-	-	-	-	-	1,640
Kotor Varos	-	-	-	-	21,745	-	-	-	-	-	-	21,745
Knezevo	-	-	-	-	-	-	-	-	-	427	-	427
Celinac	-	-	-	-	-	-	750	-	-	-	-	750
Total	46,687	97,520	5,601	980,224	246,685	1,470	1,459	1,380	470	1,297	130	1,382,923

Table 5

NO_x emission [g] from the vehicles transporting the waste in the Banja Luka region

Type of engine	Euro I	Euro II		Euro III		Euro IV			Euro V		Euro VI	Total
Vehicles capacity	< 7.5	< 7.5	7.5-16	< 7.5	7.5-16	< 7.5	7.5-16	15-32	< 7.5	7.5-16	7.5-16	
Banja Luka	50,752	633,784	34,155	3,410,110	995,106	51,315	14,360	-	-	18,513	533	5,208,628
Gradiska	-	-	-	4,826	-	-	-	6,431	-	-	-	11,257
Laktasi	194,651	-	-	148,411	-	-	-	-	9,342	-	-	352,404
Prnjavor	-	-	-	708,333	-	-	11,994	-	-	-	-	720,27
Srbac	-	-	-	7,388	-	-	-	-	-	-	-	7,388
Kotor Varos	-	-	-	-	96,200	-	-	-	-	-	-	96,200
Knezevo	-	-	-	-	-	-	-	-	9,087	-	-	9,087
Celinac	-	-	-	-	-	-	3,073	-	-	-	-	3,073
Total	245,403	633,784	34,155	4,279,068	1,091,306	51,315	29,427	6,431	18,429	18,513	533	6,408,364

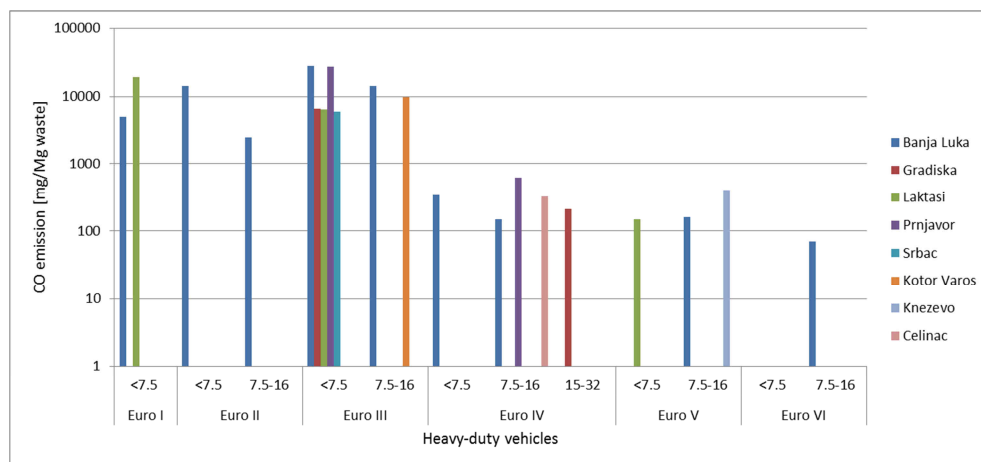


Fig. 2. CO emission from the vehicles

On Figure 3 the NO_x emission from the vehicles transporting the waste and estimated per a Mg of transported waste are presented. The NO_x emission per a Mg of waste are the highest from the vehicles with Euro I, II and III engine. The waste transported by the oldest vehicles (Euro I) for the vehicles with smaller capacity (< 7.5 Mg) generated NO_x from Banja Luka was 25.250 mg/Mg of waste, 101.410 mg/Mg of waste from Laktasi. The waste transport to the landfill conducted by the Euro III engine vehicles (< 7.5 Mg) from Banja Luka, Gradiska, Laktasi, Prnjavor and Srbac generated the NO_x emission of 126.74 g/Mg, 29.03 g/Mg, 29.05 g/Mg, 124.53 g/Mg and 26.14 g/Mg of waste, respectively. The newer vehicles with Euro V - Euro VI engines generated far less emission of NO_x per a Mg of waste, apropos these values varied in the volume from 0.31 g/Mg - 8.50 g/Mg of waste. The lowest NO_x emission was from the only vehicle with the Euro VI engine that is only 2 years old. The NO_x emission generated during the waste transportation from Gradiska during a year was 140.126 g of NO_x from the Euro III engine vehicle (< 7.5) or 29.03 g/Mg of waste, while the emission from the vehicle with Euro IV engine was 50,372 g NO_x , apropos 7.83 g/Mg of waste.

