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SHARE OF MECHANICAL-BIOLOGICAL INSTALLATION OF WASTE PROCESSING (MBP) IN THE LEVEL OF RECYCLING AND PREPARATION FOR RE-USE OF PAPER, METALS, PLASTICS, AND GLASS ACHIEVED BY MUNICIPALITIES

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ABSTRACT: The article aims to determine the share of mechanical-biological installation of waste processing (MBP) in the levels of recycling and preparation for the reuse of paper, metals, plastics, and glass (PMPG) achieved by municipalities. Two MBP installations were taken for the analysis – with the highest and the lowest share of municipalities in the Podlaskie Voivodship (Poland), which reached the recycling level required in 2019. In order to determine the share of MBP installations in the level of recycling achieved by communes, the share of the mass of recycled PMPG waste segregated from mixed municipal waste was calculated: in the total mass of generated PMPG waste and in the total mass of recycled PMPG waste from the municipal waste stream. On the basis of the conducted analyses, it should be stated that the MBP installation may have an impact on the achievement by municipalities of the recycling level required by law.

KEYWORDS: recycling rate, waste, waste treatment facility

Introduction

According to the Act of September 13, 1996, on maintaining cleanliness and order in municipalities, from 2012-2020, municipalities were obliged to achieve a level of recycling and prepare for the re-use of paper, metals, plastics, and glass (PMPG) (Act, 1996). The levels mentioned above for individual years were specified in the Regulation of the Minister of the Environment of December 14, 2016, on the levels of recycling, preparation for re-use, and recovery by other methods of specific fractions of municipal waste (Regulation, 2016). For failure to achieve the required level in a given year, the municipality was subject to a financial penalty calculated as the product of the unit rate of the fee for placing unsorted (mixed) municipal waste at the landfill, specified in the regulations issued under Art. 290 sec. 2 of the Act of April 27, 2001, Environmental Protection Law and the missing mass of municipal waste expressed in Mg, required to achieve an appropriate level of recycling and preparation for re-use of PMPG (Act, 1996).

When calculating the level of recycling and preparation for re-use of PMPG, municipalities considered the waste of four of the fractions mentioned above with specific codes following the regulation mentioned above (Regulation, 2016), both from the selective collection of municipal waste collected from inhabited and uninhabited properties where municipal waste is generated, waste collected at municipal selective municipal waste collection points (PSZOK), but also waste sorted from unsorted (mixed) municipal waste in a mechanical-biological installation municipal waste processing (MBP installations). Thus, the level of recycling and preparation for re-use of PMPG achieved by municipalities was influenced not only by the amount of waste collected and collected as sorted but also by the amount of waste of the four fractions mentioned above sorted from mixed municipal waste (in MBP installations).

The available scientific studies do not provide information on the impact of MBP installations on the level of recycling and preparation for re-use achieved by municipalities. There is a lack of analysis on how secondary raw materials segregated from mixed municipal waste in MBP installations affect the level of recycling and preparation for reuse achieved by municipalities. Currently, the impact of MBP installations on the achieved level of recycling is not monitored in any way. On the other hand, the share of secondary raw materials separated from mixed municipal waste added when calculating the recycling rate may determine the achievement of the level required by law. Pursuant to the provisions of the Act (1996), the levels of preparation for the reuse and recycling of municipal waste increase annually, reaching the level of 65% in 2035. Therefore, it can be expected that municipalities will have

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more and more problems with achieving the required levels of recycling, which will entail financial penalties. Directing mixed municipal waste to MBP installations, which have the highest share of recycled secondary raw materials segregated from mixed municipal waste, may increase the chances of the municipality achieving the level of recycling and preparation for re-use.

According to the best knowledge of the authors, current information on the impact of segregated secondary raw materials from mixed municipal waste on the recycling levels achieved by municipalities is not analysed and made public. Monitoring and spread of knowledge in this area could contribute to the fact that entities managing MBP installations would focus more on activities resulting in increasing the number of recycled materials separated from mixed municipal waste.

A novelty of this work is the assessment of the impact of MBP installations on the level of recycling achieved by municipalities. The aim of the article is to determine the share of MBP installations in the levels of recycling and preparation for the reuse of PMPG achieved by municipalities. The article determines the impact of the amount of PMPG recycled raw materials separated from mixed municipal waste in the MBP installation on the PMPG recycling rate obtained by municipalities. The above studies may also be an introduction to broader analyses concerning assessing the efficiency of MBP installations.

An overview of the literature

Performing a literature review, we find a number of articles on issues involving recycling rates for specific types of municipal waste. These include studies on the recycling of plastic waste (Antonopoulos et al., 2021; Thoden van Velzen et al., 2017; Huysman et al., 2015), metals (Fizaine, 2020; Das et al., 2006), or paper (Tatoutchoup, 2016; Schenk et al., 2008), among others.

The existing literature also includes analyses of the dependence of achieved waste recycling rates on various factors (Abbot et al., 2011; Cerqueira et al., 2022; Dijkgraaf et al., 2017; Zhang et al., 2021; Muñoz et al., 2004).

