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Fuel-related Emissions from the Croatian Municipal Solid Waste Collection System in 2013: Mixed Municipal Waste

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Abstract

Waste removal (collection and landfilling) in the Republic of Croatia is the responsibility of the municipalities and local governments in 21 administrative units (counties). They entrust the respective economic activity to 208 private and public companies specialized in waste collection and treatment. Organised waste collection affects 99 % of the population. The mixed waste from households and enterprises is at various frequencies collected at the door (kerbside collection) and transported by truck to a landfill, or processing plant.

This article aims to estimate fuel consumption and fuel-related airborne emissions from the collection of mixed municipal waste in Croatia in 2013. The input data and emission results are shown for Croatia and each Croatian county, in total, and relative to the number of inhabitants and mass of collected waste. Annual consumption of diesel for the collection of mixed waste is estimated at 10.6 million litres. At the county level, fuel consumption ranges from 87 thousand litres to 2.2 million litres, on average 504 thousand litres *per* county. Total emission of CO_2 is estimated at 28 000 t, which at county level ranges from 231 to 5711 t. Relative emission ranges from 3.3 to 13 kg CO_2 *per capita* (average 6.6 kg *per capita*), or 8.6–28.1 kg t^{-1} of municipal waste (average 17 kg CO_2 *per* ton of municipal waste). The average values of CO_2 emission from MSW collection that should also be the target values are 7–9 kg for mixed waste, and 8–15 kg CO_2 for separate waste streams. Apart from CO_2 emission, this research estimates emission of other, diesel combustion related compounds, such as NO_x, CO, lubricant related CO_2, NMVOC, PM, f-BC, N_2O, SO_2, NH_3, Pb, ID[1,2,3-cd]P, B[k]F, B[b]F, B[a]P), as well as total distance of transport.

Keywords

Municipal solid waste, mixed waste stream, collection, fuel consumption, emissions

1 Introduction

This article aims to estimate emissions to air from the Croatian municipal solid waste (MSW) collection system. The estimate of fuel consumption is based on data delivered from half of the total number of Croatian companies in the business of MSW collection.[1] The emissions to air are calculated using Tier 1 emission factors for heavy duty vehicles. Results are shown for each Croatian county, in total, and relative to the number of inhabitants and mass of collected waste. The time relevance of this research is for the year 2013, when the Croatian MSW recycling rate was only about 15 %. These data can be used as the reference level for landfilling/low recycling scenario in the studies on environmental efficiency of the various waste management scenarios.

The collection and transport of municipal solid waste is an important unit process of the waste management system that should be taken into consideration when analysing the environmental impacts.[2–8] In the analyses on environment impact of the waste management system, the collection is either ignored or its role is exaggerated.[9–11] Some authors claim that fuel consumption within a waste collection system, measured *per* mass unit of collected waste, has significant impact on the environment.[12,13] Reduction of both the mass of waste transported and the transport distance is essential for reduction of the waste management impact on the environment.[14]

Waste removal (collection and landfilling) in the Republic of Croatia is the responsibility of the municipalities and local governments in 21 administrative units (counties). They entrust the respective economic activity to 208 private and public companies specialized in waste collection and treatment. Organised waste collection affects 99 % of the population. The mixed waste from households and enterprises is at various frequencies collected at the door (kerbside collection) and transported by truck to a landfill, or, rarely, to a processing plant. The average annual mass of municipal solid waste *per capita* totals 382 kg (in the year 2014). The national municipal waste recycling rate amounts to 15 % (in the year 2013), with most of the waste being landfilled.[15]

The main constituent of the fuel-related airborne emissions is carbon dioxide. In the literature, carbon dioxide emissions *per* ton of municipal solid waste that is related to its collection and transport, varies greatly. These differences arise from the differences in:

- *applied waste collection technology: type of trucks, differences in fuel and fuel consumption;*
- *applied waste management methods in the studied area: kerbside collection of mixed or separated waste, transport to landfill or to treatment/recycling/incineration centre first;*

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- *method of data collection: direct measurement, average data;*
- *method of calculation of the CO_2 emission – impact analysis applied: complete combustion of fuel into CO_2 or incomplete combustion of fuel resulting in emission of CO_2 and CO, fuel combustion related emission, fuel life cycle related emission (including exploitation, refinery, regional storage).*

The AEA study (2001)[16] gives the emission factors for collection and transport of waste for different treatment options. The factors are resulting from general fixed assumptions on vehicle types used, payloads and km travelled. The standard emission factor for transport of collected municipal solid waste (MSW) is 7 kg of fossil CO_2 equivalent *per* ton of MSW.[16] For separately collected fractions, the factor ranges from 8 to 15 kg CO_2 (eq) *per* ton of waste (Table 1). The same factors are used in JASPERS Knowledge Economy and Energy Division Staff for Calculation of GHG emissions of Waste Management Projects.[17] Fig. 1 shows the waste management models in the AEA study, and the transport details of that model can be found in Appendix 1. Table A1.24. pp. 87–88 of the AEA study.[16]

Table 1 – Emission factors for collection and transport of waste for different treatment options[16]
Tablica 1 – Faktori emisija za sakupljanje i transport otpada za razne metode obrade otpada[16]

Treatment option	mass of CO_2 equivalent *per* mass of MSW / kg t^{-1}
separately collected metal to sorting and recycling	10
separately collected plastic to sorting and recycling	15
separately collected paper/cardboard to sorting and recycling	10
separately collected glass to sorting and recycling	10
separately collected biowaste to composting	8
separately collected biowaste to AD	8
mixed waste to MBT	9
mixed waste to incineration	8
mixed waste to landfill	7

Table 2 – Breakdown of the CO_2 emissions for the MRF scenario in Dresden (*Winkler and Bilitewski, 2007, p. 1027*)[18]
Tablica 2 – Pojedinačne emisije ugljikova dioksida iz sustava gospodarenja otpadom grada Dresdena izračunate u različitim programima (*Winkler and Bilitewski, 2007, p. 1027*)[18]

	CO_2 / Mg					
software	collection	MRF	remanufacturing	transport	landfill	total
ARES	233	11 202	7 597	188	44 210	63,429
EPIC/CSR	368	3 128	−46 451	75	44 712	1 1832
DST	1639	11 389	−34 676	538	32 675	11 566
IWM2	416	3 376	−3 271	0	24 103	24 624
ORWARE	740	12 375	−194 223	567	54 866	−125 674
UMBERTO	1278	446	−276 261	154	24 965	−249 418

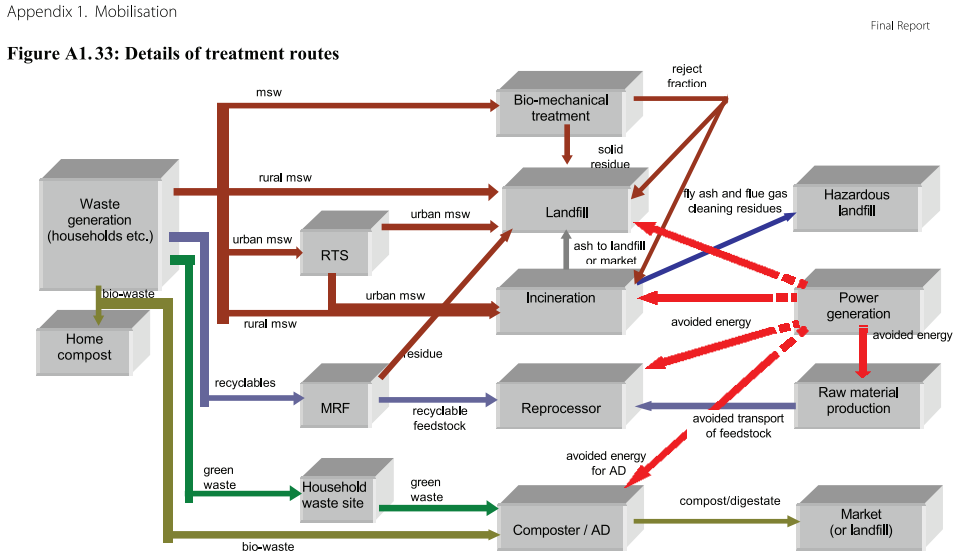
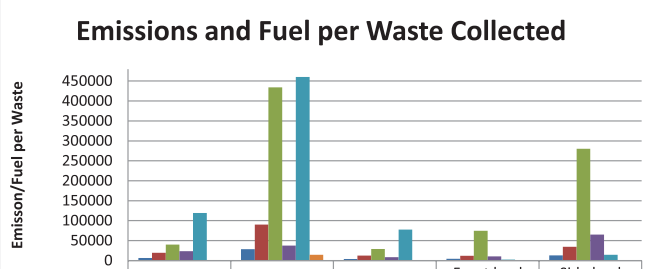


Fig. 1 – Details of treatment routes (*AEA Technology, Final Report. Appendix 1. Mobilisation. Figure A1.33. p. 83*)[16]
Slika 1 – Detalji metoda obrade otpada za koje su izračunati faktori emisija (*AEA Technology, Final Report. Appendix 1. Mobilisation. Figure A1.33. str. 83*)[16]

Winkler and Bilitewski (2007)[18] performed a comparative evaluation of different LCA models for analysis of solid waste management in Dresden based on data for 1999. Dresden, a city with a population of approx. 1.2 million, produced that year 215 420 t of solid waste from households and small businesses. The waste management of Dresden is shown in three scenarios: landfill, material recovery, and incineration. All scenarios assumed kerbside waste collection in bin and transport to the waste treatment facility in the waste collection truck. From their article, indicative is the table with CO_2 emissions calculated for the materials recovery facility (MRF) scenario (Table 2). Their results show that total emission of CO_2 from waste collection ranges from 233 to1639 Mg CO_2 (t CO_2).[18]

Hauser (2015)[19] evaluated air emissions from trucks for solid waste management. The research was performed for a typical collection route in the Raleigh area, North Carolina. Total number of trucks in research was twenty-four. Fig. 2 shows the fuel consumption (diesel or compressed natural gas), and air emissions of carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbon (HC), nitrous oxide (NO_x), and particulate matter (PM) *per* ton of waste collected in five types of WM trucks. The results of Hauser (2015) show diesel use of approx. 3.9–28.7 kg t^{-1}; emissions CO_2 12.6–90.0 kg t^{-1}, CO 29.0–434.4 kg t^{-1}, HC 8–38 g t^{-1}, NO_x 78–460 g t^{-1}, and PM 11 mg t^{-1} – 14 g t^{-1}. The calculated models represent the average fuel economy of trucks based on truck data that were recorded for every second spent in route.[19]