In Table 6 the emission of NMVOC from the vehicles transporting the waste to the Banja Luka regional landfill are presented.

The total estimated emission of NMVOC from all vehicles transporting the waste to the Banja Luka regional landfill was 0.28 Mg. The emission of NMVOC was the highest from the vehicles with Euro I, II and III engine, while it was far lesser from the vehicles of newer generation (Euro IV, V and VI).

About 79 % of all NMVOC emission was generated just when the vehicles transport collected waste from the Banja Luka town territory to the landfill that is at 10 km distance.

All other municipalities participate with only 21 % of emission compared to the overall NO_x generated emission during a year. From Banja Luka town the total emission caused by Euro III engine vehicles was 192.85 kg NMVOC or 85 % regarding the overall NMVOC emission generated during the waste transportation and calculated per a Mg of transported waste.

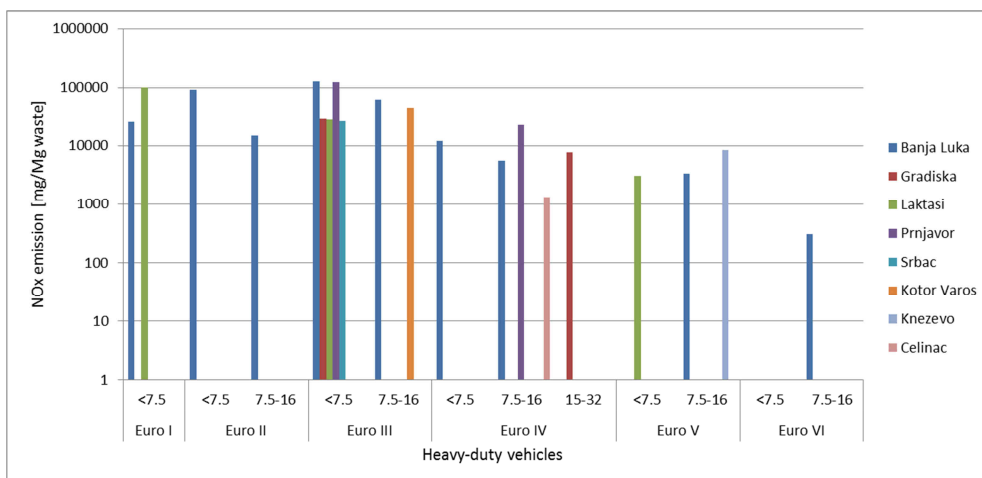


Fig. 3. Emission of NO_x from the vehicles

On Figure 4 the NMVOC emission from the vehicles transporting the waste are presented. The emission is calculated per a Mg of transported waste. Nevertheless, if we estimate the emission from the vehicles according to the quantity of waste the values of these emissions per a Mg of transported waste from the vehicles with Euro IV - Euro VI engine are far lesser. The emission of NMVOC per a Mg of waste are the highest from the vehicles with Euro I, II and III engines. The transport of waste by the oldest vehicles (Euro I) for the vehicles of smaller capacity (< 7.5 Mg) generated 1.44 g/Mg of waste from Banja Luka, 5.80 g/Mg of waste from Laktasi. The waste transported to the landfill by vehicles of Euro III engines (< 7.5 Mg) from Banja Luke, Gradiska, Laktasi, Prnjavor and Srbac produced NMVOC emission of 5.54 g/Mg, 1.27 g/Mg, 0.82 g/Mg, 5.45 g/Mg and 1.14 g/Mg of waste, respectively.

