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Urban nitrogen cycles: new economy thinking to master the challenges of climate change

D6/2: Waste uncertainty

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Dissemination Level		
PU	Public	☒
PP	Restricted to other programme participants (including funding agencies)	☐
RE	Restricted to a group specified by the consortium (including funding agencies)	☐
CO	Confidential, only for members of the consortium (including funding agencies)	☐

Executive Summary

The calculations of nitrogen emissions from the management and treatment of waste and wastewater use a lot of data that lack established and reliable sources, and the quantifications are often based on assumptions. Therefore, it is important to include the uncertainty in the calculations of all flows (Winiwarter and EPNB, 2016). This document provides assumptions for the calculation of the uncertainty in the calculation of nitrogen emissions from sewage treatment plants and waste treatment plants based on the guidance provided in Deliverable 2.2.

1. Introduction

The dynamics of changes in physico-chemical processes and socio-economic phenomena make it difficult to obtain reliable and complete data for modeling pollutant emissions in waste and sewage management. In order to validate the model calculations, it is necessary to take into account the uncertainty of the input parameters. Uncertainty is inherent in physical and chemical measurements. It is also related to the model itself, which often maps real processes in a simplified manner.

Both complex and simplified models can introduce uncertainty, including both bias and random error (IPCC, 2019). As a good practice, emissions calculations should be accurate in the sense that they neither systematically overstate nor underestimate actual emissions or reductions as far as this can be assessed, and should be as precise as practicable (IPCC, 2019).

The general approach to uncertainty estimation is discussed below, using the example of the Waste Treatment Plant and the Sewage Treatment Plant in Zielona Góra. An integral part of this study is Appendix No. 1 on: Waste management in Zielona Góra in 1995-2030 and Appendix No. 2 on: Balance and nitrogen emissions from wastewater treatment systems in the Zielona Góra agglomeration in 2007-2020.

2. Municipal solid waste

Municipal Solid Waste (MSW) includes waste from households, commerce, industry, institutions, street sweeping, construction and demolition, and sewage treatment plants. The MSW stream includes recyclable materials (paper, plastic, glass, metals, etc.), toxic substances (paints, pesticides, used batteries, medicines), compostable organic matter (fruit and vegetable peels, food waste) and contaminated waste (blood-stained cotton, sanitary napkins, disposable syringes), medical and veterinary waste (Kolektar et al., 2016).

The amount of nitrogen emission from waste depends on the mass of generated individual classes of waste, their physical and chemical composition, the scope of separate collection and the methods of their processing and the amount of raw materials recovery. The physical and chemical components of waste and their mass depend on many factors, such as: eating habits, standard of living, degree of commercial activity, season, dynamics of economic development, cultural conditions, technical and sanitary equipment, type of industry and its efficiency, etc. The qualitative and quantitative characteristics of waste change at different levels of data aggregation, ranging from clear differences between European Union countries, through differences in individual regions, to smaller units: voivodships and cities.

The amount of data on the volume of waste generated and its composition is not always available. Hence, these values are determined based on the number of inhabitants, unit waste production per capita during the year and the adopted percentage shares of the respective waste classes. Additionally, the scope of selective waste collection and material recovery should be assumed.

The forecast of the quantity and quality of waste is made based on two indicators:

- population growth rate - with the increase in the number of inhabitants, the number of waste producers increases, the amount of waste in the production of goods to satisfy the needs of the population increases
- Gross Domestic Product index - the consumption model, and thus the amount and composition of the generated waste, changes with the increase or decrease of GDP.

Both indicators are important for the increase in the amount of municipal waste generated both in households and in other sectors of public life (trade, services, etc.). However, the rapidly changing socio-economic conditions increasingly make waste production independent of economic growth. Hence, when forecasting the volume of waste production and its composition, the significance of this correlation should be checked.

Annex No. 1 presents the method of determining the quantity and quality of waste for the city of Zielona Góra along with the forecast values.

Table 1 shows the parameters considered when calculating nitrogen emissions from the waste treatment plant in Zielona Góra. General scheme of nitrogen flow in the MBP in Zielona Góra is shown in Figure 1.

Table 2 presents the assumptions for the calculation of the uncertainty in the estimation of nitrogen emissions from waste.

Table 1. Parameters considered when calculating nitrogen emissions from the waste treatment plant in Zielona Góra

Point	Waste stream	Description
1.1.	Input (MSW)	Mass of waste delivered to the mechanical biological treatment (MBT) installation
1.1a.	Waste composition	Dry matter – 65%; dry organic matter (DOM) given as % dry matter (DM) – 38% DM; N – 1.0% DM (household waste contains 0.8-1.1% N in DM)
1.2.	OFMSW (fraction<80mm)	Separation on a sieve 80 mm allows to quantify the “under the sieve fraction” (OFMSW - organic fraction of municipal solid waste) - it constitutes 60% of the mass of incoming waste (range 50.8-71.8%).
1.2a.	Waste composition	M – 45%; DOM – 43,3% DM; N – 1,0% DM
1.3.	fraction >80mm	Over the sieve fraction - it constitutes 40% of the mass of incoming waste
1.3a.	Waste composition	RDF (high calorie fraction) – it constitutes 36% of the mass of incoming waste, M – 5%, DOM – 36% DM, N – 1,34% DM

