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INVESTIGATING THE ECONOMIC EFFICIENCY OF WASTE COLLECTION AND TRANSPORTATION – CASE STUDY FOR URBAN AND RURAL MUNICIPALITIES IN POLAND

Summary. This article presents the results of the analysis of waste collection in selected rural and urban municipalities in the Silesian Voivodship in Poland in the years 2014-2018. A new approach has been presented for the evaluation of the economic efficiency of the waste management system including all costs and revenues both for the local administration and the waste collection company in a circular economy context.

The results include the impact of significant factors affecting the total cost of collection, which include transportation costs, personal costs, as well as administrative costs, including fees for using the environment and the fee for waste management at the landfill. The mass from the separate collection increased for three municipalities from 2014, showing a positive impact of the new regulations considering secondary raw materials for recycling. In the five years of the study, the variable purchase prices of recyclable materials adversely affected the economic efficiency of the collection, which increased fees charged by municipalities to residents. The increase in costs was significant for the five years included in the study for a landfill fee increase of 40%, for an environmental fee increase of 15% and an increase of waste collection costs above 20%. The main contribution of revenues is the waste collection fee from residents. As a consequence, the municipalities must increase waste collection fees. Due to a much larger number of waste categories and unstable purchase prices of secondary raw materials, waste-collecting companies should pay attention towards reducing transport costs and using human resources more efficiently.

1. COLLECTION OF WASTE AS A COMPONENT OF CIRCULAR ECONOMY

Since several years, a linear model of economy where end-of-life products and product packages ended in landfills has been replaced by a circular economy model [13]. At present, the rule of closing the supply chain and the circulation of raw materials in the circular economy model dominates. The most important element in this new approach is the principle of reusing products and recycling secondary raw materials including the maximum reduction of the stream going to the landfill [2,15]. One of the key elements in the circular economy is the collection of waste from households and companies and then using different techniques to recycle, reuse, or recover raw materials included in different waste streams (Fig. 1) [17].

Since the introduction of the amendment to the act on maintaining cleanliness and order in communes in Poland, from 2013, significant changes had to be introduced in the municipal waste

management field [7]. After the period in which the collecting companies had to adapt to these changes and the residents had to adapt to new ways of sorting and disposal of waste, the functioning of the system stabilized.
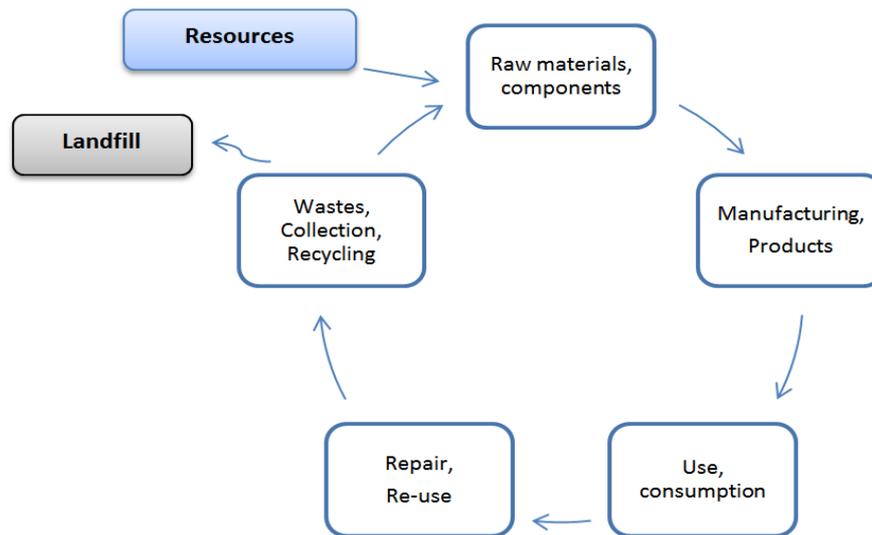

Fig. 1. Concept of a circular economy approach

In the new waste collection system, the relationship between the owner of the property, the entity managing municipal waste collection from the property owners and the municipality has changed. Based on the new regulations, the municipality takes over the control of municipal waste and property owners pay the so-called waste collection tax. Separation of different groups and categories of waste for separately collected waste has also become a priority and is on behalf of the waste-generating source (a resident or a company). New waste categories and new collection rules have been introduced. These changes required the development of appropriate collection schedules and the selection of appropriate vehicles to collect waste.

In addition, the company collecting municipal waste from property owners is obliged to transfer received mixed municipal waste, green waste and residues from the sorting of municipal waste for storage to a regional waste treatment installation - Regional Municipal Waste Treatment Facilities (RIPOK). This paragraph in the legislation completely changes the method of planning the routes of collecting vehicles, resulting in longer collection times and their total length.