The quality of waste recycling is influenced by the existing collection system and product design (Eriksen et al., 2019) but also by the design and operation of materials recovery facilities (MRFs) (WRAP, 2014). Despite this, there are few studies in the available literature with primary data on the recovery and cleanliness rates of MRFs and recycling plants in the EU (Antonopoulos et al., 2021). Available studies on recovery rates at materials recovery facilities refer to mixed packaging waste and the post-consumer plastic waste being processed (Mastellone et al., 2017; Brouwer et al., 2018; Antonopoulos et al., 2021), as well as mixed municipal waste (Cimpan et al., 2015). However, they do not show the contribution to municipalities' recycling rates

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of recyclables separated from mixed municipal waste at an MBP facility. Hence, the purpose of the article is to fill the research gap that exists in this area.

Research methods

The analysis covers the level of recycling and preparation for re-use of PMPG (hereinafter referred to as the recycling level) achieved by municipalities from the Podlaskie Voivodeship (Poland) in 2019. The municipalities and the recycling levels they achieved were grouped according to MBP installations, to which unsorted (mixed) municipal waste collected from the municipal area was directed.

Two MBP installations were adopted for the analysis – with the highest (Installation A) and the lowest (Installation B) share of municipalities in Podlaskie Voivodeship, which achieved the recycling level of 40% required in 2019.

In 2019, both MBP installations processed a comparable amount of unsorted (mixed) municipal waste (25.93 thousand Mg and 25.98 thousand Mg, respectively), with Installation A servicing 19 municipalities and Installation B serving 26 municipalities. For the performed calculations, the data contained in the annual reports on the implementation of tasks in the field of municipal waste management, prepared by the municipality head, mayor, or president, submitted via the Database on products and packaging and waste management were used (Act, 1996) and data obtained from the managers of Installation A and B. The recycling level obtained by individual municipalities in 2019 was calculated following the Regulation (2016), according to the formula:

$$\mathrm{Ppmts} = \frac{\mathrm{Mrpmts}}{\mathrm{Mwpmts}}, \tag{1}$$

where:

Ppmts – level of recycling and preparation for re-use of PMPG, expressed in %,

Mrpmts – total weight of recycled and prepared for re-use PMPG waste from the municipal waste stream from households and other municipal waste producers, expressed in Mg. These are recycled and prepared for re-use waste coming from both selective collection of municipal waste collected from residential and uninhabited properties where municipal waste is generated, waste collected at separate municipal waste collection points (PSZOK), as well as waste sorted from unsorted (mixed) municipal waste in the MBP installation,

Mwpmts – total mass of PMPG waste generated from the municipal waste stream from households and other municipal waste producers, expressed in Mg.

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To determine the share of MBP installations in the level of recycling achieved by municipalities, the following were calculated:

- U1MBP – share of recycled and prepared for re-use PMPG waste sorted from unsorted (mixed) municipal waste in the total weight of PMPG waste generated from the municipal waste stream from households and other municipal waste producers and
- U2MBP – share by weight of recycled and prepared for re-use PMPG waste sorted from unsorted (mixed) municipal waste in the total amount of recycled and prepared for re-use PMPG waste from the municipal waste stream from households and other municipal waste producers.

The U1MBP value was calculated according to the formula:

$$\mathrm{U1MBP} = \frac{\mathrm{Mw200301}}{\mathrm{Mwpmts}}, \tag{2}$$

where:

Mw200301 – the total weight of recycled PMPG waste prepared for re-use sorted in the MBP installation from unsorted (mixed) municipal waste, calculated for individual municipalities from Installation A according to the formula:

$$\mathrm{Mw200301} = \mathrm{Mp200301\ x}\ \frac{\mathrm{Mw200301\ MBP}}{\mathrm{Mp200301\ MBP}}, \tag{3}$$

where:

Mp200301 – a mass of unsorted (mixed) municipal waste from a given municipality, processed in Installation A,

Mw200301 MBP – the total mass of PMPG waste, recycled and prepared for re-use, sorted in the MBP installation from the total mass of unsorted (mixed) municipal waste processed in Installation A, calculated as the sum of the masses of individual waste codes included in the level of recycling and preparation for re-use following the Regulation (2016) sorted from mixed (unsorted) municipal waste separately for the first and second half of the year,

Mp200301 MBP – total mass of unsorted (mixed) municipal waste processed in Installation A.

In the case of Installation B, the Mw200301 value was determined individually for each of the municipalities, while information about its amount was obtained from the Installation manager.

The size of U2MBP was calculated for individual municipalities from Installations A and B according to the formula:

$$\mathrm{U2MBP} = \frac{\mathrm{Mw200301}}{\mathrm{Mrpmts}}. \tag{4}$$

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The obtained results were subjected to fundamental statistical analysis and presented in a tabular and graphical manner using an Excel spreadsheet.

Results of research

Table 1 summarises the essential statistical data on the weight of waste and the level of recycling in municipalities directing unsorted municipal waste to Installation A.