		Metal: quantity – 4%; M – 5%; DOM – 10% DM; N – 0% DM
1.4.	Stabilized waste	The reduction of organic mass in the biostabilization process was 50%
1.4a.	Stabilized waste composition	quantity – 43%; M – 40%; DOM – 28% DM; N – 0,97% DM
2.1.	Air emission	NH_3 emission - 0.504 kgN/Mg (range: 20 - 40 mg/m^3; 30 mg/m^3 was assumed). The air demand in the biostabilization process was assumed -10 m^3/ Mg*h) and the duration of the process - 10 weeks (8-12 weeks) N_2O emission - 1.176kg kgN/Mg (range: 11 - 110 mg/m^3; assumed 70 mg/m^3)
2.2.	Emission from wastewater	Calculated on the basis of the amount of wastewater generated in the biostabilization process (range 260-470 dm^3/Mg; assumed 350 dm^3/Mg) and total nitrogen concentration in wastewater (range 70-8449 mgN/dm^3; assumed 1000 mgN/dm^3).
2.3.	Air emission from landfill	Ammonia emission assumed: 0.008 kgN/Mg of waste Ammonia emission from Mg of waste delivered to the MBT installation - 0.004 kgN/Mg
2.4.	Leachate	Emissions from waste after MBP Ammonia concentration in the leachate: 570 mg/dm^3 Total nitrogen emission in the leachate: 0.6-2.4kg/Mg DM (1.5 kg/Mg DM was taken) Total nitrogen emission from Mg of waste delivered to the MBT installation - 0.4 kgN/Mg Emission from unprocessed waste: Ammonia concentration in leachate: 750 mg/dm^3 Total nitrogen concentration in leachate: 1250 mg/dm^3 Total nitrogen emission in the leachate: 2.4-4.6 kg/Mg DM (3.5 kg/Mg DM was taken)

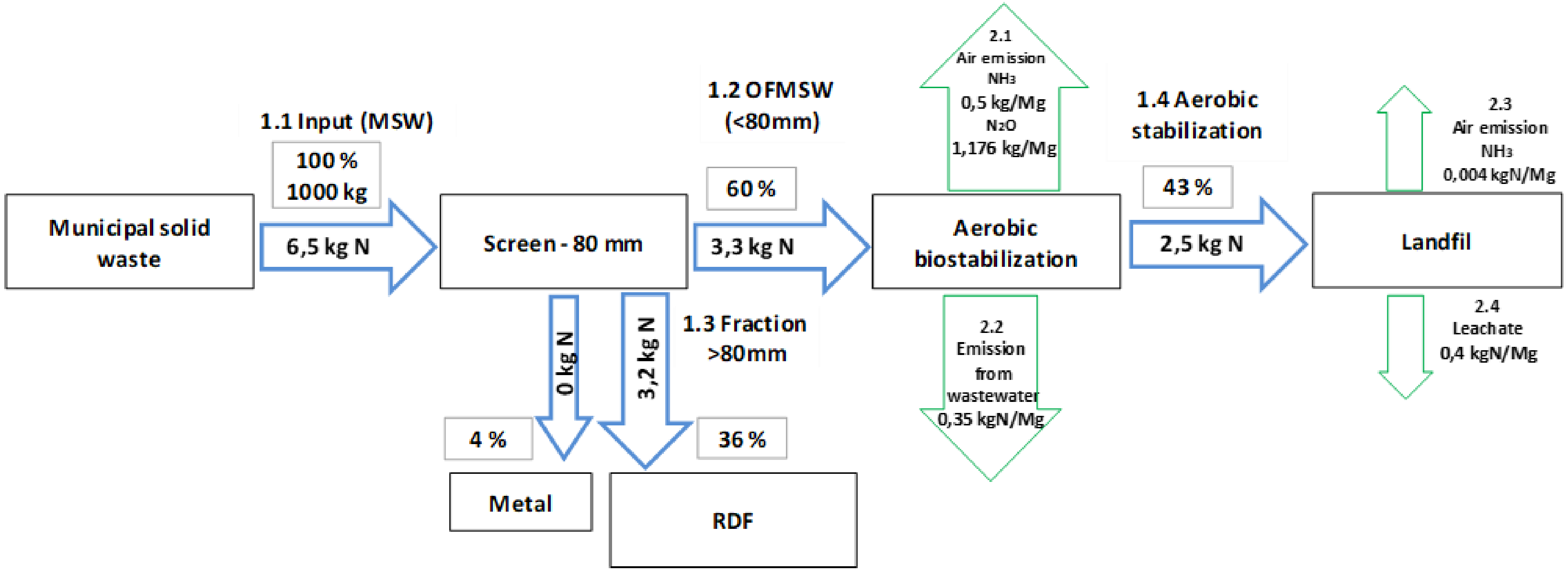

Fig.1. General scheme of nitrogen flow in the MBP in Zielona Góra

Table 2. Assumptions for calculating uncertainty in estimating nitrogen emissions from waste