One of the main objectives of the implemented municipal waste management system is to achieve decreased levels of biodegradable and municipal solid waste directed to landfills within the indicated period, and increase the level of recycling and recovery of separately collected waste. The municipalities are obliged by law of Art. 3b of the Act of 13 September 1996 on maintaining cleanliness and order in communes, as well as executive acts to the Act in the form of appropriate regulations and its amendments [6,8]. In accordance with the provisions contained in the aforementioned sources, municipalities are required to achieve appropriate levels by December 31, 2020:

- for municipal waste from the separate collection: paper, metals, plastics and glass - recycling and preparation for re-use of at least 50% by weight;
- for construction and demolition waste (other than hazardous) - recycling, preparation for re-use and recovery of at least 70% by weight; and
- limitation of the mass of biodegradable municipal waste transferred to landfill by 16 July 2020 - up to not more than 35% by weight of the total weight of biodegradable municipal waste transferred to landfill in relation to the mass of this waste generated in 1995.

In accordance with the annex to the above regulation for the next years, the required levels of recycling, preparation for re-use and recovery by other methods of some municipal waste fractions have been defined (table 1).

Table 1

Recycling and reuse ratio for separated waste stream – paper, glass, metals and plastics [%]

Year	2014	2015	2016	2017	2018	2019	2020
Required recycling ratio for secondary raw materials [%]	14	16	18	20	30	40	50

The requirements to achieve high recycling rates for the municipal solid waste are challenging not only for Poland but also for all European Union members [10]. The municipal solid waste from households has variations for different countries in the European Union. This is illustrated in Fig. 2.
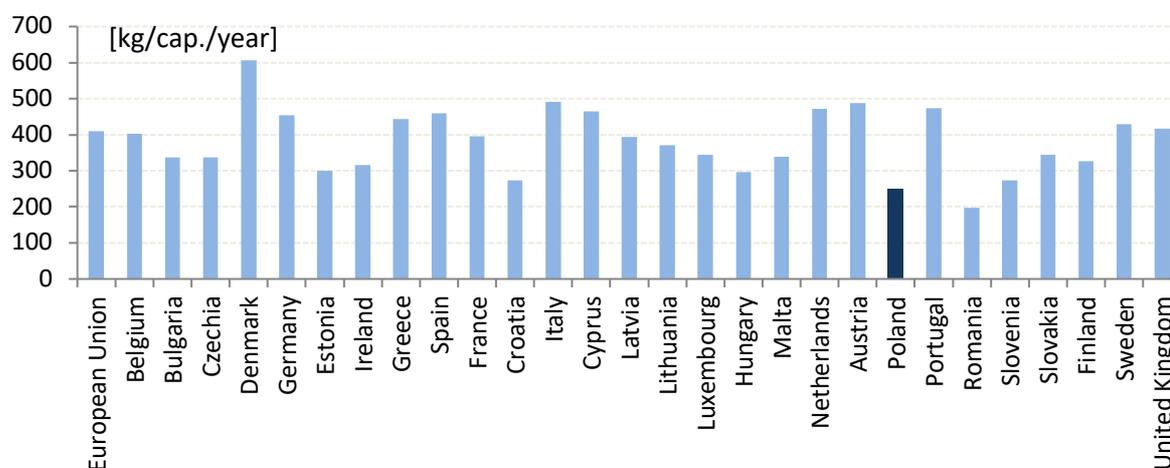

Fig. 2. Total mass of municipal solid waste per capita in the European Union in 2016

Fig. 3 shows the recycling rate of municipal waste in the European Union in 2018 [11]. The target of the recycling rate was achieved by many countries. However, some of them including Poland managed to recycle only about 30% of the resources from waste. Germany, Austria, Netherlands, Slovenia and Belgium are the countries with the highest recycling rate – above 50%.

Another element of the waste management system is the collection of waste electrical and electronic equipment (WEEE). Directive 2012/19 / EU introduces a number of significant changes in the organization of the collection of this equipment. First of all, the percentage WEEE collection rates that each country will have to achieve are increased. Member States are to ensure that the volume of collected WEEE increases gradually over the period from 2016 to 2019. From 2019, the minimum annual collection rate to be achieved will be 65% of the average weight marketed in the three previous years in a given Member State, or alternatively, 85% by weight of WEEE produced in that Member State. Poland (as well as several other countries), due to shortages of the necessary infrastructure and low level of WEEE collection, will be able to postpone the deadline to reach levels by August 14, 2021 [9].

