ORIGINAL ARTICLE

ASSESSMENT OF SEPARATE COLLECTION OF RECYCLABLE MUNICIPAL WASTE IN CROATIAN MUNICIPALITIES AND DETERMINATION OF POTENTIAL FOR MATERIAL RECOVERY

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Keywords: separate collection, municipal waste, waste assessment, mixed municipal waste
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ABSTRACT

The aim of this paper is to determine the level of unused potential for material recovery of the components of municipal waste and to give an overview of the current situation in the Republic of Croatia regarding the achievement of the European quantitative target for recovery of municipal waste. The data analyses were conducted for separately collected amounts of waste paper, plastics, metals, glass, textiles and biowaste from the household municipal waste in the period 2011 - 2015 for 556 local self-government units which were then grouped into 5 regions. Municipal waste which originated from commercial sector in 2015 was additionally allocated to local self-government units.

For the analysis of achievement of the European quantitative target regarding material recovery, 2015 was taken as the baseline year and covered both household and commercial municipal waste. The results show that in all analysed regions the remaining unused material recovery potential of municipal waste is exceptionally high, especially when considering unused potential of municipal waste managed by local self-government units (household waste without commercial sector). The regions with the highest utilization of resources from municipal waste (households and commercial sector) are City of Zagreb and Northwestern Croatia, followed by Coastal and Mountain Croatia while Dalmatia region and Eastern Croatia have the lowest utilized potential from municipal waste. If separate collection and material recovery, as observed in 2015, continue in the upcoming years, the defined target will not be met within the set deadline.

It is necessary to increase utilisation of material recovery potential of all analysed waste flows in all the analysed regions.

The highest remaining material recovery potential from municipal waste is determined for textile waste and biowaste.

Recommendation for the forthcoming period is to focus on the separate collection and material recovery of biowaste and plastics because of their high share in the mixed municipal waste of 37% and 23%, respectively.

Key words: separate collection, municipal waste, waste assessment, mixed municipal waste.

INTRODUCTION

Waste management is certainly one of the most recognised fields regarding its high impact on the environment, which influenced the development of very strict European legislation covering waste sector. Thus, more than 20 groups of legislation (e.g. waste batteries, landfilling of waste etc.) are in place with a general purpose to produce a change from widespread dumping of waste in landfills to the imaginative exploitation of waste as a resource that can be re-used, recycled or treated to produce energy [1]. Within these waste management options,

the environmental benefits of materials recycling have been well established, as recycling not only reduces solid waste, but can also reduce the energy and pollutant intensity of raw materials production [2; 3]. Determination of factors which influence a waste management system is essential to make decisions which can ensure progress towards the achievement of the desired targets. One of those factors is undoubtedly the generation of municipal waste itself: the amount of waste generated is the amount of waste that has to be managed [4]. Thus, in order to design a more efficient waste recycling system we have to determine the potential for recycling of the valuable recyclables. However, organisation of a municipal waste management system is one of the most complicated issues connected with waste which asks for detail planning and a longer period to implement [5].

The Republic of Croatia has been fully harmonizing its national waste management policy with the European waste management policy. In 2013, by the adoption of the Act on Sustainable Waste Management [6] the provisions of the Directive 2008/98/EC [7] were transposed into the Croatian legislation. In January 2017, when Waste Management Plan of the Republic of Croatia for 2017 – 2022 [8] came into force, a number of measures and activities focused on the strengthening the implementation of the waste hierarchy and the implementation of guidelines and measures resulting from the Circular Economy Package [9] have been adopted.

In the recent past, the municipal waste management policy of the Republic of Croatia was mainly based on the models that ensure that generated municipal waste does not end up dumped in the environment. Collected municipal waste was mostly landfilled, wherein the valuable components of municipal waste were not used in adequate extent. National Waste Management Plan [8] stipulated series of measures and regulatory and financial activities, with an aim of directing waste management policy into the resource-efficient model. Thus, official data for Croatia indicate the insufficient progress and the need for further strengthening, in implementation terms, of separate collection and material recovery of municipal waste.

According to the official data provided by Croatian Agency for the Environment and Nature (CAEN) in the period from 2011 to 2015 the amount of separately collected municipal waste increased by 8%. During 2015 out of 1,653,918 tonnes of generated municipal waste (386 kg per inhabitant) 24% was separately collected. About 80% of generated municipal waste was landfilled. These data indicate that for the achievement of European quantitative target for 2020 related to the municipal waste it is necessary, in the short term, to make extremely significant progress.