Table 1. Primary data on waste masses and the level of recycling achieved in municipalities sending unsorted (mixed) municipal waste to Installation A in 2019

Parameter	Mwpmts [Mg]	Mrpmts [Mg]	Ppmts [%]	Mw200301 [Mg]	U1MBP [%]	U2MBP [%]
Minimum	154	48	31	12	6	13
Maximum	2 946	1 319	61	443	28	50
Average	637	295	48	82	12	25
Standard dev.	638	280	7	108	5	10

Source: author's work based on data from annual reports on the implementation of tasks in the field of municipal waste management for 2019 and data from the manager of Installation A.

The value of the total mass of PMPG waste generated from the municipal waste stream from households and other municipal waste producers (Mwpmts) ranges from 154 Mg to 2,946 Mg, with an average of 637 Mg. The recycling level in the analysed 19 municipalities ranges from 31% to 61% (48% on average).

The share of the weight of recycled waste, sorted from municipal waste in the total weight of the waste mentioned above (U1MBP) ranges from 6% to 28%, with an average value of 12%. The share of recycled waste sorted from municipal waste in the total weight of the waste mentioned above (U2MBP) ranges from 13% to 50%, which gives an average of 25%.

The high value of the standard deviation of the Mwpmts, Mrpmts, and Mw200301 masses indicates a large dispersion of the results in individual municipalities.

Figure 1 shows the achieved recycling levels in municipalities sending mixed municipal waste to Installation A and the share of sorted waste in the MBP installation in 2019.

The achieved recycling levels ranged from 31% in the A19 municipality to 61% in the A1 municipality. In both of the above municipalities, the share of MBP in the obtained recycling level was comparable and amounted to 8%

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and 9%, respectively. Two of the 19 municipalities failed to achieve the required 40% recycling rate.

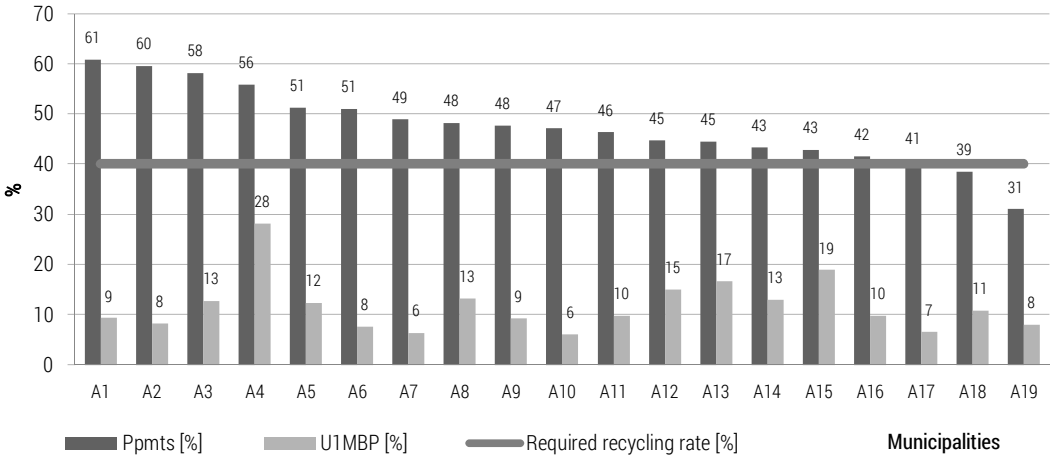

Figure 1. The level of recycling (Ppmts) and the share of MBP installations (U1MBP) in it achieved in individual municipalities, directing unsorted (mixed) municipal waste to Installation A

Source: author's work is based on data from annual reports on the implementation of tasks in the field of municipal waste management for 2019 and data from the manager of Installation A.

The share of MBP installations in the achieved recycling level ranged from 6% in the A7 and A10 municipalities to 28% in the A4 municipalities. There was no clear relationship between the recycling level achieved by individual municipalities and the share of MBP installations in it. The required level of recycling was achieved by the A4 municipality, where the highest MBP share was recorded, amounting to 28%, and the A7 and A10 municipalities, with the lowest MBP share of 6%.

Figure 2 shows the level of recycling in individual municipalities directing unsorted (mixed) municipal waste to Installation A, calculated without considering the weight of waste sorted from mixed municipal waste in the MBP installation.

The presented data show that without the participation of MBP installations, the levels of recycling in municipalities would range from 23% in the A19 municipality to 52% in the A1 municipality. The number of municipalities with a 40% level of recycling achieved without the share of MBP, compared to the level with the share of MBP, decreased from 17 (89.5% of municipalities) to 6 (31.6% of municipalities). The analyses show that even a small share (less than 10%) of MBP installations at the recycling level may affect municipalities' achievement of the required 40% recycling rate. It is espe-

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cially true in the case of municipalities where the achieved recycling rate is just above 40%. The share of the fractions of PMPG sorted in Installation A ensured that 11 out of 19 municipalities (57.9% of municipalities) achieved the level of recycling that would not be achieved without the waste sorted in the plant.