The new collection rules have essentially contributed to the increase in collection costs. This applies to the collection of waste categories that have not been previously collected, for example, ash, or the possibility of giving an unlimited amount of waste of any kind [21]. Other factors affecting the waste collections include an increase in the amount of waste collected from all waste groups and a change in the location of waste collection (collection directly from the estate – or kerbside collection), a necessity to approach the property in many cases, which significantly affects the duration of the entire collection [19]. A new way of returning bulky waste and WEEE has become the novel method of collection of waste – on demand of a resident [18,20]. Mixed municipal waste due to the need to send to RIPOK installations is subject to additional fees and secondary raw material prices on the market are unstable. For this reason, the economic efficiency of collection is subject to

considerable fluctuations. In addition, information campaigns for residents regarding the new system were not conducted in a way that broadly reaches the society, which meant that the companies collecting waste encountered various problems in the collection [24].
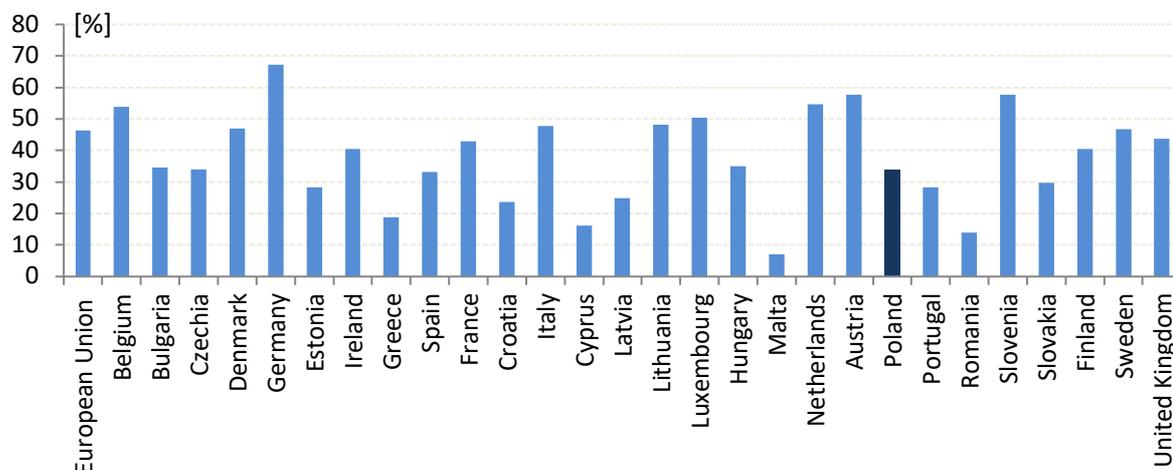

Fig. 3. Recycling rate of municipal waste in the European Union in 2018

The main goal guiding this study focuses on investigating the difference for a five-year period in the collection rate for the individual waste streams from households. The waste stream data and practical approach towards waste collection were possible by the exploration of the sources of the Transgór company and regional collection centres. The experiences from each year's municipal waste collection helped in adjustment and corrections of the waste management practices, proposing the collection schedules and cost calculations. This comparative study provides an inside view of the waste collection system of urban and rural communities after the introduction of a new law in Poland and also highlights problems when the external costs change. The new legislation complies with the requirements of the European Union towards the implementation of a circular economy and gradual increase in the recycling rate for individual waste streams of separated waste.

This study will analyse the functioning of the municipal waste collection system in two municipalities – Jastrzębie-Zdrój, Wodzisław Śląski, and the rural commune Marklowice, in the Śląskie Voivodship in Poland, in the period 2014-2018.

2. CHARACTERISTICS OF WASTE COLLECTIONS IN COMMUNITIES IN POLAND

Vehicles and employees are essential elements to run waste collections. Due to the division of waste into quite large number of categories in terms of raw material contents and overall dimensions, it is necessary to use specialized or regular vehicles [3,23]. Each of the vehicles is operated by a crew of two or three people. Table 2 presents the basic parameters of vehicles participating in waste collection in the analysed municipalities.

Due to the multiplicity of categories of waste, the schedule and frequency of waste collection in municipalities were set at the meetings of the local authorities. There is a distinction between mixed waste, waste from selective collection as well as bulky waste and WEEE [4,5]. This is presented in table 3.

Waste collections in households are conducted by providing replacement bags or containers. The methods of collecting waste in both types of communes are presented in table 4. The size of the vehicle's payload capacity determines the number of premises serviced and the need to return to the base and unload the collection vehicle.

The total economic efficiency of the collection will depend on the difference in revenues and costs in the waste management system [1]. The proposed model in this paper includes all external and operational costs and revenues. The income group includes the residents' fee for waste disposal and the

income of sales of secondary recyclable materials to recycling companies. The costs will depend on the components related to transport, human resources (employees) and additional fees: environmental and waste storage or treatment in RIPOK. The W_{ez} (1) economic efficiency indicator can be expressed on the basis of [21] as follows:

Table 2

Specification of the waste collection vehicles including the number of personnel

Type of a vehicle	Gross vehicle weight [kg]	Payload weight [kg]	Payload capacity [m³]	Average fuel consumption [l/100km]	Number of personnel
Three-axle garbage truck	26000	10200	24	60	3
Two-axle garbage truck	19000	8140	16	42	3
Two-axle garbage truck	3500	1360	5,5	17	2
Van	3500	380	19	17	3