Salhofer et al. (2007)[20] report global warming potential (GWP, kilograms of CO_2), eutrophication (EP, grams of PO_4), acidification (AP, grams of SO_2), photochemical ozone – summer smog creation (POCP, grams of C_2H_4),



	Front load	Side load	Roll off	Front load CNG	Side load CNG
Fuel (g/ton)	6184	28671	3991	4467	12825
CO2 (g/ton)	19457	90034	12572	11874	34670
CO (g/ton)	39888	434411	28985	74777	280154
HC (mg/ton)	23675	37510	8269	10460	65285
NOx (mg/ton)	119150	460251	77709	2602	14453
PM (mg/ton)	1454	14459	1087	14	63

Fig. 2 – Emissions and fuel *per* waste collected *per* truck (*Hauser, 2015, p. 52*)[19]
Slika 2 – Emisije i gorivo po sakupljenom otpadu po vozilu (*Hauser, 2015., str. 52*)[19]

human toxicity (HTP, grams of DCB), and cumulated fossil energy demand (CED_{fos}) for various fractions of separately collected waste at kerbside in three waste management scenarios: material recycling, thermal recycling, and disposal (Table 3). The scenarios represent the Austrian transport values for fractions of waste. The emission of CO_2 (GWP) ranged from 12 to 703 kg t^{-1} of waste: refrigerators 171–178, paper 13–22, polyethylene (PE) films 12–137, and expanded polystyrene (EPS) 12–703 kilograms of CO_2 *per* ton of transported waste. For the refrigerators, the ozone depletion potential (ODP) in transport was also reported (16 g CFC11).[20]

Table 3 – Results of impact analysis for waste collection system (*S. Salhofer et al., 2007*)[20]
Tablica 3 – Rezultati analize utjecaja za sustav sakupljanja otpada (*S. Salhofer et al., 2007*)[20]

Indicator	GWP (kilograms of CO_2)				EP (grams of PO_4)			
waste scenario	refrigerators	paper	PE films	EPS	refrigerators	paper	PE films	EPS
material recycling	178	22	137	703	6	23	142	783
thermal recycling	–	20	106	–	–	22	107	803
disposal	171	13	12	12	0	7	11	11
	AP (grams of SO_2)				POCP(grams of C_2H_4)			
waste scenario	refrigerators	paper	PE films	EPS	refrigerators	paper	PE films	EPS
material recycling	8	24	153	763	1	2	15	65
thermal recycling	–	22	122	–	–	2	13	–
disposal	0	7	14	14	0	1	1	1
Indicator	HTP (grams of DCB)				CED_{fos}			
waste scenario	refrigerators	paper	PE films	EPS	refrigerators	paper	PE films	EPS
material recycling	421	1908	12906	53855	184	537	3437	17447
thermal recycling	–	1779	11482	–	–	310	2685	–
disposal	11	1321	1402	1402	4	176	298	298

2 Experimental (mathematical formulas, tables & equations)

2.1 Input data

The input data for the analysis are based on the research of *Ljubić* (2015) and raw data tables from the Croatian environmental protection agency. Ljubić collected data from the waste collection companies (by phone and e-mail). Half of the 208 companies responded and delivered information on diesel consumption in 2013. Some companies delivered information on diesel consumption in volume unit litres, others in money (HRK) spent for the diesel with VAT (value added tax) included or excluded, some delivered information in both, litres and HRK.[14]

In this research, raw data retrieved from *Ljubić*[14] are corrected. Firstly, the companies that were non-existent in the table received from the Croatian environmental protection agency are excluded because they were not operating in 2013. Secondly, the diesel volume is calculated from prices using the annual average price of diesel. Thus, the diesel figures presented here (Table 4) are somewhat different.

The Croatian environmental protection agency delivered raw data in an Excel document with registry of all the companies, counties they operate, and quantity and type of waste they collected. From that file, the quantity of waste in each county by type and total were summed. A copy was then made and all data for companies which had not delivered fuel data were deleted. That resulted with the

Table 4 – Diesel consumption in MSW collection system in Croatia 2013 and data representativeness

Tablica 4 – Prikupljeni podatci o potrošnji dizela u sustavu sakupljanja komunalnog otpada u Republici Hrvatskoj u 2013. i reprezentativnost podataka

Administrative unit	Population	Delivered data on diesel consumed		Waste collected by the companies which delivered data	Total waste collected	Waste collected by the companies which delivered data on fuel consumption.	Structure of waste collected by the companies which delivered data	
							Mixed municipal waste	other municipal waste (paper. glass. plastics. bulky. packages….)
		volume / dm^3	mass / kg	mass / Mg	mass / Mg	%	%	%
Bjelovarsko-bilogorska	104 416	128 582	106 980	20 778	25 309	82.10	97.12	2.88
Brodsko-posavska	158 567	62 916	52 346	9 241	45 277	20.41	100.00	0.00
Dubrovačko-neretvanska	123 043	60 473	50 314	9 069	63 184	14.35	98.70	1.30
Grad Zagreb	780 000	303	252	54	332 047	0.02	6.56	93.44
Istarska	206 286	417 690	347 518	85 648	115 732	74.01	88.10	11.90
Karlovačka	125 532	102 398	85 195	19 899	43 957	45.27	83.16	16.84
Koprivničko-križevačka	112 782	138 340	115 099	18 801	25 075	74.98	86.35	13.65
Krapinsko-zagorska	126 724	141 528	117 751	16 400	65 293	25.12	90.83	9.17
Ličko-senjska	49 700	93 112	77 469	8 764	22 837	38.37	97.51	2.49
Međimurska	113 197	69 000	57 408	14 522	29 338	49.50	70.91	29.09
Osječko-baranjska	300 959	550 899	458 348	67 695	97 881	69.16	96.64	3.36
Požeško-slavonska	66 995	83 945	69 842	13 250	13 796	96.04	94.54	5.46
Primorsko-goranska	295 988	730 319	607 625	84 064	125 357	67.06	72.96	27.04
Sisačko-moslavačka	150 696	193 585	161 063	27 462	53 186	51.63	95.24	4.76
Splitsko-dalmatinska	454 936	504 732	419 937	113 508	214 875	52.82	96.29	3.71
Šibensko-kninska	109 345	78 800	65 561	14 883	49 717	29.94	98.74	1.26
Varaždinska	162 761	64 804	53 917	10 725	73 158	14.66	92.43	7.57
Virovitičko-podravska	84 449	9 952	8 280	1 958	24 222	8.08	98.67	1.33
Vukovarsko-srijemska	173 760	114 032	94 875	26 313	52 888	49.75	97.29	2.71
Zadarska	169 165	710 110	590 811	85 286	93 163	91.54	92.37	7.63
Zagrebačka	325 226	40 385	33 600	12 469	144 797	8.61	76.60	23.40
MIN	**49 700**	**303**	**252**	**54**	**13 796**	**0.02**	**6.56**	**0.00**
MAX	**780 000**	**730 319**	**607 625**	**113 508**	**332 047**	**96.04**	**100.00**	**93.44**
AVERAGE	**199 739**	**204 567**	**170 200**	**31 466**	**81 480**	**45.88**	**87.19**	**12.81**
CROATIA	**4 194 527**	**4 295 904**	**3 574 192**	**660 790**	**1 711 089**	**38.62**	**90.13**	**9.87**

waste figures for companies which delivered data on fuel consumption.

Data representativeness for the county-level was calculated from the ratio of waste collected by the companies which delivered data on fuel consumption (column 7 of 9 in Table 4, and column 20 of 20 in Table 5).

Considering that the companies were unable to deliver the data on fuel consumption *per* waste stream collected, it was necessary to inspect for which type of waste the data is representative. That was calculated from the ratios of waste types in total waste collected by the companies which delivered data (summary in columns 8 and 9 in Table 4, detailed ratios in Table 6).

Table 5 – Percentage of waste in administrative unit collected by companies which delivered data on fuel consumption (by waste type)

Tablica 5 – Udio tvrtki – sakupljača otpada (koji su dostavili podatke o potrošnji goriva) u ukupno sakupljenom otpadu u administrativnoj jedinici (po vrsti otpada) u Republici Hrvatskoj u 2013.