The newest vehicles with Euro V - Euro VI engines generated far less emission of NMVOC per a Mg of waste, apropos those values varied in the volume of (10-50) mg/Mg of waste NMVOC. The smallest emission of NMVOC was from the only vehicle that has the newest Euro VI engine and is only 2 years old. The NMVOC emission of transported waste from Gradiska during a year was 6,127 g of NMVOC from the Euro III (< 7.5 Mg) engine vehicle or 1,270 mg/Mg of waste, while the Euro IV (25 Mg) engine vehicle had the total emission of NMVOC of 132 g, apropos 20 mg/Mg of waste.

In Table 7 the emission of PM_{2.5} from the vehicles transporting the waste to the Banja Luka regional landfill are presented.

The total estimated emission of PM_{2.5} from all vehicles transporting the waste to the Banja Luka regional landfill was 0.14 Mg. The emission of PM_{2.5} was the highest from the vehicles with Euro I, II and III engines, while the lowest was from the vehicles of newer generation (Euro IV, V and VI).

About 77 % of all PM_{2.5} emission was just from the vehicles transporting the waste collected on the territory of Banja Luka town to the landfill that is approximately 10 km afar. All other municipalities participate with only 23 % in regard to the overall emission of PM_{2.5} during a year. For the Banja Luka town the total emission caused by the Euro III engine vehicles was 93.78 g PM_{2.5} or 87 % considering the total emission of PM_{2.5}

generated by the Euro III engine vehicles while transporting the waste from this town to the landfill.

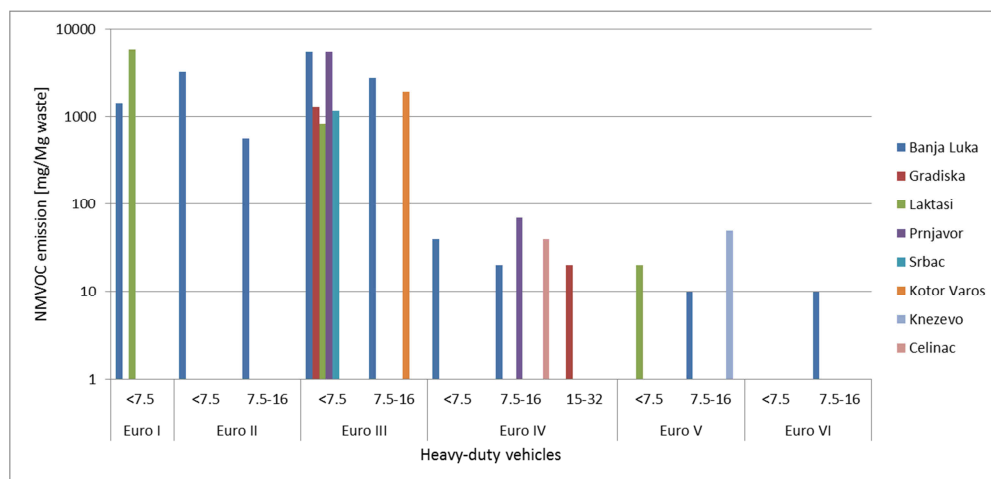


Fig. 4. NMVOC emission from the vehicles

Table 6
Emission of NMVOC [g] from the vehicles transporting the waste to the Banja Luka regional landfill

Type of engine	Euro I		Euro II		Euro III		Euro IV			Euro V		Euro VI	Total
Vehicle capacity	< 7.5	< 7.5	7.5-16	< 7.5	7.5-16	< 7.5	7.5-16	15-32	< 7.5	7.5-16	7.5-16		
Banja Luka	2,907	22,337	1,285	149,111	43,738	156	43	-	-	16	15	219,608	
Gradiska	-	-	-	6,127	-	-	-	132	-	-	-	6,259	
Laktasi	11,148	-	-	4,326	-	-	-	-	50	-	-	15,524	
Prnjavor	-	-	-	30,972	-	-	36	-	-	-	-	31,008	
Srbac	-	-	-	323	-	-	-	-	-	-	-	323	
Kotor Varos	-	-	-	-	4,228	-	-	-	-	-	-	4,228	
Knezevo	-	-	-	-	-	-	-	-	-	48	-	48	
Celinac	-	-	-	-	-	-	84	-	-	-	-	84	
Total	14,055	22,337	1,285	190,859	47,966	156	163	132	50	64	15	277,082	