Table 3

Waste collection schedules in municipalities in the Silesian Region in Poland

Category of waste	Schedule of waste collection	
	Rural communities	Urban municipalities
Mixed municipal waste	Once per month (Nov. - Apr.); Twice per month (May – Oct.);	Houses: Once per month (Nov. - Apr.), Twice per month (May – Oct.); Multi-storey buildings: 3 times per week
Separated waste (paper, glass, plastics)	Once per month	At least once per month
Bulky waste	Once per year or Twice per year	Once per year; Twice per year as kerbside collection
Waste electrical and electronic equipment	Once per year; or twice per year	Once per year; or twice per year as kerbside collection
Biodegradable waste	Once per month (Jan.-May) and (Oct.-Dec.); Twice a month in Jun.-Sep.	At least Twice a month (Apr. – Nov.) Remaining months once per month
Construction and demolition waste	Kerbside collection or collection on demand to ordered container	Own transportation of the waste to Municipal Collection Centre

Table 4

Methods of storage of various categories of waste in urban and rural municipalities

Waste category	Collection method
Mixed municipal waste	Containers of capacity 110-1100 litres
Ash	Containers of capacity 110-1100 litres
Separated waste (plastic, glass, paper)	Bags 80-120 litres / Containers 1,5-2,5 m³
Biodegradable waste	Bags 80-120 litres
Bulky waste	Kerbside collection
Waste electrical and electronic equipment	Kerbside collection
Construction and demolition waste	Containers of capacity 5-7 m³

$$W_{ez} = (\sum_{j=1}^{l} p_j + \sum_{i=1}^{m} p_i) - (\sum_{c=1}^{n} k_c^z + \sum_{d=1}^{t} (k_d^{sk} + k_d^{sr})), \qquad (1)$$

where: W_{ez}– economic efficiency of waste collection [PLN], p_j – revenue from the fee for collecting waste from the j-th commune's inhabitant from [PLN], p_i – revenue from the sale of the i-th secondary raw material [PLN], l –number of inhabitants in the municipality, m –number of secondary raw materials for sale, n –number of collected waste categories, t –number of tonnes of waste, k_c^z – a component of collection costs of the c-th waste category [PLN], k_d^{sk} – costs of landfilling [PLN], k_d^{sr} – costs of the environmental fee of d-th tons of waste [PLN].

3. CHARACTERISTICS OF MUNICIPALITIES IN A CASE STUDY FOR WASTE COLLECTION ANALYSIS

Jastrzębie-Zdrój is a city located in the Silesian Region in the south of Poland. It covers an area of about 86 km^2. Within the administrative boundaries of Jastrzębie-Zdrój, there are six village administrative units and fifteen housing estates with flats in multi-storey buildings. The population of Jastrzębie-Zdrój is around 90.000 inhabitants. On the basis of the submitted waste declarations registering participation system and obligation to pay the municipal waste management fee, the number of people living in the city in 2017 was about 80.000 (as of December 2017). The estimated number of residential real estates is 6.595 properties developed with single-family buildings and 330 properties built with multi-storey buildings. For this reason, most households (around 26.000) are located in blocks of flats [30]. Wodzisław Śląski is located in the south of the Silesian Region. It covers an area of 49.5 km^2 and is divided into 9 districts. The number of inhabitants in 2015 was about 49.000 inhabitants. The structure of households includes about 4,500 single-family houses and 16.500 apartments, which gives about 20.000 households [22, 29].