Administrative unit (county)	*Type of waste collected / %																		
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	Sum
Bjelovarsko-bilogorska	0.00	0.00	0.00	0.00	0.10	0.00	0.01	79.73	0.00	1.05	0.00	0.15	0.84	0.00	0.00	0.00	0.20	0.00	82.10
Brodsko-posavska	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.41
Dubrovačko-neretvanska	0.00	0.00	0.00	0.00	0.00	0.19	0.00	14.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.35
Grad Zagreb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02
Istarska	0.02	1.19	0.05	0.00	3.75	0.94	0.00	65.20	0.00	1.32	0.35	0.42	0.40	0.00	0.09	0.22	0.04	0.00	74.01
Karlovačka	0.00	0.02	0.00	0.00	0.05	5.30	0.00	37.64	0.00	1.86	0.25	0.00	0.00	0.00	0.05	0.00	0.00	0.09	45.27
Koprivničko-križevačka	0.04	0.27	3.08	0.00	5.37	0.35	0.00	64.75	0.00	0.04	0.18	0.05	0.18	0.00	0.03	0.37	0.06	0.22	74.98
Krapinsko-zagorska	0.00	0.03	0.00	0.00	0.61	1.62	0.00	22.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	25.12
Ličko-senjska	0.00	0.60	0.22	0.00	0.00	0.00	0.00	37.42	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.11	0.00	0.00	38.37
Međimurska	0.23	2.99	2.28	0.00	6.17	1.71	0.00	35.10	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.87	0.00	0.00	49.50
Osječko-baranjska	0.00	0.12	0.02	0.00	0.02	0.29	0.04	66.84	0.00	0.00	0.01	0.00	1.62	0.00	0.11	0.09	0.00	0.00	69.16
Požeško-slavonska	0.00	0.00	0.00	0.00	3.31	0.92	0.00	90.80	0.00	0.00	0.16	0.31	0.55	0.00	0.00	0.00	0.00	0.00	96.04
Primorsko-goranska	0.02	2.68	0.59	0.00	4.71	7.87	0.00	48.93	0.00	0.74	0.18	0.43	0.31	0.00	0.04	0.56	0.00	0.00	67.06
Sisačko-moslavačka	0.00	0.80	0.03	0.00	0.34	1.08	0.07	49.18	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.02	0.00	0.00	51.63
Splitsko-dalmatinska	0.00	0.09	0.00	0.00	0.00	1.23	0.00	50.86	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	52.82
Šibensko-kninska	0.00	0.27	0.00	0.00	0.00	0.06	0.00	29.56	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	29.94
Varaždinska	0.00	0.10	0.04	0.00	0.74	0.03	0.00	13.55	0.00	0.00	0.01	0.00	0.15	0.00	0.00	0.04	0.00	0.00	14.66
Virovitičko-podravska	0.00	0.00	0.00	0.00	0.00	0.11	0.00	7.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.08
Vukovarsko-srijemska	0.00	0.00	0.00	0.00	0.05	0.61	0.00	48.40	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	49.75
Zadarska	0.00	0.17	0.08	0.00	0.82	5.24	0.00	84.56	0.00	0.37	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	91.54
Zagrebačka	0.00	0.00	0.00	0.00	0.01	0.13	0.00	6.60	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.01	1.84	8.61
MIN	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.02**
MAX	**0.23**	**2.99**	**3.08**	**0.00**	**6.17**	**7.87**	**0.07**	**90.80**	**0.00**	**1.86**	**0.35**	**0.43**	**1.62**	**0.00**	**0.11**	**0.87**	**0.20**	**1.84**	**96.04**
AVERAGE	**0.02**	**0.54**	**0.41**	**0.00**	**1.40**	**1.55**	**0.01**	**41.97**	**0.00**	**0.36**	**0.07**	**0.08**	**0.27**	**0.00**	**0.02**	**0.14**	**0.02**	**0.19**	**46.06**
CROATIA	**0.01**	**0.41**	**0.14**	**0.00**	**0.93**	**1.41**	**0.00**	**34.81**	**0.00**	**0.32**	**0.05**	**0.07**	**0.19**	**0.00**	**0.02**	**0.09**	**0.01**	**0.18**	**38.62**

* A – Metal packaging; B – Paper and cardboard packaging; C – Plastic packaging; D – Batteries and accumulators covered by 16 06 01. 16 06 02 or 16 06 03 and unassembled batteries and accumulators containing these batteries; E– Biodegradable waste; F – Bulky waste; G – Used tires; H – Mixed municipal waste; I – Discarded equipment containing chlorofluorocarbons. HCFCs. HFCs; J – Street cleaning residue; K – Other non-biodegradable waste; L – Waste from the market; M – Paper and cardboard; N – Ashes from the litter grate. precipitate and dust from the boiler (other than the dust from the boiler mentioned under 10 01 04); O – Plastics; P – Glass packaging; Q – Glass; R – Soil and rock

Table 6 – Waste stream representativeness of delivered data on fuel consumption

Tablica 6 – Reprezentativnost dostavljenih podataka o potrošnji goriva za sakupljanje otpada u Republici Hrvatskoj u 2013. godini po vrstama otpada

Administrative unit (county)	*Type of waste collected / %																		
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	Sum
Bjelovarsko-bilogorska	0.00	0.00	0.00	0.00	0.12	0.00	0.02	97.12	0.00	1.27	0.00	0.18	1.03	0.00	0.00	0.00	0.24	0.00	100.00
Brodsko-posavska	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Dubrovačko-neretvanska	0.00	0.00	0.00	0.00	0.00	1.30	0.00	98.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Grad Zagreb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	93.44	100.00
Istarska	0.02	1.61	0.07	0.00	5.07	1.27	0.00	88.10	0.00	1.78	0.48	0.57	0.54	0.00	0.12	0.30	0.05	0.00	100.00
Karlovačka	0.00	0.04	0.00	0.00	0.11	11.72	0.00	83.16	0.00	4.10	0.55	0.00	0.01	0.00	0.11	0.00	0.00	0.20	100.00
Koprivničko-križevačka	0.05	0.36	4.11	0.00	7.17	0.46	0.00	86.35	0.00	0.05	0.23	0.07	0.24	0.00	0.04	0.49	0.08	0.29	100.00
Krapinsko-zagorska	0.00	0.13	0.01	0.00	2.45	6.45	0.00	90.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	100.00
Ličko-senjska	0.00	1.56	0.58	0.00	0.00	0.00	0.00	97.51	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.28	0.00	0.00	100.00
Međimurska	0.46	6.04	4.60	0.00	12.46	3.46	0.00	70.91	0.00	0.00	0.30	0.00	0.00	0.00	0.00	1.77	0.01	0.00	100.00
Osječko-baranjska	0.00	0.18	0.02	0.00	0.03	0.42	0.06	96.64	0.00	0.00	0.01	0.00	2.34	0.00	0.17	0.14	0.00	0.00	100.00
Požeško-slavonska	0.00	0.00	0.00	0.00	3.44	0.96	0.00	94.54	0.00	0.00	0.17	0.33	0.57	0.00	0.00	0.00	0.00	0.00	100.00
Primorsko-goranska	0.03	4.00	0.88	0.00	7.02	11.74	0.00	72.96	0.00	1.11	0.27	0.63	0.45	0.00	0.06	0.84	0.01	0.00	100.00
Sisačko-moslavačka	0.00	1.55	0.07	0.00	0.66	2.09	0.13	95.24	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.04	0.00	0.00	100.00
Splitsko-dalmatinska	0.00	0.18	0.00	0.00	0.00	2.33	0.00	96.29	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Šibensko-kninska	0.00	0.92	0.00	0.00	0.00	0.19	0.00	98.74	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	100.00
Varaždinska	0.00	0.70	0.29	0.00	5.05	0.19	0.00	92.43	0.00	0.00	0.04	0.00	1.00	0.00	0.00	0.30	0.00	0.00	100.00
Virovitičko-podravska	0.00	0.00	0.00	0.00	0.00	1.33	0.00	98.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Vukovarsko-srijemska	0.00	0.00	0.00	0.00	0.10	1.22	0.00	97.29	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	100.00
Zadarska	0.00	0.19	0.08	0.00	0.90	5.73	0.00	92.37	0.00	0.40	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	100.00
Zagrebačka	0.00	0.00	0.00	0.00	0.12	1.47	0.00	76.60	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.11	0.08	21.40	100.00
MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
MAX	0.46	6.04	4.60	0.00	12.46	11.74	0.13	100.00	0.00	4.10	0.55	0.63	2.34	0.00	0.17	1.77	0.24	93.44	100.00
AVERAGE	0.04	1.02	0.67	0.00	2.48	2.79	0.01	84.24	0.00	0.64	0.11	0.11	0.41	0.00	0.03	0.27	0.03	9.11	100.00
CROATIA	0.05	1.07	0.69	0.00	2.59	2.91	0.01	83.68	0.00	0.61	0.12	0.10	0.38	0.00	0.03	0.28	0.02	9.50	100.00

* A – Metal packaging; B – Paper and cardboard packaging; C – Plastic packaging; D – Batteries and accumulators covered by 16 06 01. 16 06 02 or 16 06 03 and unassembled batteries and accumulators containing these batteries; E– Biodegradable waste; F – Bulky waste; G – Used tires; H – Mixed municipal waste; I – Discarded equipment containing chlorofluorocarbons. HCFCs. HFCs; J – Street cleaning residue; K – Other non-biodegradable waste; L – Waste from the market; M – Paper and cardboard; N – Ashes from the litter grate. precipitate and dust from the boiler (other than the dust from the boiler mentioned under 10 01 04); O – Plastics; P – Glass packaging; Q – Glass; R – Soil and rock

2.2 Calculation method for the diesel consumption estimate

The data sample represents:

- 50 % of the statistical population (*i.e.* more than 100 companies out of 208) approximately
- 39 % of the waste collected in the Republic of Croatia in 2013, 84 % of which was mixed municipal waste

At the administrative unit level, data samples represent:

- 0–100 % of the statistical population in a county, on average 50 %,
- 0.02–96.04 % (on average 46.06 %) of the waste collected in a county in 2013,
- 6.56–100 % (on average 84.24 %) of the collected waste was mixed municipal waste.

With assumptions that diesel consumption *per* ton of waste is county-specific and that the gathered data is sufficiently representative, the diesel consumption from the partial data for each county is up-scaled to the whole county. The structure of waste streams collected in each county in total, and by the companies that participated in the research are already shown in the previous section in Tables 4–6.

County-specific diesel consumption *per* ton of waste is calculated by dividing the data on diesel that the companies had delivered with the quantity of collected waste that those companies had reported. The specific diesel consumption is then multiplied with the total quantity of waste collected by all companies in the county, resulting in total waste collection related diesel consumption in a county.

The described procedure is applied to all counties except for the county of the City of Zagreb for which no relevant data is collected. For that county, the estimate is performed by multiplying the country-specific fuel consumption *per* ton of waste (6,50 l mg^{-1}; 5,41 kg mg^{-1}) with the quantity of reported waste for the City of Zagreb.