point	Sample size	level	source	mean	UF	RSD	SD	SE
1.1	N>2	-	current official statistics, measurement data, data from appropriate literature	$\frac{1}{N}\sum_{i=1}^{N} x_i$	-	-	$\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-\mu)^2}$	$\frac{SD}{\sqrt{N}}$
1.1a	N=1	2	expert estimates	x	1.33	0.145	RSD*x	
1.2	N=1	1	data from appropriate literature (Jędrczak)	x	1.10	0.048		
1.2a	N=1	2	expert estimates	x	1.33	0.145		
1.3	N=1	1	data from appropriate literature (Jędrczak)	x	1.10	0.048		
1.3a	N=1	2	expert estimates	x	1.33	0.145		
1.4	N=1	1	data from appropriate literature (Jędrczak)	x	1.10	0.048		
1.4a	N=1	2	expert estimates	x	1.10	0.048		
2.1	N=1	1	data from appropriate literature (Nguyen Thanh Phong)	x	1.10	0.048		
2.2	N=1	1	data from appropriate literature (DEFRA)	x	1.10	0.048		
2.3	N=1	1	data from appropriate literature (Nguyen Thanh Phong)	x	1.10	0.048		
2.4	N=1	1	data from appropriate literature (DEFRA)	x	1.10	0.048		

3. Wastewater

The quantity and composition of municipal wastewater, including the content of nitrogen compounds, as in the case of waste, is correlated with population and socio-economic growth, as well as with cultural changes. The composition of wastewater and the amount of nitrogen flowing to the treatment plant additionally depends on the parameters of the sewer network (its length, slope, number of pumping stations) affecting the degree of nitrogen degradation in the network (Henze et al., 2000).

Thus, the sources of nitrogen emissions from wastewater are the sewer network and the nitrification/denitrification or nitrification biological reactor at the wastewater treatment plant (IPCC, 2019).

However, the most common assumption is that the amount of nitrogen decomposed in the sewer network to gaseous nitrogen is small.

A key parameter affecting nitrogen balancing at a wastewater treatment plant is the nitrogen load in the raw wastewater influent, which are most often determined by wastewater volume and total nitrogen concentration or unit nitrogen load per population equivalent.

The table (Table 3) summarizes parameters commonly used to design and model wastewater treatment and sludge management systems. They are derived from operational experience and can therefore be considered reliable. Parameters such as unit pollutant loads, water consumption per PE, unit volume of primary and surplus sludge are based on European guidelines (ATV-A 131). Also the concentration of nitrogen in the treated wastewater is determined according to the regulations. The population equivalent (PE) value is derived from statistical data provided by the wastewater treatment plant operator. Other data were obtained from literature sources and institutional reports, as well as from the results of various studies.

Based on the case study of nitrogen cycle analysis at the wastewater treatment plant in Zielona Góra (Table 3, Fig. 2) and the data adopted for calculations and their sources of availability, indications of SD and SE calculation method were determined for individual nitrogen balancing streams in the technological process of wastewater treatment and sludge treatment, as well as the emission of nitrogen compounds to the environment. These data are summarized in Table 4.

A detailed analysis of wastewater management in Zielona Góra and the methodology of calculating N fluxes at the WWTP are presented in Appendix 2.

Table 3. Nitrogen flow for the WWTP Zielona Góra

point	description	value	parameters
1.1	Input	795 Mg N/year	4,015 g N/PE/year, 11 g N/PE/day (PE - population equivalent)
		669 Mg N/year	annual inflow 11,796,000 m^3/year, average nitrogen concentration 57 g N/m^3
1.2	Mechanical treated wastewater	702 Mg N/year	3,546 g N/PE/year
1.3	Input to biological treatment	782 Mg N/year	3,948 g N/PE/year
1.4	Output	87 Mg N/year	10 g N/m^3, 120 dm^3/PE/day, 1.2 gN/PE/day

		80 Mg N/year	annual inflow 11,796,000 m^3/year, average nitrogen concentration 7 g N/m^3
2.1	Primary sludge	93 Mg N/year	469 g N/PE/year, 28 g DM/PE/day, 3.8% N in dry matter
2.2	Waste Activated Sludge	157 Mg N/year	1,723 g N/PE/year, 32 g DM/PE/day, 4 % N in dry matter
2.C	Sludge liquids	80 Mg N/year	402 g N/PE/year, 10% increase of nitrogen load compared to the load in raw sewage
3.1	N_2, N_2O losses to atmosphere during transport and treatment	539 Mg N /year incl. 1.94 Mg N_2O/year 0.85 Mg NH_3/year	0.0036 kg N_2O/kgN 4.3kg NH_3/PE/year
3.2	Nitrogen emission from wastewater and aquatic receiving environments	1.65 Mg N_2O/year	0.019 kg N_20/kg N