MATERIALS AND METHODS

Research area

The Republic of Croatia is administratively and territorially divided into 21 counties which are further divided into 128 cities and 428 municipalities. For the purpose of this paper, based on spatial disposition, five regions were identified. A detailed description of the administrative and territorial organization of the Republic of Croatia is available in the Statistical Yearbook of the Republic of Croatia, 2015 [10]. The five analysed regions of the Republic of Croatia are presented in Table 1 and Figure 1.

Table 1 The 21 Counties of the Republic of Croatia divided into five regions analysed in this paper

Eastern Croatia Region	Northwestern Croatia Region	City of Zagreb Region	Coastal and Mountain Croatia Region	Dalmatia Region
Vukovar-Srijem County	Zagreb County	City of Zagreb	Primorje-Gorski Kotar County	Zadar County
Osijek-Baranja County	Krapina-Zagorje County		Istria County	Šibenik-Knin County
Požega-Slavonia County	Karlovac County		Lika-Senj County	Split-Dalamtia County
Brod-Posavina County	Koprivnica-Križevci County			Dubrovnik-Neretva County
Virovitica – Podravina County	Varaždin County			
Sisak – Moslavina County	Međimurje County			
Bjelovar-Bilogora County				

Data sources

Data analysed in this paper are provided by CAEN and refer to the annual data on municipal waste reported by waste collectors into the national electronic database Environmental Pollution Registry (EPR). All waste collectors are obliged to report data into the EPR according to Act on Sustainable Waste Management [6] and Ordinance on Environmental Pollution Register [11].

In this paper, annual data for 6 fractions of municipal waste were analysed. Waste types reported to EPR are classified according to the European List of Waste (LoW) codes [12]. Those fractions are:

- paper (LoW 150101, 200101),
- plastic (LoW 150102, 200139),
- metal (LoW 150104, 200140),
- glass (LoW 150107, 200102),
- textile (LoW 150109, 200110, 200111) and
- bio-waste (LoW 200108, 200125, 200201, 200302).

Analysis for household municipal waste was made for self-government units (all 556 self-government units were covered) divided into 5 regions and covering a period from 2011 to 2015.

On the level of self-government units, household municipal waste data are reported according to the place of generation, while data for municipal waste from commercial sector are reported by a collection company storage location. Commercial municipal waste generated in 2015 was allocated to the self-government units.

Methodology

The unused potential for material recovery from household waste in a certain year for a certain self-government unit (SGU) for the period 2011-2015 was calculated by using the following equation:

$$UP_{SGUwm} = (1 - \frac{SC_{SGUwm}}{SC_{SGUwm} + (SH_{wm} * W_{mixSGU})}) * 100\ [\%] \quad (1)$$

UP_{SGUws} presents the unused potential for material recovery of specific waste material *wm* (Paper, Plastics, Metal, Glass, Textile and Biowaste) from household waste in one year for a specific self-government unit *SGU*, SC_{SGUwm} presents the amount of separately collected specific waste material *wm* from household waste in one year for a specific self-government unit *SGU*, SH_{wm} presents the share of specific waste material *wm* in mixed municipal waste [8g and W_{mixSGU} presents the amount of collected mixed municipal waste in one year for a specific self-government unit *SGU*.

The unused potential for material recovery from municipal waste (households and commercial sector) was calculated for the year 2015 in a following way:

$$UPS_{SGUwm} = (1 - \frac{(SC_{SGUwm} + SCS_{SGUwm})}{(SC_{SGUwm} + SCS_{SGUwm}) + (SH_{wm} * W_{mixSGU})}) * 100\ [\%] \quad (2)$$

UPS_{SGUws} presents the unused potential for material recovery of specific waste material *wm* (Paper, Plastic, Metal, Glass, Textile and Bio-waste) from municipal waste (household waste and commercial sector) in one year for a specific self-government unit *SGU*, SC_{SGUwm} presents the amount of separately collected specific waste material *wm* from household waste in one year for a specific Self-governmental Unit *SGU*, SCS_{SGUwm} presents the amount of separately collected specific waste material *wm* from the commercial sector in one year for a specific self-government unit *SGU*, SH_{wm} presents the share of specific waste material *wm* in mixed municipal waste and W_{mixSGU} presents the amount of collected mixed municipal waste in one year for a specific self-government unit *SGU*.