2.3 Emission factors for heavy duty diesel vehicles

For the calculation of fuel combustion related emission, the Tier 1 emission factors for heavy duty diesel vehicles (Table 7) from the EMEP/EEA air pollutant emission inventory guidebook are used (*EEA,* 2016).[21]

Table 7 – Tier 1 emission factors for heavy duty diesel vehicles (from Tables 3.5–3.15 in *EMEP/EEA air pollutant emission inventory guidebook 2016 – Update Dec. 2016*)[21]

Tablica 7 – Faktori Tier 1 emisija za teška dizelska vozila (iz tablica 3.5 – 3.15 u *EMEP/EEA air pollutant emission inventory guidebook 2016 – Update Dec.* 2016)[21]

Emission	Unit	Mean	Min	Max
carbon dioxide, CO_2	kg/kg fuel	3.18	3.18	3.18
nitrogen oxides, NO_x	g/kg fuel	33.37	28.34	38.29
carbon monoxide, CO	g/kg fuel	7.58	5.73	10.57
carbon dioxide from lubricant, CO_2	g/kg fuel	2.54	1.99	3.32
non-methane volatile organic compounds, NMVOC	g/kg fuel	1.92	1.33	3.77
particulate matter, PM	g/kg fuel	0.94	0.61	1.57
black carbon fraction of particulate matter, f-BC, 0.53	g/kg fuel	0.4982	0.3233	0.8321
nitrous oxide, N_2O	g/kg fuel	0.051	0.03	0.089
SO_2, sulphur content fuel 2009 8ppm	mg/kg fuel	16	16	16
ammonia, NH_3	g/kg fuel	0.013	0.01	0.018
lead, Pb	µg/kg fuel	52	16	19.4
indeno[1,2,3-cd] pyrene, ID[1,2,3-cd]P	µg/kg fuel	7.9	8.6	7.3
benzo[k]fluoranthene, B[k]F	µg /kg fuel	34.4	37.2	31.8
benzo[b]fluoranthene, B[b]F	µg/kg fuel	30.8	33.3	28.4
benzo[a]pyrene, B[a]P	µg /kg fuel	5.1	5.5	4.7
typical fuel consumption	g fuel/km	240	240	240

3 Results and discussion

3.1 Results

Table 8 shows the diesel consumption estimate based on data delivered from 50 % of the companies (up-scaled data), relative consumption *per* ton of waste and *per capita* in each county, and for the whole country. Tables 9 and 10 show the diesel related emissions to air from the waste collection system, for each county, and for the whole country.

Annual consumption of diesel in Croatian MSW collection systems in 2013 was 10.6 million litres or 8.8 thousand tons. At county level, this ranges from 87 thousand litres to 2.2 million litres (73–1796 t). Median value for consumption, at county level, was 375 thousand litres (312 t), average 503 thousand litres (419 t). Relative consumption of diesel from waste collection was on average 6.50 l (5.41 kg t^{-1}) of MSW (ranging from 3.24 to 10.62 l),

Table 8 – Diesel consumption estimate for Croatian municipal solid waste collection system in 2013

Tablica 8 – Procjena potrošnje dizelskog goriva u sustavu sakupljanja komunalnog otpada u Hrvatskoj u 2013. godini

Administrative unit (county)	Diesel consumption *per* mass of waste		Diesel consumption *per capita*		Total diesel consumed	
	dm^3/Mg	kg/Mg	dm^3	kg	dm^3	kg
Bjelovarsko-bilogorska	6.19	5.15	1.50	1.25	156 625	130 312
Brodsko-posavska	6.81	5.66	1.94	1.62	308 272	256 482
Dubrovačko-neretvanska	6.67	5.55	3.42	2.85	421 332	350 548
Grad Zagreb	6.50	5.41	2.77	2.30	2 158 690	1 796 030
Istarska	4.88	4.06	2.74	2.28	564 407	469 587
Karlovačka	5.15	4.28	1.80	1.50	226 198	188 197
Koprivničko-križevačka	7.36	6.12	1.64	1.36	184 503	153 507
Krapinsko-zagorska	8.63	7.18	4.45	3.70	563 465	468 803
Ličko-senjska	10.62	8.84	4.88	4.06	242 640	201 876
Međimurska	4.75	3.95	1.23	1.02	139 390	115 973
Osječko-baranjska	8.14	6.77	2.65	2.20	796 549	662 728
Požeško-slavonska	6.34	5.27	1.30	1.09	87 403	72 719
Primorsko-goranska	8.69	7.23	3.68	3.06	1 089 056	906 094
Sisačko-moslavačka	7.05	5.86	2.49	2.07	374 915	311 929
Splitsko-dalmatinska	4.45	3.70	2.10	1.75	955 482	794 961
Šibensko-kninska	5.29	4.41	2.41	2.00	263 229	219 007
Varaždinska	6.04	5.03	2.72	2.26	442 024	367 764
Virovitičko-podravska	5.08	4.23	1.46	1.21	123 109	102 427
Vukovarsko-srijemska	4.33	3.61	1.32	1.10	229 201	190 695
Zadarska	8.33	6.93	4.59	3.82	775 696	645 379
Zagrebačka	3.24	2.69	1.44	1.20	468 962	390 176
MIN	**3.24**	**2.69**	**1.23**	**1.02**	**87 403**	**72 719**
MAX	**10.62**	**8.84**	**4.88**	**4.06**	**2 158 690**	**1 796 030**
AVERAGE	**6.41**	**5.33**	**2.50**	**2.08**	**503 388**	**418 819**
MEDIAN	**6.34**	**5.27**	**2.41**	**2.00**	**374 915**	**311 929**
CROATIA	**6.50**	**5.41**	**2.52**	**2.10**	**10 571 147**	**8 795 195**

or 2.52 l *per capita* (1.23–4.88 l). Total consumption of diesel for MSW collection in Croatia is estimated at 10.6 million litres (Table 8). The data is graphically presented in Figs. 3–8.

Emissions at county level (Tables 9 and 10) are following the same trends as the diesel consumption data shown in Figs. 3, 4 and 5. Twelve counties have below-average relative diesel consumption *per capita*, and eleven counties have below-average relative diesel consumption *per* ton of MSW. Below the median value for diesel consumption *per capita* and *per* ton of MSW are counties nine and ten respectively (Figs. 3 and 4). The relative diesel consumption is the lowest in the continental counties, and highest in counties with mountainous terrain, such as Ličko-senjska, Primorsko-goranska, Krapinsko-zagorska and Zadarska.

Twelve counties have total diesel consumption below the median value, fourteen below the average value; most of them are the continental counties (Fig. 5). Total diesel consumption is the highest in the county of the City of Zagreb (Grad Zagreb), and the lowest in the county of Požega (Požeško-slavonska županija).

Carbon dioxide. Emission of carbon dioxide into the air from diesel combustion in Croatian MSW collection systems in 2013 ranged from 231 to 5711 t *per* county. Total annual emission of CO_2 from MSW collection systems was 28000 t. Median value for CO_2 emission at county level was 992 t, average 1 332 t (Table 9). Relative emission ranged from 3.26 to 13 kg CO_2 *per capita* (average 6 kg *per capita*),

or 8.57–28.11 kg t^{-1} of municipal waste (average 16.95 kg of CO_2 *per* ton of municipal waste) (Appendices 1 and 2).

Nitrogen oxides. Emission of nitrogen oxides into the air from diesel combustion in Croatian MSW collection systems in 2013, at county level, ranged from 2.4 to 52 t. Total annual emission of NO_x from MSW collection systems was 284 t. Median value for NO_x emission at county level was 8.5 t, average 13.5 t (Table 9). Relative emission ranged from 26 to 134 g NO_x *per capita* (average 67 g NO_x *per capita*), or 127–431 g t^{-1} of municipal waste (average 231 g of NO_x *per* ton of municipal waste) (Appendices 1 and 2).

Carbon monoxide. Emission of carbon monoxide into the air from diesel combustion in Croatian MSW collection systems in 2013, at county level, ranged from 0.55 to 12 t. Total annual emission of CO from MSW collection systems was 12 t. Median value for CO emission at county level was 1.9 t, average 3 t (Table 9). Relative emission ranged

Table 9 – Diesel related emissions to air from the Croatian municipal solid waste collection in 2013: CO_2, NO_x, CO, CO_2 from lubricant, NMVOC, PM, f-BC and N_2O

Tablica 9 – Emisije u zrak vezane uz potrošnju dizelskog goriva u sustavu sakupljanja komunalnog otpada u Hrvatskoj u 2013. godini: CO_2, NO_x, CO, CO_2 od izgaranja maziva, NMVOC, PM, f-BC i N_2O

Administrative unit	CO_2	NO_x	CO	CO_2-lub.	NMVOC	PM	f-BC	N_2O
County of	Mg	Mg	Mg	kg	kg	kg	kg	kg
Bjelovarsko-bilogorska	414.39	4.35	0.99	330.99	250.20	122.49	64.92	6.65
Brodsko-posavska	815.61	8.56	1.94	651.46	492.45	241.09	127.78	13.08
Dubrovačko-neretvanska	1 114.74	11.70	2.66	890.39	673.05	329.52	174.64	17.88
Grad Zagreb	5 711.38	59.93	13.61	4 561.92	3 448.38	1 688.27	894.78	91.60
Istarska	1 493.29	15.67	3.56	1 192.75	901.61	441.41	233.95	23.95
Karlovačka	598.47	6.28	1.43	478.02	361.34	176.91	93.76	9.60
Koprivničko-križevačka	488.15	5.12	1.16	389.91	294.73	144.30	76.48	7.83
Krapinsko-zagorska	1 490.79	15.64	3.55	1 190.76	900.10	440.67	233.56	23.91
Ličko-senjska	641.97	6.74	1.53	512.77	387.60	189.76	100.57	10.30
Međimurska	368.79	3.87	0.88	294.57	222.67	109.01	57.78	5.91
Osječko-baranjska	2 107.48	22.12	5.02	1 683.33	1 272.44	622.96	330.17	33.80
Požeško-slavonska	231.25	2.43	0.55	184.71	139.62	68.36	36.23	3.71
Primorsko-goranska	2 881.38	30.24	6.87	2 301.48	1 739.70	851.73	451.42	46.21
Sisačko-moslavačka	991.93	10.41	2.36	792.30	598.90	293.21	155.40	15.91
Splitsko-dalmatinska	2 527.98	26.53	6.03	2 019.20	1 526.33	747.26	396.05	40.54
Šibensko-kninska	696.44	7.31	1.66	556.28	420.49	205.87	109.11	11.17
Varaždinska	1 169.49	12.27	2.79	934.12	706.11	345.70	183.22	18.76
Virovitičko-podravska	325.72	3.42	0.78	260.16	196.66	96.28	51.03	5.22
Vukovarsko-srijemska	606.41	6.36	1.45	484.37	366.14	179.25	95.00	9.73
Zadarska	2 052.31	21.54	4.89	1 639.26	1 239.13	606.66	321.53	32.91
Zagrebačka	1 240.76	13.02	2.96	991.05	749.14	366.77	194.39	19.90
MIN	**231.25**	**2.43**	**0.55**	**184.71**	**139.62**	**68.36**	**36.23**	**3.71**
MAX	**5 711.38**	**59.93**	**13.61**	**4 561.92**	**3 448.38**	**1 688.27**	**894.78**	**91.60**
AVERAGE	**1 331.84**	**13.98**	**3.17**	**1 063.80**	**804.13**	**393.69**	**208.66**	**21.36**
MEDIAN	**991.93**	**10.41**	**2.36**	**792.30**	**598.90**	**293.21**	**155.40**	**15.91**
CROATIA	**27 968.72**	**293.50**	**66.67**	**22 339.79**	**16 886.77**	**8 267.48**	**4 381.77**	**448.55**