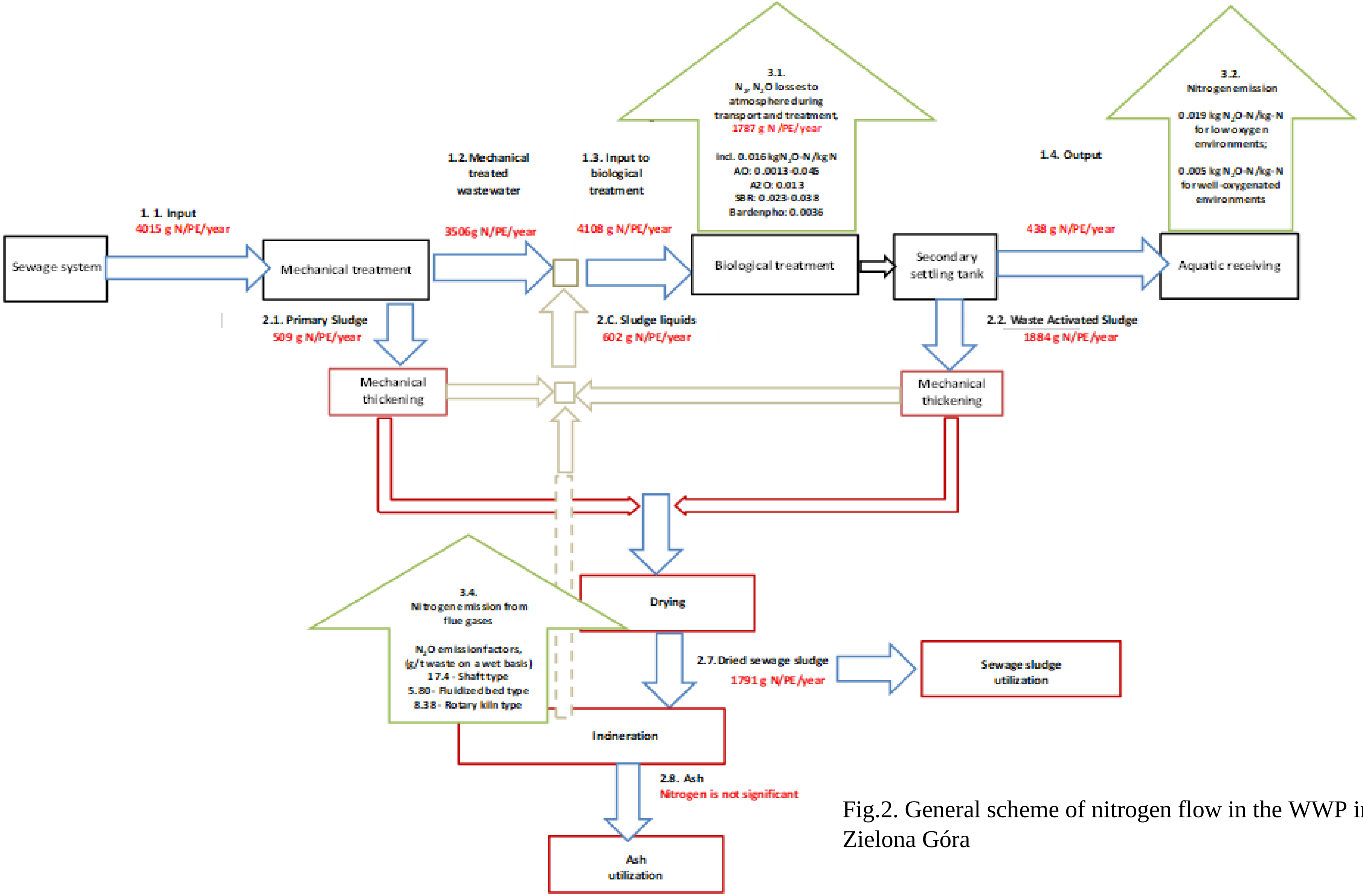

Fig.2. General scheme of nitrogen flow in the WWP in Zielona Góra

Table 4. Assumptions for the calculation of uncertainty in the estimation of nitrogen emissions from wastewater

point	parameter	Sample size	level	source	mean	UF	RSD	SD	SE
1.1	PE	N=1	1	current official statistics from measurements data	x	1.1	0.048	RSD*x	$SD/\sqrt{N}$= SD
	11 gN/PE/day	N=1	2	design guidelines	x	1.33	0.145		
1.2/2.1	PE	N=1	1	current official statistics from measurements data	x	1.1	0.048		
	28gN/PE/day	N=1	2	design guidelines	x	1.33	0.145		
	3.8% N/dry matter	N=1	1	data from appropriate literature, measurements data (Tezel)	x	1.1	0.048		
1.3/2.C	PE	N=1	1	current official statistics from measurements data	x	1.1	0.048		
	10% increase of nitrogen load	N=1	2	design guidelines (ATV)	x	1.33	0.145		
1.4	10 gN/m^3	N=1	1	variable value depending on WWTP location and legal requirements	x	1.1	0.048		
	0,120 m^3/PE/day	N=1	2	design guidelines	x	1.33	0.145		
	PE	N=1	1	current official statistics from measurements data	x	1.1	0.048		
2.2	PE	N=1	1	current official statistics from measurements data	x	1.1	0.048		
	32gN/PE/day	N=1	2	design guidelines	x	1.33	0.145		
	4% N/dry matter	N=1	1	data from appropriate literature, (Tezel)	x	1.1	0.048		
3.1	0,0036 kg N_2O-N/kgN	N=1	1	data from appropriate literature (IPCC)	x	1.1	0.048		
	4,3kg NH_3/PE/year	N=1	1	data from appropriate literature (Samuelsson)	x	1.1	0.048		
3.2	0,019 kg N2O/kg N	N=1	1	data from appropriate literature (IPCC)	x	1.1	0.048		

4. Summary

Parameters used to calculate nitrogen emissions from waste and wastewater treatment plants are characterized by large data uncertainty associated with the high temporal variability of parameters affecting nitrogen emissions and the complexity of biochemical processes.