Marklowice is a commune in the Silesian Region, which belongs to Wodzisław Śląski, the main municipality. The commune has an area of 13.76 km^2, and the population of Marklowice is about 5.500 inhabitants. The number of residential properties on which municipal waste is generated is 1252 [28]. The location of the three municipalities covered by the study is presented in Fig. 4.
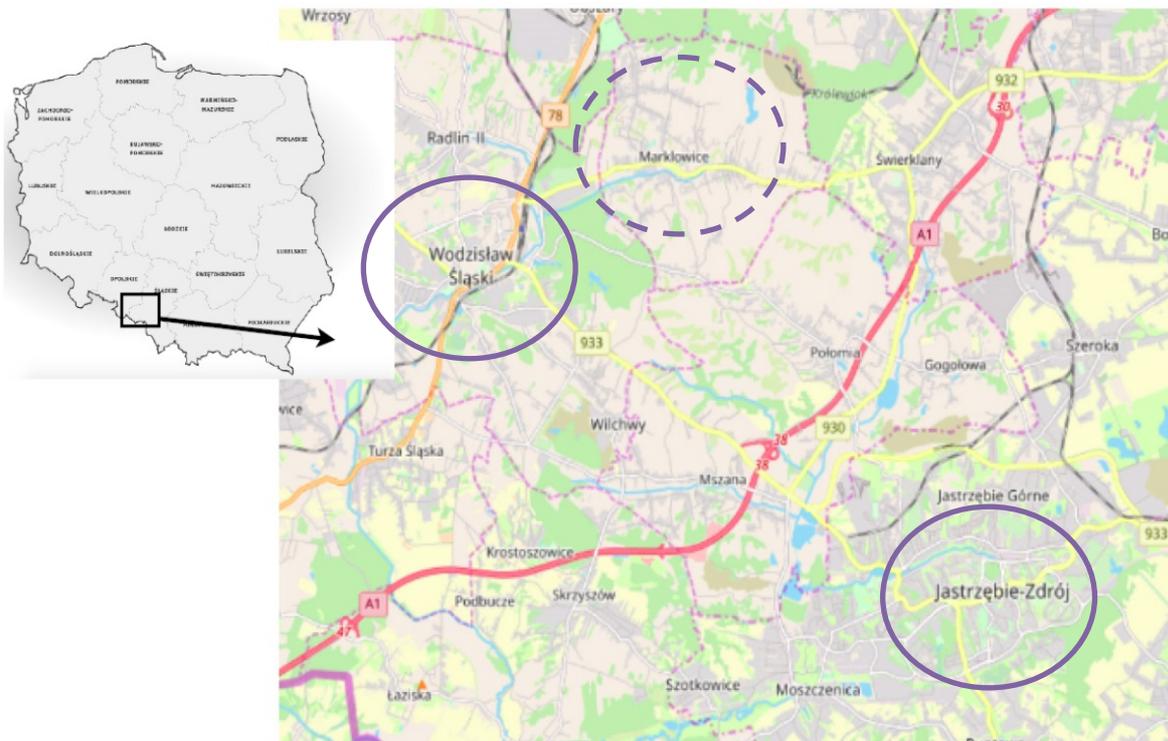

Fig. 4. Map including municipalities in the case study (urban municipalities Wodzisław Śląski and Jastrzębie-Zdrój, and rural community Marklowice)

4. RESULTS OF ANALYSIS OF THE REVENUE, COSTS AND SIZE OF THE WASTE STREAM

The main revenues related to the waste management system include payments from residents (waste collection fee). Due to the increase in the costs of servicing the collection system, the municipalities decided to increase it, and above all to increase the fee for the collection of mixed waste. The rates of fees are presented for individual municipalities in Tables 5-7.

Table 5

Waste collection fees for residents in the years 2014-2018 in Wodzisław Śląski [5]

Year	Municipal waste collection fee [PLN/person/month]	
	Residents declared separated collection of the waste	Residents refused to separate waste
Till 31.03.2014	7,60 - flats in multi-storey buildings 8,30 - single-family house	14,00
From 01.05.2014	8,30	16,00
2015	10,80	18,00
2016	10,80	18,00
Till 30.06.2017	10,80	18,00
From 01.07.2017	12,00	20,00
2018	12,00	20,00

Table 6

Waste collection fees for residents in the years 2014-2018 in Jastrzębie-Zdrój [4]

Year	Municipal waste collection fee [PLN/person/month]	
	Residents declared separated collection of the waste	Residents refused to separate waste
Till 31.03.2014	9,00	12,00
From 01.05.2014	7,00	14,00
2015	7,00	14,00
Till 31.01.2016	7,00	14,00
From 01.02.2016	9,00 – single-family house 12,60 - flats in multi-storey buildings	16,00 – single-family house 19,60 - flats in multi-storey buildings
2017	9,00 – single-family house 12,60 - flats in multi-storey buildings	16,00 – single-family house 19,60 - flats in multi-storey buildings
Till 31.03.2018	9,00 – single-family house 12,60 - flats in multi-storey buildings	16,00 – single-family house 19,60 - flats in multi-storey buildings
From 01.04.2018	12,00	20,00

Table 7

Waste collection fees for residents in the years 2014-2018 in Marklowice [27]

Year	Municipal waste collection fee [PLN/person/month]	
	Residents declared separated collection of the waste	Residents refused to separate waste
2015	7,00	15,00
2017	9,50	25,00
2018	11,00	30,00
2019	15,50	42,00

The second source of income is the sale of secondary raw materials collected in selective collection. These materials can be sold to recycling companies. Over the last five years, there have been significant fluctuations in the prices of raw materials (table 8). Currently, an increase in purchase prices can be observed only for a few groups of packaging waste, e.g. PET (polyethylene terephthalate) bottles and fractions derived from household chemistry products and packaging.