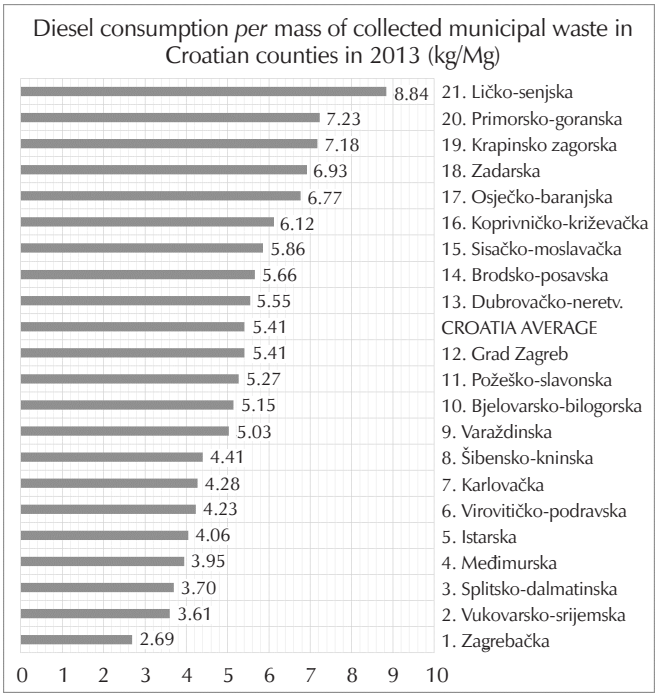


Fig. 3 – Relative diesel consumption *per* mass of collected mixed waste and *per capita* for mixed waste collection in Croatian counties in 2013

Slika 3 – Relativna potrošnja dizela u sustavu sakupljanja komunalnog otpada u Hrvatskoj u 2013. godini po megagramu (toni) otpada i po stanovniku županije

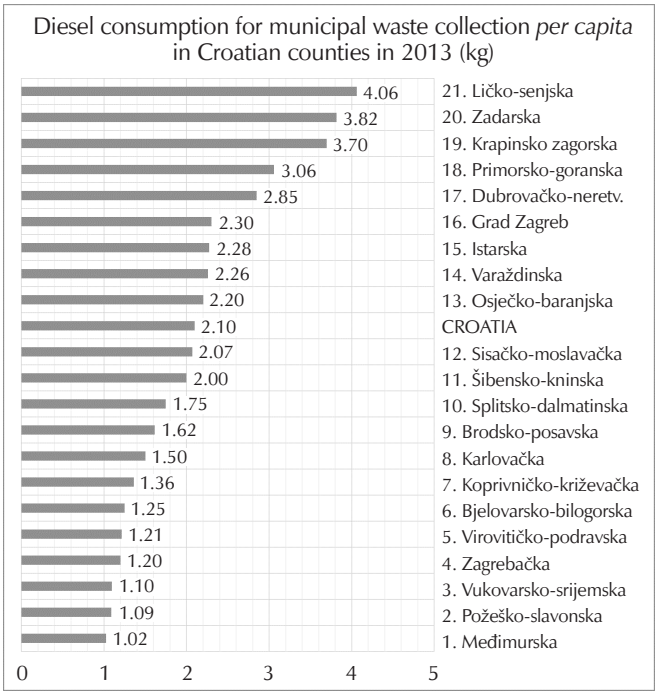


Fig. 4 – Relative diesel consumption *per capita* for mixed waste collection in Croatian counties in 2013

Slika 4 – Relativna potrošnja dizela u sustavu sakupljanja komunalnog otpada u Hrvatskoj u 2013. godini po stanovniku županije

from 6 to 30 g CO *per capita* (average 15 g CO *per capita* or 29–98 g t^{-1} of municipal waste (average 53 grams of CO *per* ton of municipal waste) (Appendices 1 and 2).

Carbon dioxide from lubricant. Emission of carbon dioxide into the air from engine lubricant in Croatian MSW collection systems in 2013, at county level, ranged from 0.2 to 4 t. Total annual emission of CO_2 from lubricant in MSW collection systems was 22 t. Median value for engine lubricant CO_2 emission at county level was 0.65 t *per* county, average 1 t (Table 9). Relative emission ranged from 2 to 10 kg CO_2 *per capita* (average 5 g *per capita*), or 10–33 g t^{-1} of municipal waste (average 18 g of CO_2 *per* ton of municipal waste) (Appendices 1 and 2).

Non-methane volatile organic compounds. Emission of non-methane volatile organic compounds into the air from diesel combustion in Croatian MSW collection systems in 2013, at county level, ranged from 0.14 to 3 t. Total annual emission of NMVOC from MSW collection systems was 16.4 t. Median value for NMVOC emission at county level was 0.5 t, average 0.8 t (Table 9). Relative emission ranged from 1 to 8 g NMVOC *per capita* (average 4 g *per capita*), or 7–25 g t^{-1} of municipal waste (average 13 g of NMVOC *per* ton of municipal waste) (Appendices 1 and 2).

Particulate matter. Emission of particulate matter into the air from diesel combustion in Croatian MSW collection systems in 2013, at county level, ranged from 67 to 1 500 kg. Total annual emission of PM from MSW collection systems was 8 t. Median value for PM emission at county level was 240 kg, average 380 kg (Table 9). Relative emission ranged from 1 to 4 g PM *per capita* (average 2 g PM *per capita*), or 4–12 g t^{-1} of municipal waste (average 7 grams of PM *per* ton of municipal waste) (Appendices 1 and 2).

Black carbon fraction of particulate matter. In the emission of particulate matter, the black carbon fraction (f-BC) at county level ranged from 36 to 770 kg. Total annual value of black carbon fraction was 4.2 t (more than half of the PM was black carbon fraction). Median value was 130 kg *per* county, or on average 200 kg *per* county (Table 9). Relative emission ranged from 0 to 2 g f-BC *per capita* (average 1 g f-BC *per capita*) or 2–6 g t^{-1} of municipal waste (average 3 g of f-BC *per* ton of municipal waste) (Appendices 1 and 2).

Nitrous oxide. Emission of nitrous oxide (N_2O) into the air from Croatian MSW collection systems in 2013, at county level, ranged from 3.6 to 79 kg. Total annual emission of N_2O from MSW collection systems was 435 kg. Median value for N_2O emission at county level was 13 kg *per* county, average 20.7 kg (Table 9). Relative emission ranged from 39 to 205 mg N_2O *per capita* (average 102 mg N_2O *per capita*) or 194–658 mg t^{-1} of municipal waste (average 353 mg of N_2O *per* ton of municipal waste) (Appendices 1 and 2).

Sulphur dioxide. Emission of sulphur dioxide (SO_2) into the air from Croatian MSW collection systems in 2013, at county level, ranged from 1.1 to 25 kg. Total annual emission of sulphur from MSW collection systems was 136 kg.

Table 10 – Diesel related emissions to air from the Croatian municipal solid waste collection in 2013: SO_2, NH_3, Pb, ID[1,2,3-cd]P, B[k]F, B[b]F, B[a]P, and estimated driving distance

Tablica 10 – Emisije u zrak vezane uz potrošnju dizelskog goriva u sustavu sakupljanja komunalnog otpada u Hrvatskoj u 2013. godini: SO_2, NH_3, Pb, ID[1,2,3-cd]P, B[k]F, B[b]F, B[a]P te prijeđeni put

Administrative unit	SO_2	NH_3	Pb	ID[1,2,3-cd]P	B[k]F	B[b]F	B[a]P	Distance
County of	kg	kg	g	g	g	g	g	km
Bjelovarsko-bilogorska	2.08	1.69	6.78	1.03	4.48	4.01	0.66	542 966.70
Brodsko-posavska	4.10	3.33	13.34	2.03	8.82	7.90	1.31	1 068 675.85
Dubrovačko-neretvanska	5.61	4.56	18.23	2.77	12.06	10.80	1.79	1 460 618.02
Grad Zagreb	28.74	23.35	93.39	14.19	61.78	55.32	9.16	7 483 458.17
Istarska	7.51	6.10	24.42	3.71	16.15	14.46	2.39	1 956 612.14
Karlovačka	3.01	2.45	9.79	1.49	6.47	5.80	0.96	784 153.63
Koprivničko-križevačka	2.46	2.00	7.98	1.21	5.28	4.73	0.78	639 610.44
Krapinsko-zagorska	7.50	6.09	24.38	3.70	16.13	14.44	2.39	1 953 344.56
Ličko-senjska	3.23	2.62	10.50	1.59	6.94	6.22	1.03	841 150.56
Međimurska	1.86	1.51	6.03	0.92	3.99	3.57	0.59	483 219.02
Osječko-baranjska	10.60	8.62	34.46	5.24	22.80	20.41	3.38	2 761 368.56
Požeško-slavonska	1.16	0.95	3.78	0.57	2.50	2.24	0.37	302 995.92
Primorsko-goranska	14.50	11.78	47.12	7.16	31.17	27.91	4.62	3 775 393.61
Sisačko-moslavačka	4.99	4.06	16.22	2.46	10.73	9.61	1.59	1 299 704.64
Splitsko-dalmatinska	12.72	10.33	41.34	6.28	27.35	24.48	4.05	3 312 338.02
Šibensko-kninska	3.50	2.85	11.39	1.73	7.53	6.75	1.12	912 527.38
Varaždinska	5.88	4.78	19.12	2.91	12.65	11.33	1.88	1 532 349.88
Virovitičko-podravska	1.64	1.33	5.33	0.81	3.52	3.15	0.52	426 777.94
Vukovarsko-srijemska	3.05	2.48	9.92	1.51	6.56	5.87	0.97	794 564.22
Zadarska	10.33	8.39	33.56	5.10	22.20	19.88	3.29	2 689 080.38
Zagrebačka	6.24	5.07	20.29	3.08	13.42	12.02	1.99	1 625 734.33
MIN	**1.16**	**0.95**	**3.78**	**0.57**	**2.50**	**2.24**	**0.37**	**302 995.92**
MAX	**28.74**	**23.35**	**93.39**	**14.19**	**61.78**	**55.32**	**9.16**	**7 483 458.17**
AVERAGE	**6.70**	**5.44**	**21.78**	**3.31**	**14.41**	**12.90**	**2.14**	**1 745 078.29**
MEDIAN	**4.99**	**4.06**	**16.22**	**2.46**	**10.73**	**9.61**	**1.59**	**1 299 704.64**
CROATIA	**140.72**	**114.34**	**457.35**	**69.48**	**302.55**	**270.89**	**44.86**	**36 646 643.99**

Median value for sulphur emission at county level was 4 kg *per* county, average 6.5 kg (Table 9). Relative emission ranged from 12 to 64 mg SO_2 *per capita* (average 32 mg SO_2 *per capita*) or 61–207 mg t^{-1} of municipal waste (average 111 mg t^{-1} of municipal waste) (Appendices 1 and 2).