On Figure 5 the PM_{2.5} emission from the vehicles transporting the waste and calculated per a Mg of transported waste is presented. But, if we estimate the emission from the vehicles according to the quantity of waste, the emission has a far lesser value per a Mg of waste transported by vehicles of Euro IV - Euro VI engines. The PM_{2.5} emission per a Mg of waste was the highest from the vehicles with Euro I, II and III engine. The waste transported by the older vehicles (Euro I) for the vehicles with smaller capacity (< 7.5 Mg) generated 970 mg/Mg of waste PM_{2.5} from Banja Luke, and 3.880 mg/Mg of waste from Laktasi. The waste transport to the landfill by Euro III engine (< 7.5 Mg) vehicle from Banja Luka, Gradiska, Laktasi, Prnjavor and Srbac generated the emission of

PM2.5 as follows: 2.73 g/Mg, 0.62 g/Mg, 0.40 g/Mg, 2.68 g/Mg, and 0.56 g/Mg of waste, respectively.

The newer vehicle with Euro V - Euro VI engines generated far lesser emission of PM2.5 per a Mg of waste, apropos these values varied in the volume from (10-90) mg/Mg of waste of PM2.5. The lowest emission of PM2.5 was from the only vehicle with the Euro VI engine and it is only 2 years old.

The PM2.5 emission during the transport of waste from Gradiska and during one year was 3.016 g of PM2.5 caused by the vehicle of Euro III engine (< 7.5 Mg) or 620 mg/Mg of waste, while the emission caused by the vehicle of Euro IV (25 Mg) engine was in total 1,381 g, apropos 210 mg/Mg of waste of PM2.5.

Table 7
Emission of PM2.5 [g] from the vehicle transporting the waste to the Banja Luka regional landfill

Type of engine	Euro I		Euro II		Euro III		Euro IV			Euro V		Euro VI	Total
Vehicle type	< 7.5	< 7.5	7.5-16	< 7.5	7.5-16	< 7.5	7.5-16	15-32	< 7.5	7.5-16	7.5-16		
Banja Luka	1,943	10,078	646	73,388	20,388	332	88	-	-	197	2	107,062	
Gradiska	-	-	-	3,016	-	-	-	1,381	-	-	-	4,397	
Laktasi	7,451	-	-	2,129	-	-	-	-	106	-	-	9,686	
Prnjavor	-	-	-	15,244	-	-	73	-	-	-	-	15,317	
Srbac	-	-	-	159	-	-	-	-	-	-	-	159	
Kotor Varos	-	-	-	-	1,971	-	-	-	-	-	-	1,971	
Knezevo	-	-	-	-	-	-	-	-	-	97	-	97	
Celinac	-	-	-	-	-	-	170	-	-	-	-	170	
Total	9,394	10,078	646	93,936	22,359	332	331	1,381	106	294	2	138,859	

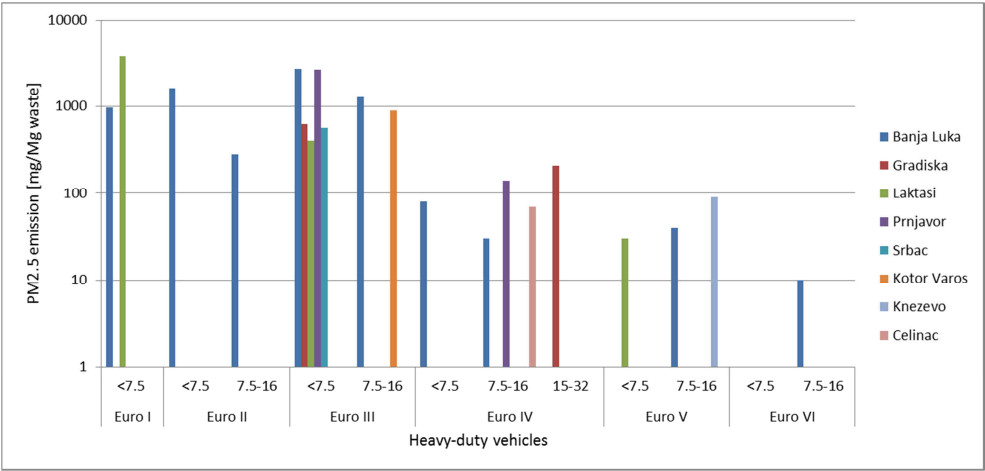


Fig. 5. The emission of PM2.5 from the vehicles

Conclusion

The problems related to the waste transportation in the Banja Luka region are following: (1) The age of vehicles - about 80 % of vehicles have Euro I, Euro II and Euro III engines, (2) Only one local community organised transfer stations and therefore cut costs of waste transportation, (3) Other local communities that are more than 20 km afar transport the waste by older vehicles or vehicles with large capacity (7.5 - 16) Mg but not fully filled - apropos the vehicles are almost half-empty.