SCS_{SGUwm} from the Equation (2) was calculated in the following way:

For the paper:

$$SCS_{SGUPa} = SCS_{RCPa}(\frac{NS_{SGU}}{NS_{RC}})\ [tonnes] \quad (3)$$

SC_{SGUPa} presents the amount of separately collected waste paper *Pa* for the commercial sector for a specific self-government unit SGU in 2015, SC_{SGUPa} presents the amount of separately collected waste paper *Pa* for the

commercial sector[1] for the Republic of Croatia in 2015, NS_{SGU} presents the number of active legal persons in commercial sector in a specific self-government unit SGU in 2015 and NS_{RH} presents the number of active legal persons in commercial sector in the Republic of Croatia in 2015.

Allocation of biowaste amounts from commercial sector was calculated based on the share of active business entities for a single unit of local self-government in the total number of business entities of 18 counties. Following NACE sections were used for allocation of biowaste: I, P, R, T [13]. For City of Zagreb, Pozega-slavonia and Brod-posavina, allocation of biowaste was made using the data reported by composting plants located in those counties. Thus, the amount of separately collected bio-waste from commercial sector was calculated as follows:

$$SCS_{SGUB} = SCS_{CB}(\frac{NS_{SGU}}{NS_C})\ [tonnes] \quad (4)$$

SCS_{GUB} presents the amount of separately collected waste bio-waste *B* from commercial sector for a specific self-government unit SGU in 2015, SCS_{GUB} presents the total amount of separately collected waste bio-waste *B* for the commercial sector for a specific county *C* in 2015 and NS_C presents the number of active legal persons in commercial sector for a specific county *C* in 2015.

For the textile waste calculations were the same as in the Equation (1) except for the City of Zagreb as there only one legal person conducting collection reported the data. Thus, for the City of Zagreb the amount of separately collected waste textile waste from commercial sector in the year 2015 equals the total amount of separately collected textile waste from commercial sector in the year 2015 for the entire Republic of Croatia.

For the plastics, metal and glass calculations were done based on the amounts of waste materials generated in commercial sector per capita in a specific county.

$$PC_{CPMG} = \frac{W_C}{C_C}\left[\frac{tonnes}{per\ capita}\right] \quad (5)$$

PC_{CPMG} presents the amount of separately collected plastics, metal or glass per capita from commercial sector in a specific county, W_C presents the amount of separately collected plastics, metal or glass from commercial sector in a specific county and C_C presents the number of inhabitants of a specific county in 2015.

Then, the amount of separately collected plastics, metal or glass from commercial sector was calculated as follows:

$$SCS_{SGUPMG} = PC_{CPMG} * C_{SGU}\ [tonnes\ ] \quad (4)$$

[1] Leve1 – Sections of Statistical Classification of Economic Activities in the European Community, Rev. 2 (2008) (NACE Rev. 2) - NACE sections: G, I, J, K, M, N, O, P, R, S, T. [13]

SCS_{GUB} presents the total amount of separately collected plastics, metal or glass from commercial sector for a specific self-government unit *SGU* in 2015 and C_{SGU} presents the number of inhabitants of a specific self-government unit *SGU* in 2015.

Unused potential for the analysed regions was obtained as the average value of unused potential of local self-government units in an individual region.

RESULTS AND DISCUSSION

The descriptive statistics of the results on the unused potential of municipal waste for material recovery for 556 Croatian municipalities are presented in Table 2. The results of the analyses covering household waste show that in the period analysed (2011-2015) a large number of local self-government units are above the average of the remaining material recovery potential. The highest remaining material recovery potential is determined for textile waste followed by biowaste, metal, plastics and paper, while the lowest potential was determined for glass (Table 2). If the dynamics of separate collection and material recovery of the household waste continues in the coming years, it can be expected that the defined target will not be met within the set deadline (Table 2).

The results of the data analyses of municipal waste for the baseline year 2015, both from the household and the service sector, further confirm the insufficient utilization of the potential for material recovery and problem regarding the achievement of the set target (Figure 2).

The results of the analysis for the year 2015 show that when total municipal waste (household waste and municipal waste from service sector) is considered, the City of Zagreb is the leading region in terms of utilization of waste paper and glass waste potential. Unused material recovery potential for waste paper is 51,29% and for glass waste 44,79%. For other analysed waste flows the unused potential in the City of Zagreb is high and ranges from 82%-91%.