Ammonia. Emission of ammonia (NH_3) into the air from Croatian MSW collection systems in 2013, at county level, ranged from 0.9 to 20 kg. Total annual emission of NH_3 from MSW collection systems was 111 kg. Median value for NH_3 emission at county level was 3.3 kg *per* county, average 5.3 kg (Table 9). Relative emission ranged from 10 to 52 mg NH_3 *per capita* (average 26 mg NH_3 *per capita*) or 49–168 mg t^{-1} of municipal waste (average 90 mg of NH_3 *per* ton of municipal waste) (Appendices 1 and 2).

Lead. Emission of lead (Pb) into the air from Croatian MSW collection systems in 2013, at county level, ranged from 3.8 to 80.4 kg. Total annual emission of lead from MSW collection systems was 443 kg. Median value for lead emission at

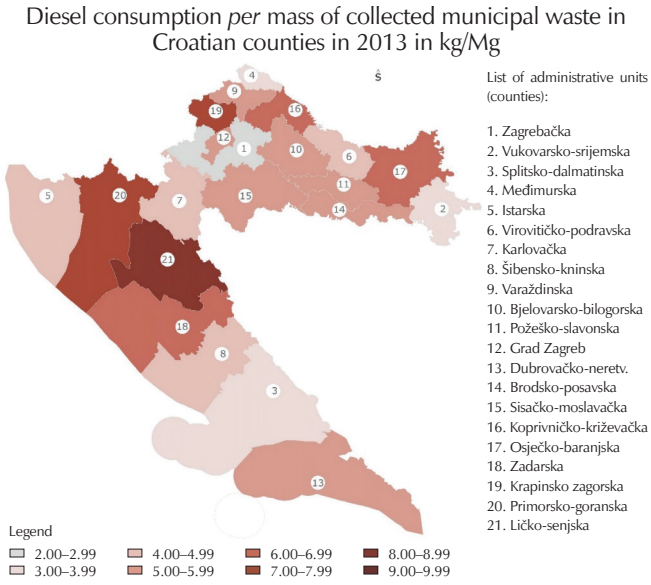


Fig. 6 – Map of relative diesel consumption *per* mass of collected mixed waste and *per capita* for mixed waste collection in Croatian counties in 2013

Slika 6 – Karta relativne potrošnja dizela u sustavu sakupljanja komunalnog otpada u Hrvatskoj u 2013. godini po megagramu otpada i po stanovniku županije

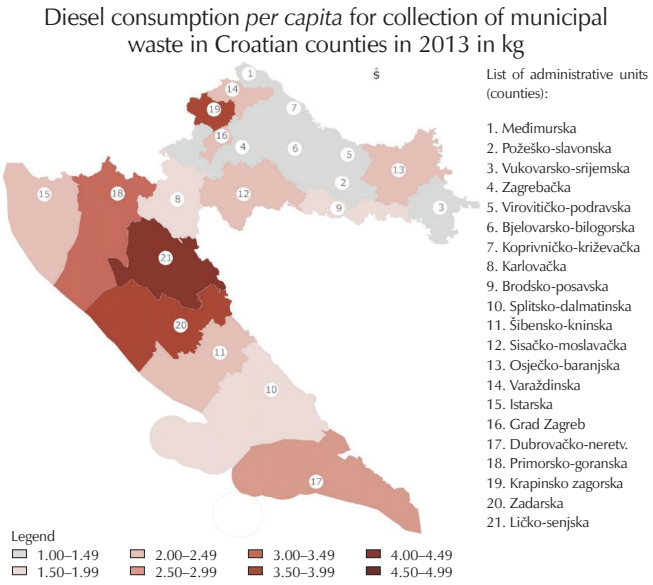


Fig. 7 – Map of relative diesel consumption *per capita* for mixed waste collection in Croatian counties in 2013

Slika 7 – Karta relativne potrošnja dizela u sustavu sakupljanja komunalnog otpada u Hrvatskoj u 2013. godini po stanovniku županije

county level was 13.2 kg *per* county, average 21.1 kg (Table 9). Relative emission ranged from 40 to 208 μg Pb *per capita* (average 104 μg Pb *per capita*) or 198–671 μg t^{-1} of municipal waste (average 360 μg t^{-1} of municipal waste) (Appendices 1 and 2).

Indeno[1,2,3-cd]pyrene. Emission of indeno[1,2,3-cd] pyrene into the air from Croatian MSW collection systems in 2013, at county level, ranged from 0.5 to 12 kg. Total annual emission of indeno[1,2,3-cd]pyrene from MSW collection systems was 67 kg. Median value for indeno[1,2,3-cd]pyrene emission at county level was 2 kg *per* county, average 3.2 kg (Table 9). Relative emission ranged from 6 to 32 μg indeno[1,2,3-cd]pyrene *per capita* (average 16 μg indeno[1,2,3-cd]pyrene *per capita*) or 30–102 μg t^{-1} of municipal waste (average 55 μg of indeno[1,2,3-cd] pyrene *per* ton of municipal waste) (Appendices 1 and 2).

Benzo[k]fluoranthene. Emission of benzo[k]fluoranthene, B[k]F, into the air from Croatian MSW collection systems in 2013, at county level, ranged from 2.5 to 53 kg. Total annual emission of B[k]F from MSW collection systems was 293 kg. Median value for B[k]F emission at county level was 8.8 kg *per* county, average 14 kg (Table 10). Relative emission ranged from 27 to 138 μg B[k]F *per capita* (average 69 μg B[k]F *per capita*) (Table 10), or 131–444 μg t^{-1} of municipal waste (average 238 μg t^{-1} of municipal waste) (Appendices 1 and 2).

Benzo[b]fluoranthene. Emission of benzo[b]fluoranthene, B[b]F, into the air from Croatian MSW collection systems in 2013, at county level, ranged from 2.2 to 48 kg. Total annual emission of B[b]F from MSW collection systems was 263 kg. Median value for B[b]F emission at county level was 7.8 kg *per* county, average 12.5 kg (Table 10). Relative emission ranged from 24 to 123 μg B[b]F *per capita* (average 62 μg B[b]F *per capita*) or 117–398 μg t^{-1} of municipal waste (average 213 μg t^{-1} of municipal waste) (Appendices 1 and 2).

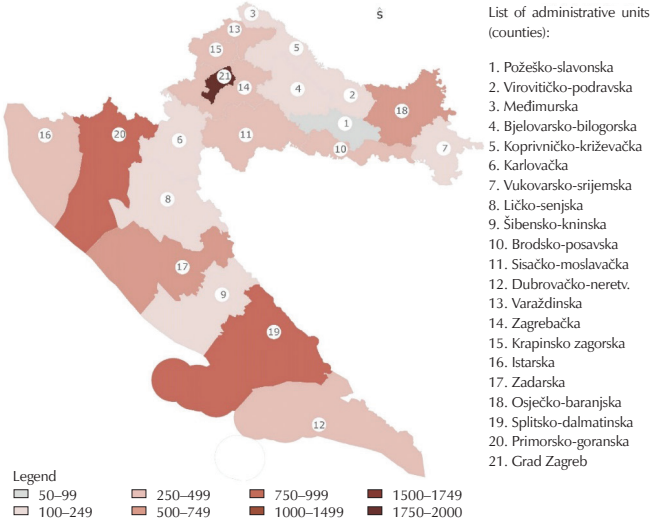


Fig. 8 – Map of total diesel consumption *per* county related to MSW collection

Slika 8 – Karta potrošnje dizela u sustavu sakupljanja komunalnog otpada

Benzo[a]pyrene. Emission of benzo[a]pyrene, B[a]P, into the air from Croatian MSW collection systems in 2013, at county level, ranged from 0.4 to 8 kg. Total annual emission of B[a]P from MSW collection systems was 44 kg. Median value for B[a]P emission at county level was 1.3 kg *per*

county, average 2 kg (Table 10). Relative emission ranged from 4 to 20 μg B[a]P *per capita* (average 10 μg B[a]P *per capita*) or 19–66 μg t^{-1} of municipal waste (average 35 μg t^{-1} of municipal waste) (Appendices 1 and 2).