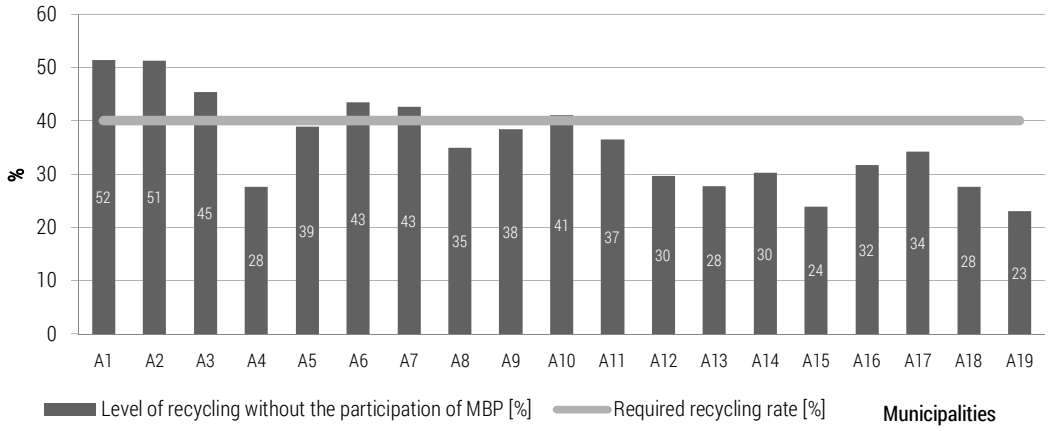

Figure 2. The level of recycling in individual municipalities directing unsorted (mixed) municipal waste to Installation A, without the participation of MBP installations in it

Source: author's work is based on data from annual reports on the implementation of tasks in the field of municipal waste management for 2019 and data from the manager of Installation A.

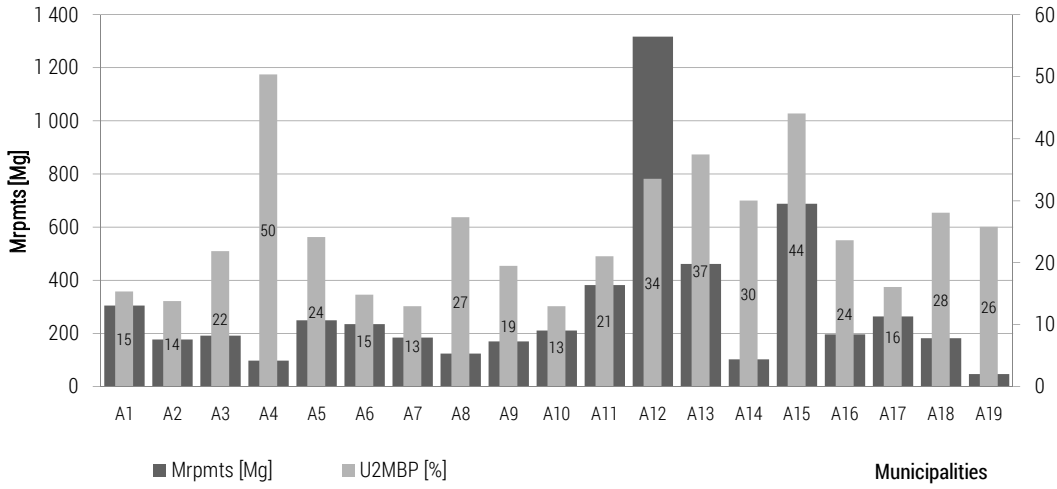

Figure 3. The total weight of recycled waste and the share of recycled waste sorted in the MBP installation in municipalities directing unsorted (mixed) municipal waste to Installation A

Source: author's work is based on data from annual reports on the implementation of tasks in the field of municipal waste management for 2019 and data from the manager of Installation A.

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Figure 3 shows the weight of recycled and prepared for re-use waste PMPG (Mrpmts) and the share of the waste mentioned above. Waste is sorted in the MBP (U2MBP) for individual municipalities, directing mixed waste to Installation A.

The total weight of recycled waste in individual municipalities ranges from 48 Mg in the A19 municipality (with an MBP share of 26%) to 1,319 Mg in the A12 municipality (with an MBP share of 34%). The share of the weight of sorted waste in the MBP installation ranged from 13% in the municipalities of A7 and A10 (with the weight of recycled waste amounting to 185 and 212 Mg, respectively) to 50% in the A4 municipality (with the weight of recycled waste equal to 98 Mg).

The municipalities of A18 and A19, which did not achieve the required level of recycling in 2019, had a high (above the average of 25%) share of the weight of recycled waste sorted from mixed municipal waste in the total weight of recycled waste (equal to 28% and 26%, respectively). Therefore, the high share of MBP in the mass of recycled waste did not determine the required recycling level by all municipalities. Its achievement depended on the total weight of recycled waste sorted from mixed municipal waste in the MBP installation and the weight of recycled waste from selective "at source" collection and collected in PSZOK.

The municipalities with the highest and the lowest mass of recycled waste achieved a similar index of MBP share, equal to 34% and 26%, respectively.

Table 2 presents the minimum and maximum values, the average and the standard deviation calculated for the values of individual waste masses, the level of recycling, and the share of U1MBP and U2MBP achieved by individual municipalities directing mixed municipal waste to Installation B.