In other four analysed regions, just like in the City of Zagreb, the highest utilization of resources from municipal waste is determined for waste paper and glass, and it ranges from 64%-82% for waste paper and from 58%-73% for glass waste.

Northwestwern Croatia is the leading region regarding the utilization of waste metal and plastic material recovery potential. The remaining material recovery potential of the Northwestwern Croatia for plastics is 76,26% and for metals 80,72%.

The largest unused material recovery potential for all four regions except for the City of Zagreb is detected for textile waste and biowaste, and amounts to more than 90%. For the City of Zagreb, the remaining unused

material recovery potential for textile and bio-waste is slightly lower compared to the other four regions (over 80% of unused potential) which is still remarkably high.

In comparison to other analysed region Dalmatia region has the highest unused material recovery potential for the most analysed waste flows. It is followed by Eastern Croatia.

Figure 1 shows unused material recovery potential of municipal waste from households and commercial sector for five regions of the Republic of Croatia for the year 2015.

Table 2 Results of the descriptive statistics analysis of the results for unused material recovery potential of municipal waste for 556 Croatian municipalities

	Paper						Plastics						Metal					
	2011	**2012**	**2013**	**2014**	**2015**	**2015***	**2011**	**2012**	**2013**	**2014**	**2015**	**2015***	**2011**	**2012**	**2013**	**2014**	**2015**	**2015***
Mean	96,80%	96,25%	95,73%	93,90%	92,23%	72,25%	97,06%	96,79%	95,96%	94,95%	94,30%	87,32%	97,13%	96,50%	96,47%	95,99%	95,66%	87,39%
Standard Error	0,0036	0,0039	0,0042	0,0048	0,0047	0,0057	0,0030	0,0031	0,0036	0,0038	0,0039	0,0049	0,0038	0,0049	0,0044	0,0043	0,0048	0,0058
Median	100,00%	100,00%	100,00%	99,67%	97,31%	74,43%	100,00%	100,00%	100,00%	99,04%	98,43%	90,42%	100,00%	100,00%	100,00%	100,00%	100,00%	91,58%
Mode	100,00%	100,00%	100,00%	100,00%	100,00%	84,65%	100,00%	100,00%	100,00%	100,00%	100,00%	#N/A	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
Standard Deviation	0,0846	0,0914	0,0987	0,1122	0,1096	0,1348	0,0710	0,0728	0,0837	0,0890	0,0909	0,1161	0,0897	0,1154	0,1036	0,1017	0,1131	0,1367
Sample Variance	0,0072	0,0084	0,0097	0,0126	0,0120	0,0182	0,0050	0,0053	0,0070	0,0079	0,0083	0,0135	0,0080	0,0133	0,0107	0,0104	0,0128	0,0187
Kurtosis	17,0994	11,9589	13,7124	13,7118	4,3332	-0,4186	16,5882	11,9050	11,0868	8,7611	5,5261	0,8684	18,6362	25,6366	25,8350	15,8071	17,8217	4,5984
Skewness	-3,7380	-3,2285	-3,3746	-3,1446	-1,9618	-0,4936	-3,6817	-3,3322	-3,1474	-2,7088	-2,2752	-1,1474	-4,2379	-4,8275	-4,6996	-3,8514	-4,0301	-1,9522
Maximum	100,00%	100,00%	100,00%	100,00%	100,00%	97,95%	100,00%	100,00%	100,00%	100,00%	100,00%	99,99%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
Minimum	25,78%	27,39%	24,90%	12,65%	37,55%	33,23%	38,44%	50,77%	43,21%	35,36%	44,50%	38,84%	37,29%	7,66%	5,43%	34,23%	14,70%	14,70%
Count	556	556	556	556	556	556	556	556	556	556	556	556	556	556	556	556	556	556
Conf. interval (95% prob.)	0,70%	0,76%	0,82%	0,93%	0,91%	1,12%	0,59%	0,61%	0,70%	0,74%	0,76%	0,97%	0,75%	0,96%	0,86%	0,85%	0,94%	1,14%
	Glass						**Textile**						**Bio-waste**					
Mean	87,22%	86,19%	85,79%	84,78%	83,09%	65,96%	99,99%	99,97%	99,73%	99,65%	98,73%	98,72%	98,08%	98,01%	97,59%	97,20%	96,68%	94,12%
Standard Error	0,0084	0,0085	0,0084	0,0088	0,0091	0,0085	0,0001	0,0002	0,0011	0,0008	0,0020	0,0020	0,0031	0,0032	0,0037	0,0042	0,0051	0,0052
Median	100,00%	98,74%	97,83%	96,58%	93,59%	68,71%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	98,23%
Mode	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
Standard Deviation	0,1990	0,2001	0,1975	0,2079	0,2133	0,1995	0,0018	0,0049	0,0252	0,0195	0,0471	0,0474	0,0720	0,0763	0,0883	0,0993	0,1194	0,1225
Sample Variance	0,0396	0,0400	0,0390	0,0432	0,0455	0,0398	0,0000	0,0000	0,0006	0,0004	0,0022	0,0022	0,0052	0,0058	0,0078	0,0099	0,0143	0,0150
Kurtosis	1,4951	0,9195	0,9333	0,8285	0,3313	-0,2549	555,9916	505,2028	169,5618	44,5786	28,9268	28,2942	23,9693	29,1097	21,8848	22,4586	16,9955	12,9359
Skewness	-1,5689	-1,4205	-1,3713	-1,3340	-1,1837	-0,4444	-23,5794	-22,1527	-12,2669	-6,5134	-4,9642	-4,9148	-4,7612	-5,1135	-4,5805	-4,6237	-4,1867	-3,5558
Maximum	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
Minimum	7,96%	13,51%	14,40%	9,87%	12,03%	5,99%	95,83%	88,71%	58,74%	82,40%	55,49%	55,49%	43,91%	29,40%	30,68%	23,44%	26,36%	26,36%
Count	556	556	556	556	556	556	556	556	556	556	556	556	556	556	556	556	556	556
Conf. inter. (95% prob.)	1,66%	1,67%	1,64%	1,73%	1,78%	1,66%	0,01%	0,04%	0,21%	0,16%	0,39%	0,39%	0,60%	0,64%	0,74%	0,83%	0,99%	1,02%