The amount of nitrogen emission from waste depends on the mass of generated individual groups of waste, their physical and chemical composition, the scope of separate collection and the methods of their processing and the amount of raw materials recovery.

Nitrogen emissions from sewage depend on the quantity and composition of the sewage and the technological solutions applied at the sewage treatment plant, including the type of sludge management applied.

The physical and chemical components of waste/sewage and their mass depend on: eating habits, standard of living, degree of commercial activity, season, dynamics of economic development, cultural conditions, technical and sanitary equipment, type of industry and its efficiency, etc.

The qualitative and quantitative characteristics of waste/sewage change at different levels of data aggregation, starting from clear differences between EU countries, through regional differences to smaller units: voivodships and cities.

The amount of available data on waste/sewage generation and composition is often insufficient. Therefore, these values are often determined on the basis of the number of inhabitants, the unit waste/sewage production per inhabitant per year, the assumed percentages of the different waste groups and the assumed concentrations of pollutants produced by the inhabitant per year.

The calculation of uncertainties for individual nitrogen streams in waste treatment and wastewater treatment facilities lends validity to the results obtained.

5. Literature

1. ATV-A. 131—The dimensioning of single-stage sewage treatment plants with activated sludge; German ATV-DVWK Rules and Standards: Hennef, German, 2000.
2. Cheba K. Prognozowanie zmian wytwarzania odpadów komunalnych 2012 Econometrics 4 (38) ISSN 1507-3866
3. IPCC (2019): Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Edited by Buendia E.C., Tanabe K., Kranjc A., Jamsranjav B., Fukuda M., Ngarize S., Osako A., Pyrozhenko Y., Shermanau P. and Federici S. IPCC, Switzerland.
4. Henze M., Gujer W., Mino T. and van Loosdrecht M.C.M. (2000): Activated Sludge Models ASM1, ASM2, ASM2d and ASM3. Scientific and Technical Report No. 9., TWA Publishing, London, UK, 16-22.
5. Jędrczak A., 2007: Biologiczne przetwarzanie odpadów. Wydawnictwo PWN, Warszawa.
6. Kolekar K.A., Hazra T., Chakrabarty S.N., A Review on Prediction of Municipal Solid Waste Generation Models 2016, Procedia Environmental Sciences 35, pp.238 – 244
7. Kupper T., Bühler M., Gruber W., Häni Ch., Methane and ammonia emissions from wastewater treatment plants, A brief literature review, https://www.bafu.admin.ch
8. Nguyen Thanh Phong, Greenhouse Gas Emissions from Composting and Anaerobic Digestion Plants. Inaugural – Dissertation. Institut für Nutzpflanzenwissenschaften und Ressourcenschutz (INRES) Lehr-und Forschungsbereich Pflanzenernährung der Rheinischen Friedrich-Wilhelms-Universität zu Bonn, 2012. https://d-nb.info/104305586X/34.
9. Samuelsson J., Delre A., Tumlin S., Hadi S., Offerle B., Scheutz C. 2018. Optical technologies applied alongside on-site and remote approaches for climate gas emission quantification at a wastewater treatment plant. Water Res. 131: 299-309.
10. Tezel U., Tandukar M., and Pavlostathis S.G. 2011. Anaerobic Biotreatment of Municipal Sewage Sludge. In Comprehensive Biotechnology (2nd eds.), Moo-Young M. and Agathos S. (eds), Vol.6: 447-461, Elsevier Sci. LTD. (ISBN: 978-0-444- 53352-4
11. Winiwarter W, and Expert Panel on Nitrogen Budgets (EPNB). 2016. Detailed Annexes to ECE/EB.AIR/119 - "Guidance document on national on nitrogen budgets. pp. 12-13.

Deliverable 6/2

ANNEX No. 1

Waste management in Zielona Góra in 1995-2030

Prof. dr hab. inż. Andrzej Jedrczak

Waste management in Zielona Góra 1995-2030

Andrzej Jędrczak

Zielona Góra, 12.08.2020

1. Waste management policy, applicable law

The term municipal waste (OK) management refers to the collection, transport and treatment of waste, including the supervision of such activities, as well as the subsequent handling of waste disposal sites and activities performed as a waste dealer or broker [1].

The legal obligations for the management of municipal waste (household and similar waste) are set out in the Waste Framework Directive [2]. It lays down, inter alia, measures to protect the environment and human health by preventing and recycling waste and reducing the negative impacts of its management.

On 2 December 2015. The European Commission published a closed loop economy package. It consisted of the Communication 'Closing the loop - An EU roadmap for a closed loop economy (with annex) and a proposal - a legislative proposal to amend 6 waste directives [3].

On 18 April 2018. The European Parliament adopted a new package on a circular economy, setting ambitious, legally binding EU targets for waste recycling and landfill reduction. On 14 June 2018, amendments to the waste management directives were published. These entered into force on 4 July 2018.

Through updated waste management legislation, the EU is promoting the transition to a more sustainable model known as the closed loop economy. This is a production and consumption model that extends the life cycle of products, components and materials, minimising waste disposal.