Table 8

Change of the prices of secondary raw materials in 2014-2018

Type of secondary raw material from the separate waste collection	Year				
	2014	2015	2016	2017	2018
	[PLN/tonne]				
PET – transparent	1300	1350	1450	1400	2200
PET – non-transparent	1200	1300	1000	1000	1200
Foil transparent	1100	1100	1200	1000	800
Foil - non-transparent	600	650	700	600	200
Plastics from household chemistry products	800	850	800	1000	1350
Glass	50	50	50	60	60
Paper	350	350	350	400	250
Mixed fraction (recyclable)	300	300	300	300	300

In the last five years, a significant increase in transportation costs related to the use of vehicles and personnel costs can be observed. This is due to the increase in wages and vehicle maintenance prices.
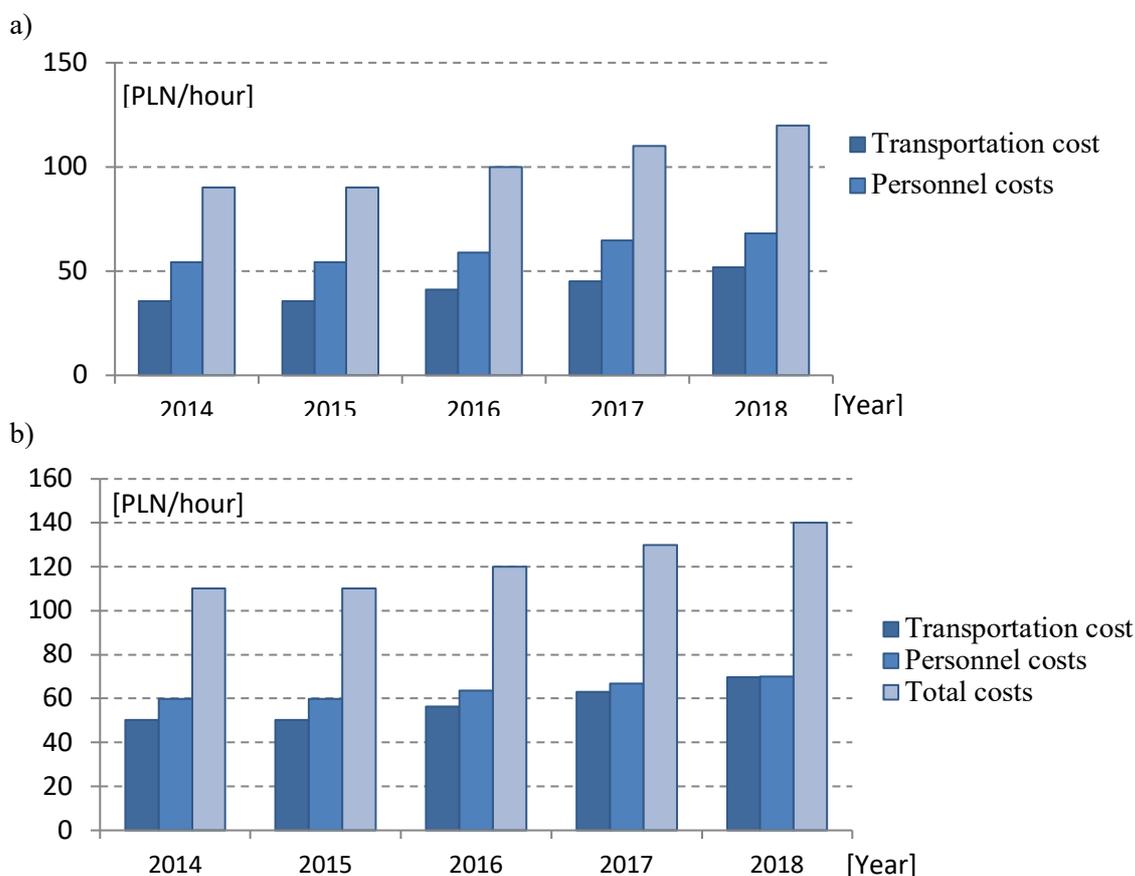

Fig. 5. Waste collection and transportation costs [PLN/hour] (a-lorry, b-garbage truck) in 2014-2018

The results of the analysis of transport costs (servicing vehicles with the crew), as well as the costs of environmental and landfill fees are presented in Figures 5 and 6.
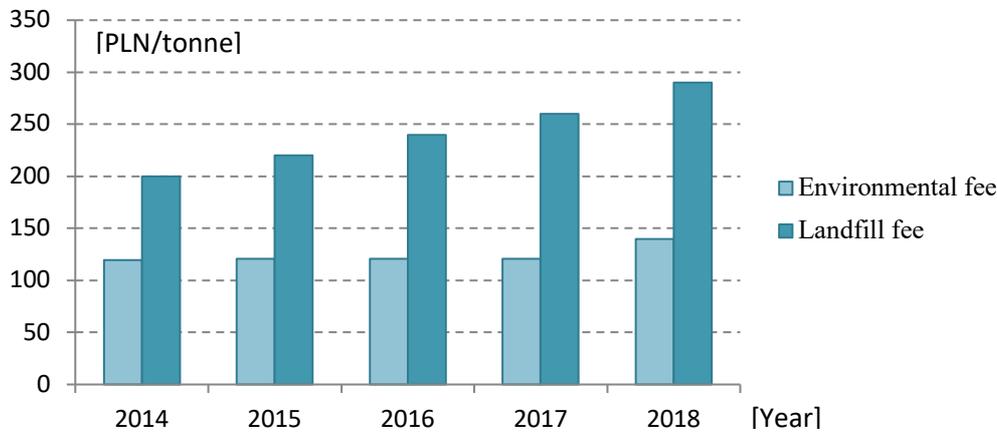