* Amounts from commercial sector included

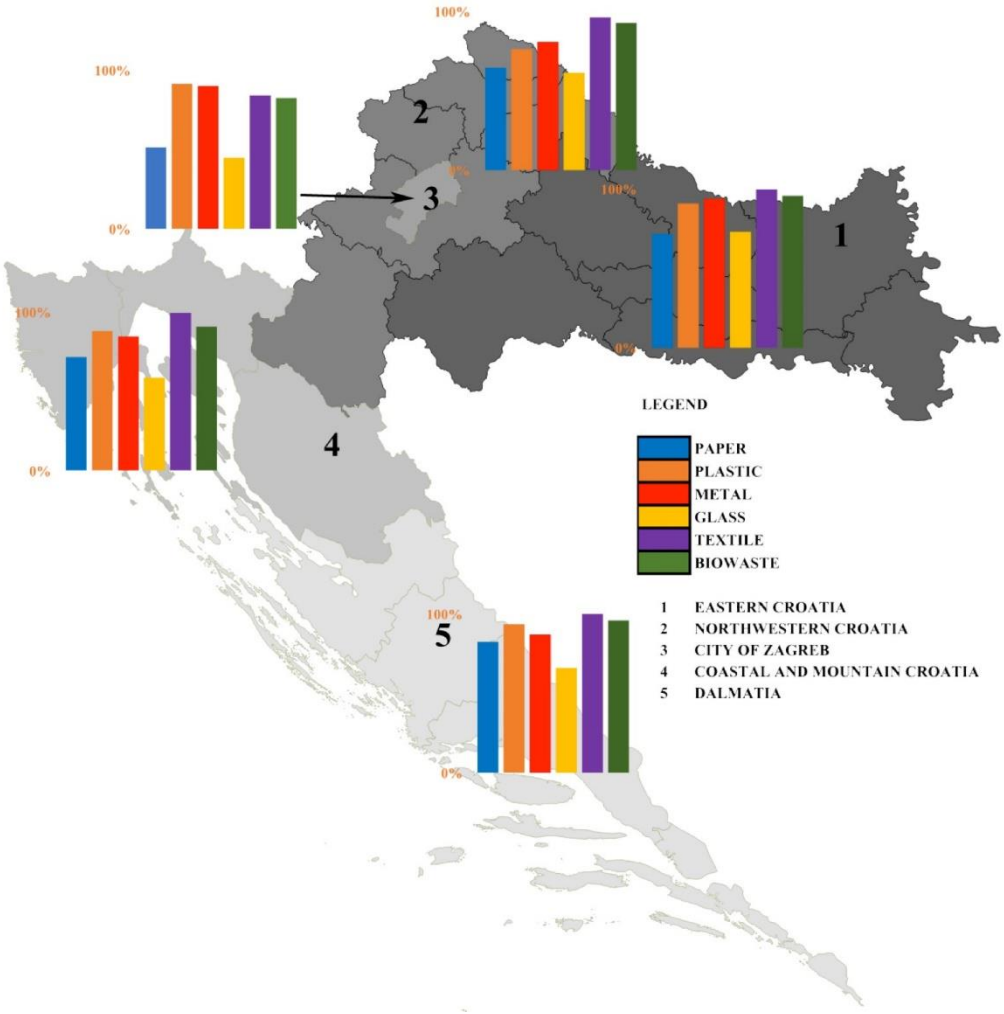

Figure 1 Unused material recovery potential of municipal waste from households and commercial sector for five regions of the Republic of Croatia for the year 2015.

In this paper, for analysed five regions and six waste flows, the analyses of target achievement regarding the preparation for re-use and recycling, as defined by Waste Framework Directive [14], was conducted. Municipal waste recovery rate for the Republic of Croatia in 2015 was 18% [15]. When considering the achievement of the objective at the level of regions and waste flows, by analysing municipal waste from the household and commercial sector, only the City of Zagreb region achieved 50% target and that was for glass waste flow only. In other four analysed regions the recovery rate is also the highest for waste glass, followed by waste paper.