Up until now no studies of consequence related to the decrease of emission from the vehicles transporting the waste were done. No detailed studies related to the betterment of the route organisation, or cutting the cost of transportation were done. One of the reasons for the lack of such studies is the fact that the local communities often aid the communal companies in case of financial loss.

Basic measures to improve waste transport, which will result in the reduction of pollutant emissions into the air, in the future should include: (1) the use of low-carbon fuels, including the use of electric and hybrid vehicles, vehicles using natural gas and biogas, liquefied petroleum gas, hydrogen-powered vehicles, (2) optimisation and efficiency of vehicles, (3) destimulation of diesel fuel consumption and imports of old diesel vehicles, (4) support for sustainable integrated freight transport, (5) optimisation of waste collection and transport routes, (6) decrease the number of tours by constructing transfer stations.

In addition to improving waste transport, improvements are needed in other segments of waste management, such as: (1) improving the waste collection system, (2) introducing separate waste collection and recycling, (3) waste prevention, (4) reducing waste (especially biodegradable waste) that is disposed of, (5) treatment of biodegradable waste (composting and anaerobic digestion), with the aim of establishing an integrated sustainable waste management system.

References

- [1] Eisted R, Larsen AW, Christensen, TH. Collection, transfer and transport of waste: accounting of greenhouse gases and global warming contribution. *Waste Manage Res.* 2009;27(8):738-45. DOI: 10.1177/0734242X09347796.
- [2] Sandhu GS, Frey HC, Bartelt-Hunt S, Jones E. In-use measurement of the activity, fuel use, and emissions of front-loader refuse trucks. *Atmospheric Environ.* 2014;92:557-65. DOI: 10.1016/j.atmosenv.2014.04.036.
- [3] Fontaras G, Martini G, Manfredi U, Marotta A, Krasenbrink A, Maffioletti F, et al. Assessment of on-road emissions of four Euro V diesel and CNG waste collection trucks for supporting air-quality improvement initiatives in the city of Milan. *Sci Total Environ.* 2012;426:65-72. DOI: 10.1016/j.scitotenv.2012.03.038.
- [4] Pérez J, Lumbreras J, Rodríguez E, Vedrenne M. A methodology for estimating the carbon footprint of waste collection vehicles under different scenarios: Application to Madrid. *Transportation Res Part D: Transport Environ.* 2017;52:156-71. DOI: 10.1016/j.trd.2017.03.007.
- [5] Friedrich E, Trois C. Quantification of greenhouse gas emissions from waste management processes for municipalities - A comparative review focusing on Africa. *Waste Manage.* 2011;31(7):1585-96. DOI: 10.1016/j.wasman.2011.02.028.
- [6] D'Angiola A, Dawidowski L, Gomez D, Granier C. NMVOCs speciated emissions from mobile sources and their effect on air quality and human health in the metropolitan area of Buenos Aires, Argentina. In *EGU General Assembly Conference Abstracts*. 2014:14898. Available from: <https://ui.adsabs.harvard.edu/abs/2014EGUGA..1614898D/abstract>.
- [7] EEA (European Environment Agency). Contribution of the transport sector to total emissions of the main air pollutants. 2018. Available from: https://www.eea.europa.eu/data-and-maps/daviz/contribution-of-the-transport-sector-6#tab-chart_4.