Fig. 6. Environmental and landfill fees [PLN/tonne] in 2014-2018

The length of routes for bulky waste collection depends on the number of collection calls. On-demand or kerbside collection routes were about 60-70 km in Jastrzębie-Zdrój, respectively; in Wodzisław Śląski, it was about 160 km. The routes consist of 2-5 courses including return and unloading the waste in the company base. The collected average mass of bulky waste is on average 1.3 tons. On the other hand, waste from selective collection requires a route of about 90 km for a working day. A large differentiated waste stream can be read out from the graphs (Fig. 7a and 7b) for individual municipalities. Since 2015, in the rural community Marklowice, a new category of waste was selected for separation from a household waste stream: ash. The majority of houses use hard coal for heating and, therefore, it was important to propose additional waste bins for the collection to exclude this fraction from the mixed-waste stream. This is highlighted in Fig 7b.
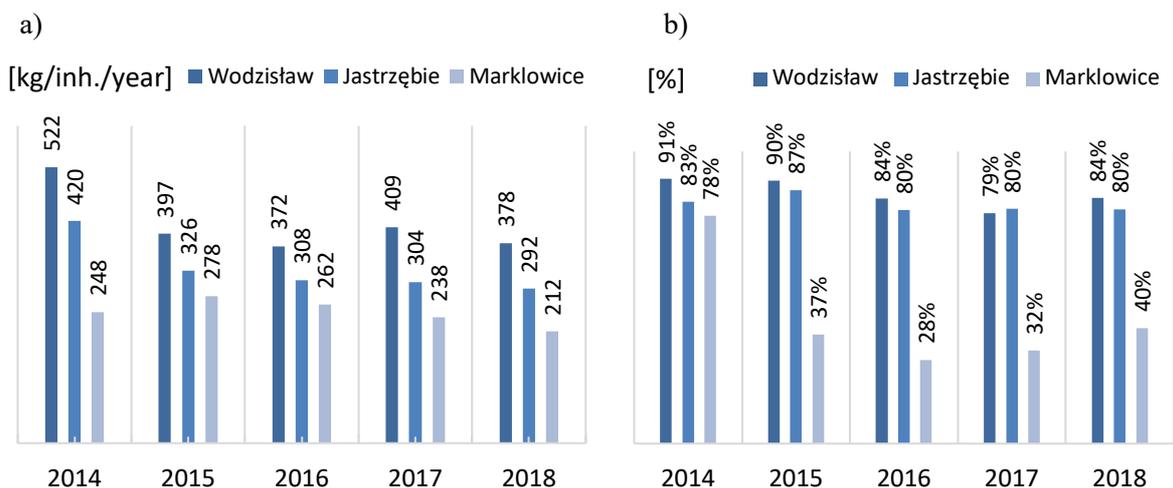

Fig. 7. Total mass of waste collected in municipalities [kg/cap./year] (a) and proportion of mixed-waste collection to total mass of waste (b) in 2014-2018

A comparison of the results of the collection with the average mass per capita in Poland [12] is shown in Fig. 8. The results indicate higher collection rates for recyclable materials from the separate waste collection. It ranges from 10% higher than average in Poland for Jastrzębie-Zdrój up to 50% for Marklowice. The separated collection of paper, plastics and glass in the rural community is mainly

from single-family houses. Therefore, each household takes responsibility for the contents of a waste bag. In the towns or cities, it is more anonymous activity with collection to larger waste bins. Therefore, it is common to mix the categories of waste or separate only a small fraction of the waste.

The difference in the size of the waste stream from urban municipalities as compared to the rural commune is also characteristic. In addition, a low share of mixed waste can be stated as compared to the total weight of waste in Marklowice. This result may indicate a greater involvement of residents in the selection of waste. In cities, however, the share of waste is mixed at a high level and has decreased by several percent over recent years.