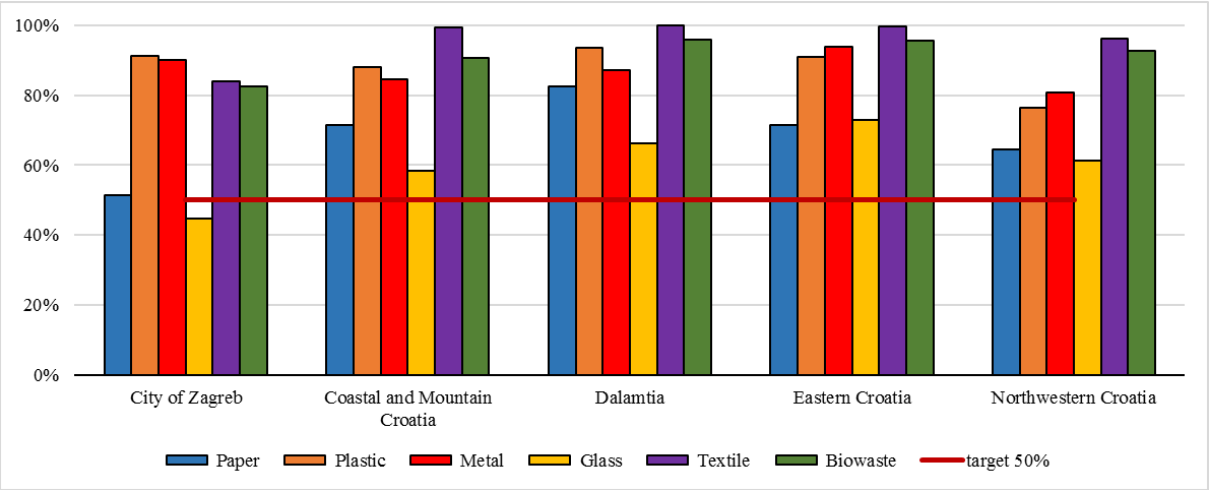

Figure 2 The results of the analysis on the unused material recovery potential of waste from households and commercial sector for the five regions of the Republic of Croatia for the year 2015.

If only the amounts of household municipal waste collected in the organization of local self-government units are considered, the target is not achieved in any of the analysed regions for any of the waste flows. It is evident that the Dalmatia region has the highest unused material recovery potential regarding household waste for all considered waste flows, followed by Eastern Croatia. The leading region in separate waste collection of municipal waste from households is Nortwestern Croatia which has the lowest available material recovery potential (Figure 3).