Among the most important changes introduced by the Closed Economy Package are:

- increasing the recycling rate of municipal waste to 55% by 2025, 60% by 2030 and 65% by 2035
- increase the recycling rate of packaging materials to 65% by 2025 and 70% by 2030
- obligation to implement separate collection of textiles, hazardous waste from 1 January 2025
- Reduce the amount of municipal waste landfilled to 10% by 2035, while several EU Member States (for example Austria, Belgium and Denmark) sent virtually no municipal waste to landfills in 2014, Other Member States such as Croatia, Greece and Malta still landfill more than three quarters of their municipal waste)
- a ban on the deposit of separated waste;
- to reduce landfill of municipal waste to 10% by 2035
- the promotion of economic instruments to discourage landfilling.

The obligation to implement separate collection of bio-waste by 31 December 2023 is important, as well as the strengthening of the provisions on the "TEEP" clause from a technical, economic and environmental point of view. The position also confirmed the phase-out of mechanical biological treatment (MBT) by 1 January 2027.

In addition, the Circular Economy Package encourages a 30% reduction in food waste by 2025 and a 50% reduction by 2030. This is equivalent to the sustainable development goals set by the UN. However, targets other than recycling and landfill targets are not legally binding.

Substantial changes will be made to the handling of biowaste. An amendment is proposed to Article 22 of the Waste Framework Directive. The first paragraph of this Article is replaced by the following " Member States shall ensure that, no later than 31 December 2023 ... bio-waste is separated and recycled at source or separately collected and not mixed with other types of waste.

There are also changes in Article 6 'Loss of waste status'. Bio-waste has been included as a specific type of waste that may cease to be waste. The introductory part reads: "1 Member States shall take appropriate measures to ensure that waste which has undergone recycling or other recovery operations ceases to be considered waste" if it meets certain conditions.

2. Characteristics of the study area

The subject of the analysis is waste management in the area of the City and Commune of Zielona Góra.

2.1. Geographical location, area

2.1.1. Zielona Góra

Zielona Góra and its neighbouring municipalities are located in western Poland, and form part of the Lubuskie Province. The city lies almost on the crossroads of international road and rail routes connecting Scandinavia with the south of Europe and Warsaw with Berlin.

Zielona Góra is entirely surrounded by forests, forming a forest glade.

Total area of the town before the merger with the municipality: 58.3 km^2 , of which: agricultural land accounts for - 9.3%, built-up and urbanised areas - 28.8% (built-up, residential areas - 5.7 km^2 , built-up, industrial areas - 2.0 km^2 , roads - 5.66 km^2), green, recreational and leisure areas - 3.2%, forests and forest land - 46.1%, land under water - 0.34%, wasteland - 0.09% and other areas - 15.4%.

2.1.2. Municipality of Zielona Góra

The Zielona Góra Commune was a rural municipality, one of the 10 municipalities of the Zielona Góra district. From the north, east and south, it surrounded its area and was directly adjacent to the city of Zielona Góra. From the west, it bordered the Czerwieńsk and Sulechów municipalities.

Total area of the municipality: 220.45 km^2 , of which: agricultural land accounted for - 33.1%, built-up and urbanized areas - 6.9%, forests and forest land - 57.9%. land under water - 0.43%, wasteland - 0.28% and other areas - 1.3%. The commune consists of 18 solectwos (Table 2) and 4 villages without the status of solectwos: Barcikowiczki, Krępa Mała, Przydroże and Stożne.

2.2. Merger of the City of Zielona Góra with the Commune of Zielona Góra

On 1 January 2015 there was a merger of two units of local government - the City of Zielona Góra - on the rights of the county and the municipality of Zielona Góra into one unit of local government - the City of Zielona Góra - on the rights of the county, covering the administrative borders of both combined units of local government. These actions are to be the fastest way to increase the spatial and demographic potential of the city, affecting the whole Lubusz region and to create a strong medium-sized agglomeration centre. The inhabitants of the city and commune expressed their consent to the creation of a joint local government unit in a communal referendum.

2.3. Demographic situation

Zielona Góra. The population of Zielona Góra was at the end of 1995. - 116329 people (Table 1), the natural growth rate was equal to about 3%, and the population density per 1 km^2 - 1995. In 2015 the population of Zielona Góra (within the limits of 2014) was - 118975 people, and the natural growth rate was equal to about 0.2%. In 2030 the city of Zielona Góra will be inhabited by 141612 people and the population density per 1 km^2 will be 508.

The basis for this forecast is data from two studies:

- Population projection of municipalities for 2017-2030 [4];
- Projections for counties and cities with county rights for the period 2014-2050 [5].

Tabela 1. *Population forecast*

Area	Population on 31.12.									
	1995	2000	2004	2005	2010	2014	2015	2020	2025	2030
m. Zielona Góra (within the limits until 2014)	116329	118103	118516	118221	118950	118920	*118975*	*120937*	*120662*	*120002*
m. Zielona Góra (Nowe Miasto District)	13 167	14 728	15 834	16 128	18 434	19 592	*19736*	*20451*	*21094*	*21610*
City of Zielona Góra (within the limits from 2015)	-	-	-	-	-	-	138711	*141388*	*141756*	*141612*

Italics - forecast values

The municipality of Zielona Góra in 1995 had 13 167 inhabitants (as of 31.12.1995). The average population density per 1 km^2 was 59.7. The natural growth rate was equal to 1.1%. In 2015, the population of the now defunct Zielona Góra Municipality was - 19736 people and the natural growth rate was equal to about 0.7%. In 2030, the population of the Nowe Miasto District will be 21610.