Table 2. Primary data on waste masses and the level of recycling achieved in municipalities sending unsorted (mixed) municipal waste to Installation B in 2019

Parameter	Mwpmts [Mg]	Mrpmts [Mg]	Ppmts [%]	Mw_{200301} [Mg]	U1MBP [%]	U2MBP [Mg]
Minimum	144	58	26.3	0	0.2	0.4
Maximum	2 191	2 229	101.7	72	24.3	70.6
Average	486	239	40.6	21	6.1	17.1
Standard dev.	445	415	13.4	25	8.2	23.1

Source: author's work based on data from annual reports on the implementation of tasks in the field of municipal waste management for 2019 and data from the manager of Installation B.

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The total mass of PMPG waste generated for the 26 analysed municipalities ranges from 144 to 2,191 Mg, with an average of 486 Mg. The recycling rate ranges from 26.3% to 101.7%, with an average of 40.6%.

The share of recycled waste sorted from municipal waste in the total weight of the above-mentioned generated waste (U1MBP) ranges from 0.2% to 24.3%, with an average of 6.1% and a standard deviation of 8.2%. The share of recycled waste sorted from municipal waste in the total weight of the waste mentioned above (U2MBP) ranges from 0.4% to 70.6%, on average, 17.1%.

The high value of the standard deviation of the Mwpmts, Mrpmts, and Mw200301 masses, the level of recycling, and the share of U1MBP and U2MBP indicate a large variability of the results in individual municipalities.

Figure 4 shows the recycling levels achieved by individual municipalities directing mixed municipal waste to Installation B and the share of sorted waste in the MBP installation in 2019.

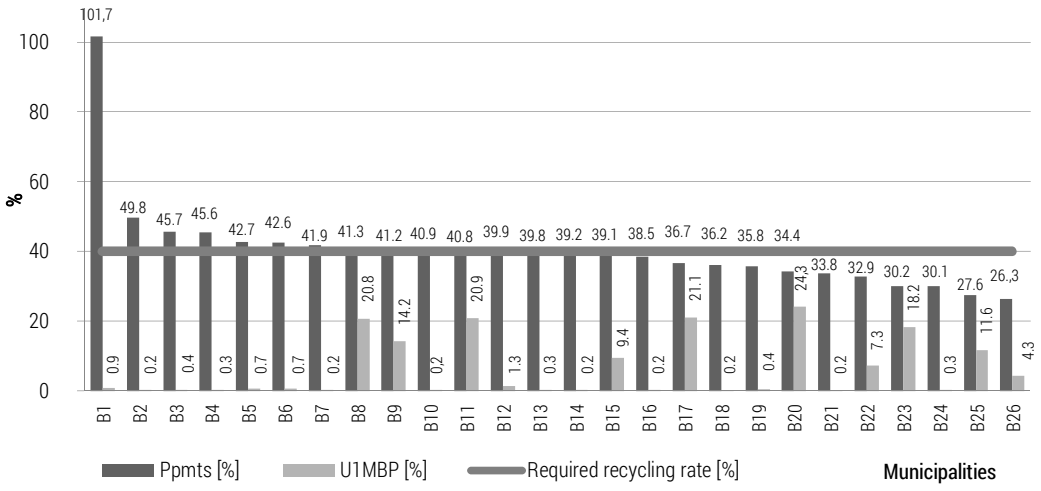

Figure 4. The level of recycling (Ppmts) and the share of MBP installations (U1MBP) in it achieved in individual municipalities directing unsorted (mixed) municipal waste to Installation B

Source: author's work is based on data from annual reports on the implementation of tasks in the field of municipal waste management for 2019 and data from the manager of Installation B.

The recycling rate achieved by individual municipalities ranged from 26.3% (with a share of MBP amounting to 4.3%) in municipality B26 to 101.7% (with a share of MBP 0.9%) in municipality B1. The required 40% recycling rate was achieved by 11 out of 26 municipalities.

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The value of the share in the level of recycling of MBP installations ranged from 0.2% in the municipalities B2, B7, B10, B14, B16, B18, and B21 (with the recycling level from 33.8% to 49.8%) to 24.3% in the municipality B20 (at a recycling rate of 34.4%). There was no correlation between the level of recycling achieved by individual municipalities and the share of MBP installations. Some municipalities achieved the required 40% level of recycling with the lowest MBP share of 0.2%, as well as municipalities with one of the highest MBP shares, over 20% (B8 and B11 municipalities). The share of MBP in the level of recycling of municipalities that did not achieve the required level reaches both the minimum (0.2%) and maximum (24.3%) values recorded for this indicator.

In 15 out of 26 municipalities, the share of MBP installations in the achieved recycling level is less than 1%, while in 4 municipalities, it is higher than 20%. The lower the share of PMPG waste sorted from mixed municipal waste in the MBP installation at the recycling level, the higher the share of those mentioned above. Waste from other sources, i.e., waste collection from real estate in the municipality and waste collected in PSZOK. In most municipalities sending mixed municipal waste to Installation B, the share of sorted waste in the MBP installation was negligible. The achieved recycling level was achieved thanks to waste from the collection of selectively collected waste "at source" and collected at the PSZOK.