Transport distance. Total annual transport distance in Croatian MSW collection systems in 2013 was estimated at 36.7 million km. From county to county, the distance varied between 303 thousand km and 7.5 million km; median value was 1.3 million km (Table 10). Relative transport distance ranged from 11.3 to 36.8 km t^{-1} of collected waste in a county, or 4.3–16.9 km *per* inhabitant of the county. Median values were 22 km t^{-1} or 8.4 km *per* inhabitant of the county. The Croatian average was 22.5 km t^{-1} or 8.7 km *per capita*. (Appendices 1 and 2)

3.2 Discussion

The emission results calculated with Tier 1 emission factors for diesel fuel are more comprehensive than the results in introductory literature. Tier 1 emission factors are, on the environmental side, showing somewhat higher emissions than Tier 2 and 3, which are based not only on the type of vehicle and quantity of the consumed fuel, but also include kilometres driven and average fuel consumption, as well as load and other elements.[21]

In different studies, emission of CO_2 ranged from 1.1 to 703 kg of CO_2 *per* ton of waste:

- *7–9 kg of fossil CO_2 equivalent per ton for mixed waste transported to a landfill*[16,17]
- *8–15 kg t^{-1} for various waste streams*[16,17]
- *1.1–7.6 kg t^{-1} for Dresden*[18] *which is per inhabitant number similar to the city of Zagreb*
- *11.9-90 kg t^{-1} for different truck types*[19]
- *12 to 703 kg* of *CO_2 (GWP) per* ton of *different waste streams and type of treatment included*[20]

As shown in the previous chapter (Table 10), values for Croatian municipal solid waste collection system range from 8.6 to 28.1 kg of CO_2 *per* ton, and average emission is 17 kg of CO_2 *per* ton of collected mixed waste. These results place Croatia far from the emission average of 7–9 kg of CO_2 *per* ton of collected mixed waste. Some counties, however, appear to be closer to standard CO_2 (eq.) emission factor *per* ton of waste, for example administrative units Zagrebačka (8.6 kg of CO_2 *per* ton), Vukovarsko-srijemska (11.5 kg t^{-1}), Splitsko-dalmatinska (11.7 kg t^{-1}) *etc.*, as given previously in Table 9. The results should be observed with data representativeness in perspective (shown in Table 4), which for the respective counties is 8.61 %, 49.75 % and 52.82 %. Additionally, representativeness for the waste stream "mixed waste" is 76.60 %, 97.29 % and 96.29 %. The data with higher representativeness give results with higher reliability.

The AEA study[16] shows higher CO_2 emission *per* mass of transported waste for separated waste fractions. This suggests that, when the collection rates of separate waste streams increase, the CO_2 burden will increase as well, due to their differences in mass *per* volume (load of trucks) and transport distance to recycling facilities.

The results for the city of Zagreb are far from the results for the city of Dresden, however, the main collector of MSW from Zagreb city delivered no data, so the reliability of the estimate for the city of Zagreb is uncertain. Therefore, it was represented by Croatian average values.

Comparison of Croatian CO_2 emission with the results of the study for different truck types,[19] show that average technology in current use in Croatia have decent fuel efficiency (at least compared to USA technology). However, the efforts to lower both the quantity of waste and the CO_2 emission *per* ton of waste should be continued. That would decrease the impact on human health and ecosystems caused by waste collection, as well as the operating costs of the waste collection companies. Investment to switch to cleaner technologies could however be significant, and should be considered at strategic level.

4 Conclusion

This article presents the fuel consumption and fuel related airborne emissions from collection of mixed municipal waste. The data is relevant for Croatia, 2013, and the mixed waste stream. The data is presented in both absolute and relative values (relative to the number of inhabitants and mass of collected waste) *per* county and for the whole country. Annual consumption of diesel for collection of mixed municipal waste in 2013, at county level, ranged from 87 thousand litres to 2.2 million litres, on average 504 thousand litres *per* county. Relative consumption of diesel was 6.4 l t^{-1} of collected waste (ranging from 3.2 to 10.6 l), or 2.5 l *per capita* (1.2–4.9 l). Total consumption of diesel for collection of mixed municipal waste in Croatia in 2013 was estimated at 10.6 million litres.

Estimated emission of carbon dioxide into the air from diesel combustion ranged from 231 to 5711 t. Total annual emission of CO_2 was close to 28 000 t, on average 1331 t *per* county. Relative emission ranged from 3.3 to 13 kg CO_2 *per capita* (average 6.6 kg *per capita*), or 8.6–28.1 kg t^{-1} of mixed municipal waste (average 17 kg of CO_2 *per* ton). The average values of CO_2 emission from waste collection that should also be the target values are 7–9 kg for mixed waste, and 8–15 kg CO_2 for separate waste streams. Together with the aim to lower the CO_2 emission *per* ton of waste, efforts to lower the quantity of waste and awareness raising should be continued. That would decrease the impact on human health and ecosystems caused by waste collection, as well as the operating costs of the waste collection companies. Investment to switch to cleaner technologies could however be significant, and should be considered at strategic level, and backed up by life cycle studies of various waste management options and their overall emissions and impacts.

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List of abbreviations and symbols
Popis kratica i simbola

AD – anaerobic digestion
– anaerobna digestija

B[a]P – benzo[a]pyrene
– benzo[a]piren

B[b]F – benzo[b]fluoranthene
– benzo[b]fluoranten

B[k]F – benzo[k]fluoranthene
– benzo[k]fluoranten

CO – carbon monoxide
– ugljikov monoksid

CO_2 – carbon dioxide
– ugljikov dioksid

f-BC – black carbon fraction of particulate matter
– frakcije čestica crnog ugljika

HC – hydrocarbons
– hidrokarbonati

LCA – life cycle assessment
– procjena životnog ciklusa

MSW – municipal solid waste
– komunalni kruti otpad

MRF – materials recovery facility
– oporavak materijala

N_2O – nitrous oxide
– dušikov(I) oksid

NH_3 – ammonia
– amonijak

NMVOC – non-methane volatile organic compounds
– nemetanski isparljivi organski spojevi

NO_x – nitrogen oxides
– dušikovi oksidi

PM – particulate matter
– čestice

RTS – refuse transfer station
– pretovarna stanica

WM – waste management
– upravljanje otpadom

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Appendices

Appendix 1 – Diesel related emissions into air from the Croatian municipal solid waste collection in 2013 *per* mass of collected waste

Dodatak 1 – Emisije u zrak vezane uz potrošnju dizelskog goriva u sustavu sakupljanja komunalnog otpada u Hrvatskoj u 2013. godini po jedinici mase sakupljenog otpada

Administrative unit (county)	Diesel	CO_2	NO_x	CO	CO_2 (from lubr.)	NMVOC	PM	f-BC	N_2O	SO_2	NH_3	Pb	ID[1,2,3-cd]P	B[k]F	B[b]F	B[a]P	Average distance
	kg	kg	g	g	g	g	g	g	g	mg	g	µg	µg	µg	µg	µg	km
Bjelovarsko-bilogorska	**1.25**	**3.97**	41.65	9.46	3.17	2.40	1.17	0.62	0.06	19.97	0.02	64.90	9.86	42.93	38.44	6.36	5.20
Brodsko-posavska	**1.62**	**5.14**	53.98	12.26	4.11	3.11	1.52	0.81	0.08	25.88	0.02	84.11	12.78	55.64	49.82	8.25	6.74
Dubrovačko-neretvanska	**2.85**	**9.06**	95.07	21.60	7.24	5.47	2.68	1.42	0.15	45.58	0.04	148.15	22.51	98.01	87.75	14.53	11.87
Grad Zagreb	**2.30**	**7.32**	76.84	17.45	5.85	4.42	2.16	1.15	0.12	36.84	0.03	119.74	18.19	79.21	70.92	11.74	9.59
Istarska	**2.28**	**7.24**	75.96	17.26	5.78	4.37	2.14	1.13	0.12	36.42	0.03	118.37	17.98	78.31	70.11	11.61	9.48
Karlovačka	**1.50**	**4.77**	50.03	11.36	3.81	2.88	1.41	0.75	0.08	23.99	0.02	77.96	11.84	51.57	46.18	7.65	6.25
Koprivničko-križevačka	**1.36**	**4.33**	45.42	10.32	3.46	2.61	1.28	0.68	0.07	21.78	0.02	70.78	10.75	46.82	41.92	6.94	5.67
Krapinsko-zagorska	**3.70**	**11.76**	123.45	28.04	9.40	7.10	3.48	1.84	0.19	59.19	0.05	192.37	29.23	127.26	113.94	18.87	15.41
Ličko-senjska	**4.06**	**12.92**	135.55	30.79	10.32	7.80	3.82	2.02	0.21	64.99	0.05	211.22	32.09	139.73	125.11	20.72	16.92
Međimurska	**1.02**	**3.26**	34.19	7.77	2.60	1.97	0.96	0.51	0.05	16.39	0.01	53.28	8.09	35.24	31.56	5.23	4.27
Osječko-baranjska	**2.20**	**7.00**	73.48	16.69	5.59	4.23	2.07	1.10	0.11	35.23	0.03	114.51	17.40	75.75	67.82	11.23	9.18
Požeško-slavonska	**1.09**	**3.45**	36.22	8.23	2.76	2.08	1.02	0.54	0.06	17.37	0.01	56.44	8.57	37.34	33.43	5.54	4.52
Primorsko-goranska	**3.06**	**9.73**	102.15	23.20	7.78	5.88	2.88	1.53	0.16	48.98	0.04	159.19	24.18	105.31	94.29	15.61	12.76
Sisačko-moslavačka	**2.07**	**6.58**	69.07	15.69	5.26	3.97	1.95	1.03	0.11	33.12	0.03	107.64	16.35	71.21	63.75	10.56	8.62
Splitsko-dalmatinska	**1.75**	**5.56**	58.31	13.25	4.44	3.36	1.64	0.87	0.09	27.96	0.02	90.87	13.80	60.11	53.82	8.91	7.28
Šibensko-kninska	**2.00**	**6.37**	66.84	15.18	5.09	3.85	1.88	1.00	0.10	32.05	0.03	104.15	15.82	68.90	61.69	10.21	8.35
Varaždinska	**2.26**	**7.19**	75.40	17.13	5.74	4.34	2.12	1.13	0.12	36.15	0.03	117.50	17.85	77.73	69.59	11.52	9.41
Virovitičko-podravska	**1.21**	**3.86**	40.47	9.19	3.08	2.33	1.14	0.60	0.06	19.41	0.02	63.07	9.58	41.72	37.36	6.19	5.05
Vukovarsko-srijemska	**1.10**	**3.49**	36.62	8.32	2.79	2.11	1.03	0.55	0.06	17.56	0.01	57.07	8.67	37.75	33.80	5.60	4.57
Zadarska	**3.82**	**12.13**	127.31	28.92	9.69	7.32	3.59	1.90	0.19	61.04	0.05	198.38	30.14	131.24	117.50	19.46	15.90
Zagrebačka	**1.20**	**3.82**	40.03	9.09	3.05	2.30	1.13	0.60	0.06	19.20	0.02	62.38	9.48	41.27	36.95	6.12	5.00
MIN	**1.02**	**3.26**	**34.19**	**7.77**	**2.60**	**1.97**	**0.96**	**0.51**	**0.05**	**16.39**	**0.01**	**53.28**	**8.09**	**35.24**	**31.56**	**5.23**	**4.27**
MAX	**4.06**	**12.92**	**135.55**	**30.79**	**10.32**	**7.80**	**3.82**	**2.02**	**0.21**	**64.99**	**0.05**	**211.22**	**32.09**	**139.73**	**125.11**	**20.72**	**16.92**
AVERAGE	**2.08**	**6.62**	**69.43**	**15.77**	**5.28**	**3.99**	**1.96**	**1.04**	**0.11**	**33.29**	**0.03**	**108.19**	**16.44**	**71.57**	**64.08**	**10.61**	**8.67**
MEDIAN	**2.00**	**6.37**	**66.84**	**15.18**	**5.09**	**3.85**	**1.88**	**1.00**	**0.10**	**32.05**	**0.03**	**104.15**	**15.82**	**68.90**	**61.69**	**10.21**	**8.35**
CROATIA	**2.10**	**6.67**	**69.97**	**15.89**	**5.33**	**4.03**	**1.97**	**1.04**	**0.11**	**33.55**	**0.03**	**109.03**	**16.56**	**72.13**	**64.58**	**10.69**	**8.74**