2.4. Characteristics of the area served by ZGKiM

All types of waste with the exception of asbestos from the entire area of Zielona Góra and waste from the group 20 03 01 (non-segregated municipal waste) from the communes bound by the Intercommunal Agreement: Zielona Góra Municipality, Czerwieńsk, Sulechów, Dąbie, Świdnica, Zabór (Table 2). The waste is collected by Zakład Gospodarki Komunalnej i Mieszkaniowej (ZGKiM) and processed and disposed of at Zakład Zagospodarowania Odpadów (ZZO) "Racula". This agreement was valid until 20 September 2018. After that time, the Sulechów Commune transferred to the Intercommunal Union Eko-Przyszłość with its seat in the city of Nowa Sól [6].

Tabela 2. *The area served by ZGKiM*

Lp.	Municipality	Village of
I	City of Zielona Góra	
II	Zielona Góra Municipality	Drzonków, Łężyca, Nowy Kisielin, Ochla, Przylep, Racula, Stary Kisielin, Sucha, Zawada, Marzęcin
		Villages included in the collection from 1.01.2015, after the merger of the city of Zielona Góra and the municipality: Barcikowie, Jany, Jarogniewie, Jeleniów, Kiełpin, Krępa, Ługowo and Zatonie
III	Dąbie commune	Dąbie, Brzeźnica, Budynia, Ciemnice, Dąbki, Godziejów, Gola, Gronów, Kosierz, Lubiatów, Łagów, Mokry, Młyn, Nowy Zagór, Pław, Połupin, Stary Zagór, Suchy Młyn, Szczawno, Trzebule,
IV	Town and Municipality of Czerwinsk	Czerwiensk
		Leśniów Mały, Leśniów Wielki, Sudoł, Nietków, Laski, Płoty, Zagórze, Wysokie,
V	Sulechów Municipality	Boryń, Brzezie k/ Pomorska, Brody, Brzezie k/ Sulechów, Głogusz, Górki Małe, Górzykowo, Kalsk, Karczyn, Kije, Klępsk, Krężoły, Kruszyna, Laskowo, Leśna Góra, Łęgowo, Mozów, Nowy Klępsk, Nowy Świat, Obłotne, Okunin, Pomorsko, Przygubiel
VI	Świdnica Municipality	Wilkanowo, Rybno hamlet, Radomia, Orzewo,
VII	Zabór Commune	Czarna, Dąbrowa, Droszków, Łaz, Mielno, Milsko, Proczki, Przytoczki, Przytok, Rajewo, Tarnawa, Wielobłota, Zabór

3. Municipal and Housing Company

In 1992, ZGKiM and the Industrial Waste Storage and Neutralisation Company in Zielona Góra started to implement a comprehensive organisational and technical system of municipal and industrial waste collection and neutralisation, called "PREKO ZG". The initiator of these system activities was the local self-government, which thereby fulfilled its obligation to create conditions for a safe, sanitary and environmentally compliant system of collection, transport and disposal of municipal waste generated in the commune [7].

In the system, ZGKiM carried out the tasks imposed by the law on municipal self-governments, i.e. it ensured proper collection, transport and safe storage of municipal waste on its behalf. It performed these tasks using its own and third-party resources. The company managed specialist vehicles for solid and liquid waste collection, containers for collecting municipal waste and recyclable materials, a municipal waste composting plant and a landfill. It also carried out environmental education. The problem of safe storage and disposal of industrial waste from the city was dealt with by the Industrial Company for Storage and Disposal of Waste.

The main municipal waste disposal facility was the landfill, operated since 1960. The composting plant built in 1994 was the first waste treatment installation. The waste composting process was and still is carried out in open composting chambers with aeration (photo 1). It is an original Polish technology developed by "BIPROWOD" - Warsaw and labelled KKO-100 [6]. The ballast, which was an inert material, was sent to the landfill, which minimised the process of biodegradation of the soil and water environment.

Fot 1. *Waste composting plant*

In 1992, a system for selective collection of secondary raw materials was implemented in Zielona Góra. The aim was to extend the life of the landfill and to improve the efficiency of the composting plant and the quality of the compost produced.

In order to meet the requirements of regulations based on EU directives [4], under the current waste management system in Zielona Góra, the following facilities were built in December 2000. - The Household Waste Sorting Station (Photo 2), the Transfer Station and the Hazardous Waste Warehouse (Photo 3).

The Voivodeship Waste Management Plan 2002 for the Lubuskie Voivodeship designated Zielona Góra as the site for a District Waste Management Plant based on the existing ZZO in Racula [10].

On 7.6.2006. 10 municipalities signed the "Inter-municipal agreement on joint waste management and disposal" ("Agreement..."). The agreement was signed by: the city of Zielona Góra, Zielona Góra Municipality, Sulechów Municipality, Czerwieńsk Municipality, Dąbie Municipality, Świdnica Municipality and Zabór Municipality. The signed "Agreement...." increased the number of inhabitants covered by comprehensive waste management to 178,000 [5].