- [8] European Commission. Communication from the Commission to the Council and the European Parliament, Strategy for Reducing Heavy-Duty Vehicles' Fuel Consumption and CO₂ Emissions, COM(2014). 285. 2014. Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0285&from=CS>.
- [9] European Commission. Commission Staff Working Document Bosnia and Herzegovina 2021 Report Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 2021 Communication on EU Enlargement Policy. Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021SC0291>.
- [10] EU Directive on Landfill of Waste. European Union Council Directive 1999/31/EC issued 26 April 1999. Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31999L0031>.
- [11] Nguyen TT, Wilson BG. Fuel consumption estimation for kerbside municipal solid waste (MSW) collection activities. *Waste Manage Res.* 2010;28(4):289-97. DOI: 10.1177/0734242X09337656.
- [12] McLeod F, Cherrett T. Quantifying the transport impacts of domestic waste collection strategies. *Waste Manage.* 2008;28(11):2271-8. DOI: 10.1016/j.wasman.2007.09.041.
- [13] Das S, Bhattacharyya BK. Optimization of municipal solid waste collection and transportation routes. *Waste Manage.* 2015;43:9-18. DOI: 10.1016/j.wasman.2015.06.033.
- [14] Chalkias C, Lasaridi K. A GIS based model for the optimisation of municipal solid waste collection: the case study of Nikea, Athens, Greece. *WSEAS Trans Environ Development.* 2009;1:11-5. Available from: <http://www.wseas.us/e-library/transactions/environment/2009/29-809.pdf>.
- [15] Larsen AW, Vrgoc M, Christensen TH, Lieberknecht P. Diesel consumption in waste collection and transport and its environmental significance. *Waste Manage Res.* 2009;27(7):652-9. DOI: 10.1177/0734242X08097636.
- [16] Boskovic G, Jovicic N, Milasinovic M, Jovicic G, Milovanovic D. Methodology for reduction of GHG emissions from municipal solid waste collection and transport. *Int J Quality Res.* 2013;7(4):641-52. Available from: <http://www.ijqr.net/journal/v7-n4/12.pdf>.
- [17] Vučijak B, Kurtagić SM, Silajdžić I. Multicriteria decision making in selecting best solid waste management scenario: a municipal case study from Bosnia and Herzegovina. *J Cleaner Production.* 2016;130:166-74. DOI: 10.1016/j.jclepro.2015.11.030.
- [18] Bjelic D, Markic DN, Pesic ZS, Sorak M, Kikanovic O, Vukic L. et al. Environmental assessment of municipal solid waste management in Banjaluka, Bosnia and Herzegovina. *Environ Eng Manage J.* 2017;16(5):1161-70. DOI: 10.30638/eemj.2017.121.
- [19] Topić M, Zimmermann F, Fischer W. Waste Management Planning: An analysis of the waste management system in Bosnia and Herzegovina. In: Planning and normative protection of space and environment: Proc 7th Sci Conf with international participation. Belgrade. 2013;205-13. DOI: 10.5937/sjm10-7360.
- [20] Markic DN, Bjelic D, Zugic ND, Carapina HS, Pesic ZS. Assessment of the impact of Banja Luka landfill on groundwater quality. *Carpathian J Earth Environ Sci.* 2015;10(2):271-80. Available from: <http://www.cjees.ro/viewTopic.php?topicId=541>.
- [21] Xin C, Zhang T, Tsai SB, Zhai YM, Wang J. An empirical study on greenhouse gas emission calculations under different municipal solid waste management strategies. *Appl Sci.* 2020;10(5):1673. DOI: 10.3390/app10051673.
- [22] Liu Y, Xing P, Liu J. Environmental performance evaluation of different municipal solid waste management scenarios in China. *Resources, Conservation Recycling.* 2017;125:98-106. DOI: 10.1016/j.resconrec.2017.06.005.
- [23] Republic Waste Management Plan. Ministry of Physical Planning, Civil Engineering and Ecology of Republic of Srpska. 2020. Available from: <https://cupdf.com/document/republiki-plan-upravlana-otpadom-u-republici-srpskoj.html?page=5>.
- [24] EUROSTAT. Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics.
- [25] World Bank. Municipal Solid Waste Management Sector Review; Strategic Directions and Investment Planning up to 2025. Part B. Republika Srpska 2018. Available from: <https://documents1.worldbank.org/curated/en/797701562143935712/text/Part-B-Republika-Srpska.txt>.
- [26] EEA. EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019. European Environment Agency; Report No 13/2019. Available from: <https://www.eea.europa.eu/publications/emep-eea-guidebook-2019>.