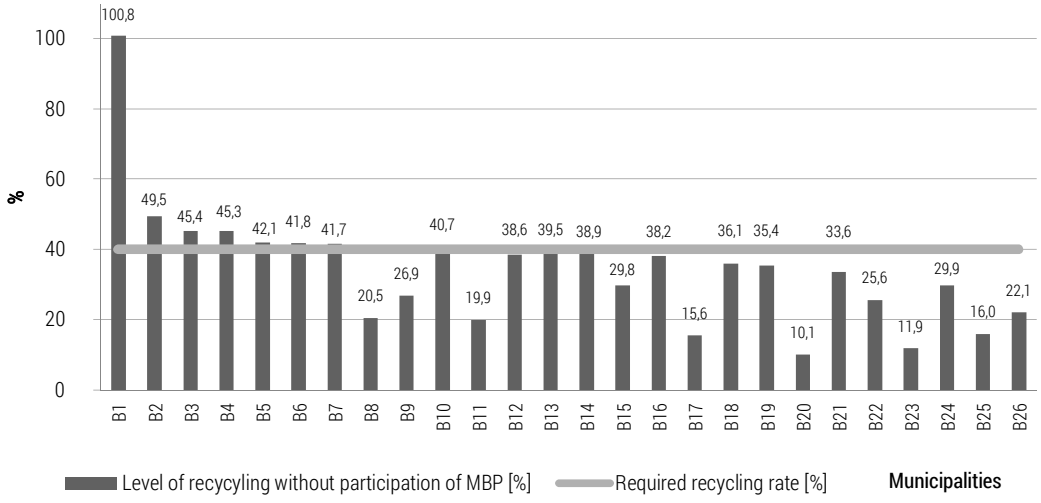

Figure 5. The level of recycling in individual municipalities directing unsorted (mixed) municipal waste to Installation B, without the participation of MBP installations in it

Source: author's work is based on data from annual reports on the implementation of tasks in the field of municipal waste management for 2019 and data from the manager of Installation B.

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Figure 5 shows the level of recycling in individual municipalities directing unsorted (mixed) municipal waste to Installation B, calculated without considering the weight of PMPG waste sorted from mixed municipal waste in the MBP installation.

The recycling level achieved without considering the weight of sorted waste from mixed municipal waste in Installation B ranges from 10.1% (municipality B20) to 100.8% (municipality B1). The number of municipalities with the legally required level of recycling without the share of MBP, compared to the level including the share of MBP, decreased from 11 (42.3% of municipalities) to 8 (30.8% of municipalities).

The share of PMPG waste sorted from mixed municipal waste in Installation B ensured that 3 out of 26 municipalities (11.5% of municipalities) achieved the level of recycling that would not be achieved without waste sorted in the installation. In these municipalities (B8, B9, and B11), the share of MBP ranged from 14.2% to 20.9%. In the case of 8 municipalities that would obtain the required level of recycling without considering the mass of waste sorted in the MBP installation, its share was so low (from 0.2% to 0.9%) that it did not significantly affect the achieved result.

Figure 6 shows the weight of recycled and waste PMPG prepared for re-use (Mrpmts) and the share of those mentioned above. Waste is sorted in municipalities' MBP (U2MBP), directing unsorted municipal waste to Installation B.

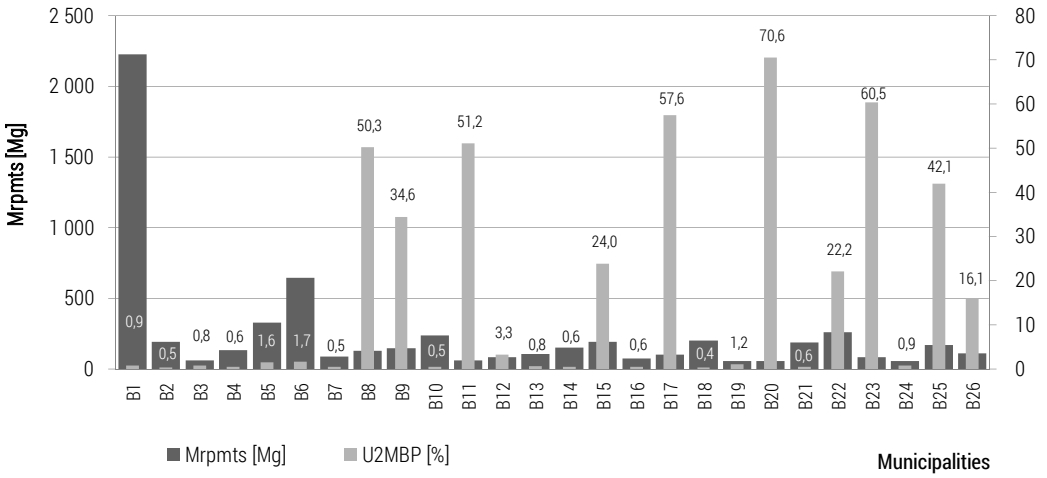

Figure 6. The total weight of recycled waste and the share of recycled waste sorted in the MBP installation in municipalities directing unsorted (mixed) municipal waste to Installation B

Source: author's work is based on data from annual reports on the implementation of tasks in the field of municipal waste management for 2019 and data from the manager of Installation B.