The economic efficiency for an urban municipality Wodzisław Śląski and a rural community Marklowice is presented in table 9. In both cases the main income are waste collection fees from residents. Additional income from sale of the secondary materials is relatively low. Increase of this income component would depend on larger mass of the collected waste and future market price of the secondary raw materials.
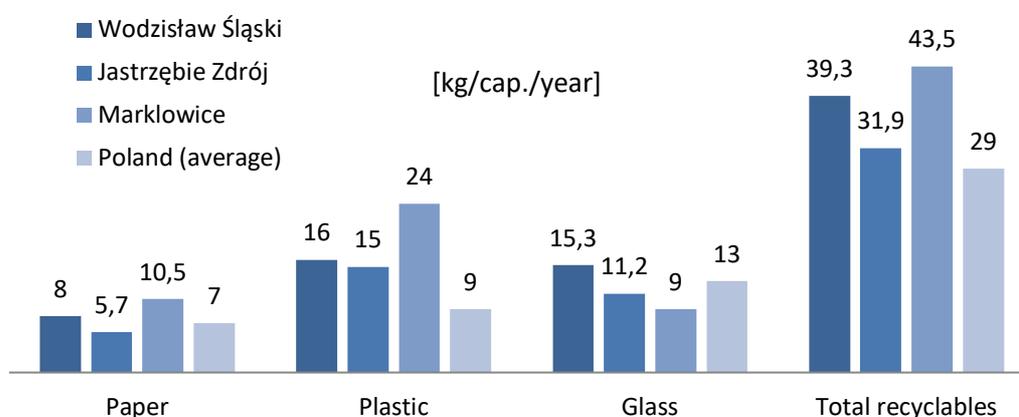

Fig. 8. Comparison of collected mass of paper, plastics and glass per capita for Poland and three communities from this study in 2018

Table 9

Total costs, revenues and economic efficiency for rural and urban municipalities in 2018

Municipality	Income [PLN]			Costs [PLN]			W_{ez} [PLN]	W_{ez} [PLN/cap]
	Waste collection fee	Raw materials sale	Total	Administration and landfill	Logistic costs	Total		Per capita, selective collection
Marklowice	720.600	156.900	877.500	190.800	426.200	617.000	260.500	52
Wodzisław	6.800.000	498.000	7.298.000	4.685.000	2.306.000	6991000	307.000	7.4

The results show variations in collected separated waste depending on an urban or rural community. Although the frequency of waste collections fulfils the requirements to collect the mass and volume for each fraction for all locations in the study, additional effort is necessary to improve the collection rate for urban settlements. Additional information campaigns are necessary for all age groups. The present practice in education is limited to school education. Therefore, the target group is limited to 14 or a maximum 18 years of age. In urban communities, additional research needs to be provided for the location and proximity of separated waste bins or containers. Some residents were discouraged by the separation of waste due to limited space in a flat. Many flats in the investigated

locations in this study have small-size kitchens and it is impossible to place bins for all categories of waste.

Different variables influence and determine the recycling behaviour of householders. They can be classified as socio-psychological, technical-organizational and individual socio-demographic. The strongest predictors of householders' recycling behaviour were identified as being convenience, moral norms, information and environmental concern [16]. It can be observed that local authorities are using behaviour-change interventions to encourage the public to recycle. It should include three key elements infrastructure, service and behaviour [25]. A review on recycling determinants for urban waste collection proposed that social modelling and environmental alterations were the most effective techniques [26]. Understanding the main social factors influencing household recycling behaviour and key motivation drivers for behavioural change of household residents need to be implemented both by practitioners and by policy-makers [14].

5. CONCLUSIONS

Based on the analysis of the economic efficiency of household waste collection in urban municipalities Wodzisław Śląski, Jastrzębie-Zdrój and a rural community Marklowice, the following conclusions can be drawn:

- there are significant differences in the size of the waste stream generated in urban municipalities and the rural commune. There is a declining trend in the amount of waste generated in households. At the same time, a clear difference can be observed in favour of the rural commune in separate collection of waste. The waste stream originating from mixed waste in relation to the total mass of collected waste is about 40%, whereas in municipal municipalities, it is about 80%; therefore, the economic efficiency from separated waste secondary waste materials sale is in favour of the rural community;
- transport and collection costs have increased over the past five years. This applies to any type of vehicle. At the same time, due to the increase in the number of categories of waste collected, vehicles from collecting companies must travel longer routes;
- administrative fees for landfill and environmental fees increased and therefore the fees for collection of waste had to be increased for residents;
- purchase prices of secondary raw materials undergo large fluctuations. Therefore, the inclusion of this component of revenues in the balance sheet contains considerable uncertainty and it is also difficult to include it in the forecasting model for the collecting company; and
- compared to the average collected separated waste in Poland, in three municipalities, the total mass of separated waste was higher, ranging from 10 to 50%. Randomly rising costs in the fiscal year are the most difficult barrier for collection companies. As a result, the estimation of the efficiency is difficult and mainly may affect rising costs of the waste collection for each household.

Future work should focus on finding factors driving behavioural habits of the residents from urban municipalities and rural communities. Such results would be helpful for practitioners for the adoption of more effective collection schedules depending on the location and types of residence.

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