Appendix 2 – Diesel related emissions into air from the Croatian municipal solid waste collection in 2013 *per capita*
Dodatak 2 – Emisije u zrak vezane uz potrošnju dizelskog goriva u sustavu sakupljanja komunalnog otpada u Hrvatskoj u 2013. godini *per capita*

Administrative unit (county)	Diesel	CO_2	NO_x	CO	CO_2 (from lubr.)	NMVOC	PM	f-BC	N_2O	SO_2	NH_3	Pb	ID[1,2,3-cd]P	B[k]F	B[b]F	B[a]P	Average distance
	kg	kg	g	g	g	g	g	g	g	mg	g	µg	µg	Mg	µg	µg	km
Bjelovarsko-bilogorska	**1.25**	**3.97**	41.65	9.46	3.17	2.40	1.17	0.62	0.06	19.97	0.02	64.90	9.86	42.93	38.44	6.36	5.20
Brodsko-posavska	**1.62**	**5.14**	53.98	12.26	4.11	3.11	1.52	0.81	0.08	25.88	0.02	84.11	12.78	55.64	49.82	8.25	6.74
Dubrovačko-neretvanska	**2.85**	**9.06**	95.07	21.60	7.24	5.47	2.68	1.42	0.15	45.58	0.04	148.15	22.51	98.01	87.75	14.53	11.87
Grad Zagreb	**2.30**	**7.32**	76.84	17.45	5.85	4.42	2.16	1.15	0.12	36.84	0.03	119.74	18.19	79.21	70.92	11.74	9.59
Istarska	**2.28**	**7.24**	75.96	17.26	5.78	4.37	2.14	1.13	0.12	36.42	0.03	118.37	17.98	78.31	70.11	11.61	9.48
Karlovačka	**1.50**	**4.77**	50.03	11.36	3.81	2.88	1.41	0.75	0.08	23.99	0.02	77.96	11.84	51.57	46.18	7.65	6.25
Koprivničko-križevačka	**1.36**	**4.33**	45.42	10.32	3.46	2.61	1.28	0.68	0.07	21.78	0.02	70.78	10.75	46.82	41.92	6.94	5.67
Krapinsko-zagorska	**3.70**	**11.76**	123.45	28.04	9.40	7.10	3.48	1.84	0.19	59.19	0.05	192.37	29.23	127.26	113.94	18.87	15.41
Ličko-senjska	**4.06**	**12.92**	135.55	30.79	10.32	7.80	3.82	2.02	0.21	64.99	0.05	211.22	32.09	139.73	125.11	20.72	16.92
Međimurska	**1.02**	**3.26**	34.19	7.77	2.60	1.97	0.96	0.51	0.05	16.39	0.01	53.28	8.09	35.24	31.56	5.23	4.27
Osječko-baranjska	**2.20**	**7.00**	73.48	16.69	5.59	4.23	2.07	1.10	0.11	35.23	0.03	114.51	17.40	75.75	67.82	11.23	9.18
Požeško-slavonska	**1.09**	**3.45**	36.22	8.23	2.76	2.08	1.02	0.54	0.06	17.37	0.01	56.44	8.57	37.34	33.43	5.54	4.52
Primorsko-goranska	**3.06**	**9.73**	102.15	23.20	7.78	5.88	2.88	1.53	0.16	48.98	0.04	159.19	24.18	105.31	94.29	15.61	12.76
Sisačko-moslavačka	**2.07**	**6.58**	69.07	15.69	5.26	3.97	1.95	1.03	0.11	33.12	0.03	107.64	16.35	71.21	63.75	10.56	8.62
Splitsko-dalmatinska	**1.75**	**5.56**	58.31	13.25	4.44	3.36	1.64	0.87	0.09	27.96	0.02	90.87	13.80	60.11	53.82	8.91	7.28
Šibensko-kninska	**2.00**	**6.37**	66.84	15.18	5.09	3.85	1.88	1.00	0.10	32.05	0.03	104.15	15.82	68.90	61.69	10.21	8.35
Varaždinska	**2.26**	**7.19**	75.40	17.13	5.74	4.34	2.12	1.13	0.12	36.15	0.03	117.50	17.85	77.73	69.59	11.52	9.41
Virovitičko-podravska	**1.21**	**3.86**	40.47	9.19	3.08	2.33	1.14	0.60	0.06	19.41	0.02	63.07	9.58	41.72	37.36	6.19	5.05
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Zadarska	**3.82**	**12.13**	127.31	28.92	9.69	7.32	3.59	1.90	0.19	61.04	0.05	198.38	30.14	131.24	117.50	19.46	15.90
Zagrebačka	**1.20**	**3.82**	40.03	9.09	3.05	2.30	1.13	0.60	0.06	19.20	0.02	62.38	9.48	41.27	36.95	6.12	5.00
MIN	**1.02**	**3.26**	**34.19**	**7.77**	**2.60**	**1.97**	**0.96**	**0.51**	**0.05**	**16.39**	**0.01**	**53.28**	**8.09**	**35.24**	**31.56**	**5.23**	**4.27**
MAX	**4.06**	**12.92**	**135.55**	**30.79**	**10.32**	**7.80**	**3.82**	**2.02**	**0.21**	**64.99**	**0.05**	**211.22**	**32.09**	**139.73**	**125.11**	**20.72**	**16.92**
AVERAGE	**2.08**	**6.62**	**69.43**	**15.77**	**5.28**	**3.99**	**1.96**	**1.04**	**0.11**	**33.29**	**0.03**	**108.19**	**16.44**	**71.57**	**64.08**	**10.61**	**8.67**
MEDIAN	**2.00**	**6.37**	**66.84**	**15.18**	**5.09**	**3.85**	**1.88**	**1.00**	**0.10**	**32.05**	**0.03**	**104.15**	**15.82**	**68.90**	**61.69**	**10.21**	**8.35**
CROATIA	**2.10**	**6.67**	**69.97**	**15.89**	**5.33**	**4.03**	**1.97**	**1.04**	**0.11**	**33.55**	**0.03**	**109.03**	**16.56**	**72.13**	**64.58**	**10.69**	**8.74**

SAŽETAK

Emisije iz sustava sakupljanja komunalnog otpada u Republici Hrvatskoj za 2013. godinu: Mješoviti otpad

Anamarija Grbeš,[a*] *Ilijana Ljubić*[b] i *Želimir Veinović*[a]

U Republici Hrvatskoj odgovornost za uklanjanje otpada (sakupljanje i odlaganje) nose jedinice lokalne samouprave 21 županije (odnosno 20 županija i posebna jedinica Grad Zagreb). Uklanjanje otpada kao ekonomska aktivnost povjerena je tvrtkama sakupljačima otpada kojih je u Hrvatskoj u analiziranom razdoblju bilo 208, a organiziranim sakupljanjem je bilo obuhvaćeno 99 % stanovništva. Sakupljanje mješovitog otpada iz kućanstava i poslovnih subjekata provodilo se različitom dinamikom, a otpad se iz kanti i spremnika preuzimao u kamione za otpad te prevozio do odlagališta odnosno postrojenja za oporabu.

U ovom radu procjenjuje se potrošnja dizelskog goriva te s njegovim izgaranjem povezane emisije u zrak uslijed sakupljanja mješovitog komunalnog otpada u Republici Hrvatskoj u 2013. godini. Ulazni podatci i rezultati prikazuju se za Hrvatsku te za svaku županiju posebno, u ukupnom iznosu te u relativnom iznosu (po stanovniku odnosno po jedinici mase prikupljenog otpada). Godišnja potrošnja dizelskog goriva u 2013. godini za sakupljanje mješovitog otpada procijenjena je na 10,6 milijuna litara. Na razini županija potrošnja je varirala od 87 tisuća do 2,2 milijuna litara (prosječno 504 tisuće litara po županiji). Ukupna emisija CO_2 procijenjena je na 28 000 tona, što na županijskoj razini varira od 231 do 5711 tona. Relativna emisija ugljikova dioksida varira od 3,3 do 13 kg CO_2 po stanovniku (prosječno 6,6 kg po stanovniku), odnosno 8,6–28,1 kg po toni prikupljenog otpada (prosječno 17 kg CO_2 po toni otpada). Prosječne vrijednosti emisije CO_2 uslijed sakupljanja otpada, koje bi također trebale biti i ciljane vrijednosti optimizacije sakupljanja otpada, kreću se od 7 do 9 kg za mješoviti otpad te od 8 do 15 kg CO_2 za različite, odvojeno prikupljene vrste otpada. Uz emisiju ugljikova dioksida, u ovom se radu prikazuju i emisije drugih tvari, kao što su NO_x, CO, CO_2 od izgaranja maziva, NMVOC, PM, f-BC, N_2O, SO_2, NH_3, Pb, ID[1,2,3-cd]P, B[k]F, B[b]F, B[a]P), te ukupna duljina transporta.

Ključne riječi
Sakupljanje komunalnog otpada, mješoviti otpad, gospodarenje otpadom, potrošnja goriva, emisije u zrak

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