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The total mass of PMPG waste recycled and prepared for re-use in individual municipalities ranges from 58 Mg (B19 and B24 municipalities) with an MBP share of 1.2% and 0.9%, respectively, to 2,229 Mg (municipality B1) with the MBP share value of 0.9%. The share of MBP in the total weight of recycled waste ranges from 0.4% (municipality B18) with a mass of recycled waste of 205 Mg to 70.6% (municipality B20) with 60 Mg. In 12 municipalities, the share of sorted waste from mixed municipal waste in the MBP installation in the total weight of recycled waste is less than 1%. In comparison, in 5 municipalities, it is higher than 50%.

In municipalities that did not achieve the required recycling level (from B12 to B26), the share of the weight of sorted waste from mixed municipal waste in Installation B in the weight of those mentioned above of total recycled waste reached the lowest values and the highest recorded for the ratio (from 0.4% to 70.6%). However, in the municipality with the highest recycling level (B1), it was 0.9%. It was observed that the low share of recycled waste sorted in the MBP installation does not mean that the municipality will not achieve the recycling level, and a high percentage does not guarantee its achievement. Obtaining the level of recycling required by law depends on the total weight of recycled waste sorted from mixed municipal waste in the MBP installation and the weight of recycled waste from the selective waste collection "at source," and the weight of waste collected in PSZOK.

Limitations and future research

During the review of the literature, no research on the share of MBP installations in the level of PMPG recycling achieved by municipalities was found. In the present study, in accordance with formulas (2 and 4), the share of the MBP installation in the recycling level achieved by municipalities was calculated as the share of the mass of PMPG recycled and prepared for reuse, separated from mixed municipal waste in the MBP installation, respectively in relation to the total mass of generated waste PMPG (U1MBP) and in the total weight of PMPG waste (U2MBP), recycled and prepared for reuse, coming from the municipal waste stream from households and from other municipal waste producers. To the best of the authors' knowledge, there are no data from similar studies in the available literature.

As pointed out by Cimpan et al. (2015), there is also a lack of detailed data on the efficiency of processes in MBT plants in terms of, e.g. sorting efficiency. Available information concerns the recovery efficiency of Mechanical-Biological Treatment (MBT) installations (defined as the weight percentage of waste in a wet state to the weight of recovered input) in relation to individual waste fractions (i.e. paper and cardboard, metals, glass, plastic films), PET,

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HDPE, beverage cartons, mixed plastics (PVC, PP, PS)) and total recovery as a per cent of total residual MSW input. For example, for the MBT Ecoparc 4 plant in Barcelona, the above-mentioned value of total recovery was set at 10.5% (Navarotto et al., 2012), while for the 8 MBT plants in Castilla y León (Spain) – an average of 7% (from 2.5% to 13%) (Montejo et al., 2013). In addition, for some MBT and MRF plants, the total input waste recovered as output products were determined; for example, for secondary raw materials at the MBT plant in Larnaca (Cyprus) was 20% (Wellacher, 2011) and at the MRF plant in California (USA) – 22% (SWANA, 2013). However, according to the results presented by Wiśniewska et al. (2018), the amount of secondary raw materials segregated from mixed municipal waste at the MBP plant in Poświętne (Poland) was less than 4%. Nevertheless, the authors of the above-mentioned works did not specify what share in the achievement of the recycling level by the communes had the recycled waste, which was segregated in the above-mentioned installations.

There are also few studies that have compared the quality of recyclable materials recovered through separate collection with the quality of materials separated by central sorting of mixed municipal waste (Cimpan et al., 2015). This topic was dealt with by Schmalbein et al. (2011), Wellacher (2011), and Van Velzen et al. (2013).

According to Cimpan et al. (2015), the main role of sorting mixed municipal waste is to supplement the systems of „at source" segregation and selective collection in areas where its efficiency is lower (e.g. in urban areas). The above statement is in line with the assumptions of the municipal waste management system regulated by law in Poland. The Act (1996) requires both selective collection of waste as well as directing mixed municipal waste to MBP installations. The legal provision constructed in this way is aimed at maximising the amount of secondary raw materials that will be sent for recycling, with the priority action being a selective collection of waste (both „at source" and in PSZOK). On the other hand, waste constituting secondary raw materials, which as a result of incorrectly conducted selective waste collection, will end up in mixed municipal waste, should be recovered by sorting it in the MBP installation.

Cimpan (2015) points to the particularly important role of central sorting of residual waste where source segregation is difficult (i.e. cities), concluding that the recovery of secondary raw materials for recycling from waste mixed in installations can be a supplement to segregation „at source" or a separate substitute collection of certain wastes, e.g. plastics and metals. He also maintains that in the context of the recycling levels that the EU Member States are obliged to achieve, the expansion of the MBT installation with the additional recovery of secondary raw materials may contribute to achieving the above-mentioned targets.

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The above conclusions are consistent with the obtained research results, which indicate the significant role of MBP installations in achieving the level of recycling required by the law by municipalities. According to the calculations obtained in the MBP installation with the highest share of municipalities that achieved the required recycling level, equal to 89.5% (Installation A), PMPG waste segregated from mixed municipal waste ensured that as many as 57.9% of municipalities achieved the level required by law. At the same time, the high share of the mass of secondary raw materials separated from mixed municipal waste in the total weight of recycled waste did not determine the achievement of the required level of recycling by municipalities. The conducted research indicates that the achievement of the required level of recycling was determined by the total mass of PMPG waste recycled, both from the selective collection and segregated from mixed municipal waste in the MBP installation.