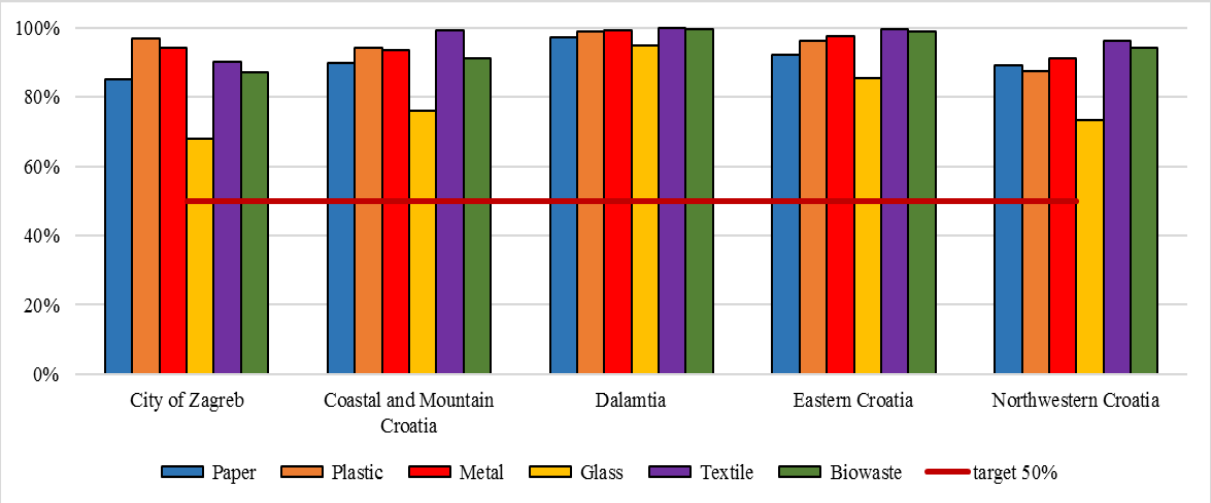

Figure 3 The results of the analysis on the unused material recovery potential of waste from households sector for the five regions of republic of Croatia for the year 2015.

CONCLUSION

In the paper, detailed data on the household municipal waste generation in the Republic of Croatia for the period from 2011 to 2015 was analysed with the aim to determine the unused potential for the material recovery of the following waste materials: paper, plastic, metal, glass, textile and biowaste. The unused potential was determined by the shares of those materials in the municipal waste for each of the 556 local self-government units, which were then grouped into 5 regions: Eastern Croatia Region, Northwestern Croatia Region, City of Zagreb Region, Coastal and Mountain Croatia Region and Dalmatia Region. Municipal waste which originated from commercial sector in 2015 was additionally allocated to local self-government units.

The results of the analysis show that in all analysed regions the remaining unused material recovery potential of municipal waste is exceptionally high, in particular when considering unused potential of household waste managed by local self-government units (without commercial sector).

The results of the analyses covering household waste show that in the period analysed (2011-2015) a large number of local self-government units are above the average of the remaining material recovery potential. The highest remaining material recovery potential of household waste is determined for textile waste followed by biowaste, metal, plastics and paper, while the lowest potential was determined for glass.

When the total municipal waste (household waste and municipal waste from commercial sector) is considered, the highest remaining material recovery potential is determined for textile and biowaste while the lowest potential was determined for glass and paper.

Data on unused material recovery potential by regions indicate that for the municipal waste from households and commercial sector, as well only for the waste from households, the highest unused potential have Dalmatia and Eastern Croatia.

Regarding the achievement of target for preparation for municipal waste re-use and recycling, defined by Waste Framework Directive, significant contribution comes from the commercial sector, 10% average.

In all regions, the use of material recovery potential is the highest for waste glass and paper, but is still insufficient. If separate collection and material recovery, as observed in baseline year 2015, continues in the upcoming years, the defined target will not be met within the set deadline.

It is necessary to increase utilisation of municipal waste material recovery potential of all analysed waste flows in all analysed regions and in particular of household waste in Dalmatia and Eastern Croatia. Because of high share of waste plastics and biowaste in mixed municipal waste in the forthcoming period it is desirable to intensify the separate collection of these waste flows, both from the households and from the commercial sector.

The data on the unused potential for the material recovery is an essential part in planning of any waste management system of any locality. In order to assess the unused potential for the material recovery more reliably, it is necessary to conduct frequent mixed municipal waste composition analyses.

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