This research, apart from filling the existing research gap in this area, may have practical significance for municipal governments obliged to achieve the levels of recycling and preparation for re-use required by law. Although from 2021, there is no longer an obligation in Polish law to achieve the level of recycling and preparation for re-use of PMPG, municipalities face the challenge of achieving in individual years the level of preparation for re-use and recycling of municipal waste, calculated as the ratio of the mass of the total (including PMPG) municipal waste prepared for re-use and recycled to the mass of municipal waste generated, excluding other than hazardous construction and demolition waste constituting municipal waste (Act, 1996). The conducted research indicates that the MBP installation may have an impact on the achievement of the recycling level required by the regulations. According to the Act (1996), the levels of preparation for re-use and recycling of municipal waste that municipalities must achieve are increasing every year (reaching 55% in 2025, reaching up to 65% in 2035). Therefore, it is likely that municipalities will increasingly not achieve the required recycling levels and incur associated financial penalties. The dissemination of this information may show the role of MBP installations in achieving the levels needed by municipalities. This, in turn, on the one hand, may enable municipalities to take appropriate steps to direct mixed municipal waste to MBP installations achieving the largest amounts of waste (secondary raw materials) separated from mixed municipal waste (e.g. by defining appropriate requirements or criteria in tenders for the management of mixed municipal waste). On the other hand, it can motivate entities managing MBP installations to be more mobilised in order to segregate as many secondary raw materials as possible from mixed municipal waste, which will be directed for recycling, which will allow municipalities to achieve higher recycling rates.

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Of course, it should be borne in mind that the amount of secondary raw materials that can be segregated from mixed municipal waste in the MBP installation also depends on the devices the plant is equipped with and on the properties of the waste being treated (Wiśniewska et al., 2018), including its content in mixed municipal waste, and thus on the effectiveness of the municipal waste segregation carried out by property owners „at source". Thus, their amount may vary depending on the efficiency of the segregation, whereby, according to the observed patterns, a higher amount of raw materials can be expected in mixed municipal waste in urban agglomeration areas, where waste segregation „at source" is difficult (Cimpan et al., 2015). However, with regard to the quality of secondary raw materials contained in mixed municipal waste and the possibility of recycling it, it should be pointed out that, according to the available literature, the quality of potentially recyclable secondary raw materials separated from mixed municipal waste is mainly influenced by cross-contamination, which depends primarily on the time of collection and storage of waste. Therefore, the high degree of moisture content of the waste may not be of great importance in the case of plastics. However, in the case of paper and board contained in mixed municipal waste, due to their high moisture absorption capacity, combined with the presence of fine particles, the degree of moisture is crucial in their contamination (Schmalbein et al., 2011) and thus their continued recyclability.

In order to achieve more analytical results, the research should be continued. The research work can be extended to other MBP installations in the Podlaskie Voivodeship. In addition, the share of MBP installations in the level of recycling and preparation for re-use of PMPG in 2020, as well as the above-mentioned share in the level of preparation for re-use and recycling of the municipal waste in subsequent years, can be examined, checking whether the same regularities will be recorded as in the year 2019 under review.

Conclusions

Based on the conducted analyses, it should be stated that the MBP installation may have an impact on the achievement by municipalities of the recycling level required by law. In the MBP installation with the highest percentage of municipalities that achieved the required level of recycling, equal to 89.5% (Installation A), PMPG waste segregated from mixed municipal waste ensured that as many as 57.9% of municipalities achieved the level required by law. On the other hand, in the case of MBP installations with the lowest percentage of municipalities that achieved the required recycling level of 42.3% (Installation B), the share of MBP installations ensured that only 11.5% of municipalities achieved the above-mentioned level. It follows that

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without the participation of MBP installations (i.e. without including PMPG waste segregated from mixed municipal waste in each municipality's recycling rate), the required level of recycling would have been achieved by a similar percentage of municipalities, i.e. 31.66% in the case of municipalities directing mixed municipal waste to Installation A, and 30.8% in the case of municipalities directing the above-mentioned waste to Installation B. Calculations made on the data of municipalities directing waste from both installations A and B indicate that the high share of the weight of recycled municipal waste separated from mixed municipal waste in the weight of recycled waste did not determine the achievement of the required level of recycling by all municipalities. The low share of recycled waste sorted in MBP did not mean that municipalities did not achieve the recycling level. Achieving the required level of recycling depended on the total mass of PMPG waste recycled, i.e. segregated from mixed municipal waste in the MBP installation and the weight of recycled waste from the selective collection (collected from residents as selectively collected waste "at source" and collected in PSZOK).

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The contribution of the authors

A. Krysztopik – conception, acquisition of data, analysis and interpretation of data – 70%.

I.A. Tałałaj – conception, analysis and interpretation of data – 20%.

P. Biedka – literature review – 10%.

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