The "PREKO ZG" system built for Zielona Góra in 1993 became an essential part of the PGO for the City of Zielona Góra adopted on 28 February 2006 by the Zielona Góra City Council. **Zielona Góra was the first city in Poland to implement a comprehensive waste management system.**

Fot 2. *Waste sorting plant*

Fot 3. *Warehouse for hazardous waste collection*

In 2012, the waste composting installation was extended with the addition of a mechanical part, consisting of a hopper for non-segregated municipal waste with a rotary screen with a mesh diameter of 80 mm.

Although the concept of regional installations for municipal waste processing (RIPOK) was defined in the Waste Act of 27 April 2001 [1], it was only after the construction of the mechanical part that the Racula installation became a regional installation for the mechanical-biological processing of mixed municipal waste[1] .

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1 Pursuant to Article 3(3)(15c) thereof, a RIPOK is defined as a waste management facility with sufficient capacity to receive and process waste from an area inhabited by at least 120 000 inhabitants, meeting the requirements of the best available technique or technology referred to in Article 143 of the Act of 27 April 2001 on Environmental

4. Waste management in the city and municipality of Zielona Góra

Waste from the City and Commune of Zielona Góra is directed to:

- a regional installation for the mechanical and biological processing of mixed municipal waste (MBP) with a capacity of 40,000 Mg/year in the mechanical part and 23,100 Mg/year in the biological part;
- a composting plant for green and other selectively collected biodegradable waste with a capacity of 3.3 thousand Mg/year;
- sorting plant for selectively collected waste

and to a regional municipal waste disposal site.

Zielona Góra was one of the first cities in Poland to introduce selective waste collection (1992) and the fourth city to build a biological waste processing installation after Katowice (1989), Warsaw (1990) and Kołobrzeg (1994).

4.1. Assumptions to the programme of selective collection of recyclable materials

The process design of a waste segregation system to recover secondary raw materials was developed in 1991. The first stage assumed recovery of secondary raw materials in an amount ensuring reduction of the total waste mass by 13%, as part of selective collection. For this purpose, 600 hundred containers (of 6 types) were to be placed in the city. The second stage assumed construction of a sorting plant. shredders, a press with a packing machine.

The capacity of 1100 dm^3 was used for "selective collection". The number of containers and the number of inhabitants for which there was one container in 1995 are presented in Table 3 [11].

It was assumed that after the construction of the sorting plant, in addition to the system of collecting waste in containers, a system of collecting waste in specially designated bags will be introduced. Bags with a capacity of 90 dm^3 will be delivered free of charge to each inhabitant. Implementation of the second stage is to ensure an increase in the amount of recovered raw materials by a further 14.3% (total 27.3%).

Tabela 3. *Number of containers and population per container in 1995*

Waste	Number of containers	Container colour	Number of inhabitants per 1 container
Waste paper	242	Yellow	482
Glass	113	Blue	1032
Batteries	28	Orange	4164

Protection, and providing thermal waste conversion or: providing thermal waste conversion, or - Environmental Protection Law, and ensuring thermal processing of waste or:
(1) mechanical and biological processing of mixed municipal waste and separation from mixed municipal waste of fractions that are fully or partly recyclable,
2) processing of selectively collected green waste and other bio-waste and production from it of a product having fertilising properties or plant growing aid, meeting the requirements set out in separate provisions,
3) storage of waste generated in the process of mechanical and biological processing of mixed municipal waste and of residues from sorting of municipal waste with a capacity to receive waste for a period of not less than 15 years.

Textiles	58	Violet	2010
Plastics	154	White	757

4.2. Description of MBP installation

The Waste Management Plant is located within the excavated clay pit of the former Racula brickyard. It covers an area of 23.48 ha. ZZO is equipped with the following facilities:

- waste reception building, with scales,
- a temporary hazardous waste collection point,
- a commercial waste sorting station;
- a bunker for unsorted municipal waste with a rotating screen with a mesh diameter of 80 mm and a baling press;
- sorting plant for the fines fraction from the mechanical treatment of municipal waste;
- installation for the biological treatment of the whitewater fraction and biodegradable waste, with compost storage;
- building of mechanical processing of stabilisate.
- landfill site with degassing
- administrative and social buildings with workshop facilities - one-storey brick buildings, covered with tarpaper, with a total surface area of 800 m^2 and cubic capacity of 2400 m^3 .

4.2.1. Municipal unsegregated waste storage facility with a rotary sieve

Unsorted municipal waste of code 20 03 01 brought to the Department of Waste Management (DZO) is directed to the MBP installation. This waste is unloaded in a bunker with an area of 400 m^2 from where, with the help of a feeder, it is transferred to the hopper of a rotary sieve (with a capacity of 120 m^3 /h, i.e. approx. 45 000 Mg/a), where it is divided into:

- the <80 mm fraction - the whitewater fraction (screening), directed in its entirety to the biological part of the MPB installation;
- the >80 mm fraction - the supernatant (screening), directed (after pre-treatment by sorting out bulky waste, scrap metal and mineral waste) to a sorting plant for the supernatant fraction and glass cullet, to plants producing alternative fuel or to a landfill.

The screen drum is fitted with bag bursting elements and blades that guide the material inside.

4.2.2. Sorting plant for the mechanical treatment of non-segregated municipal waste for the secondary fraction

The sorting line is located in a tent hall, situated on the maneuvering area of the commercial waste sorting plant. The facility is designed for mechanical and manual fine sorting and sorting of a part of the supernitial fraction separated from municipal waste on a rotary sieve and for sorting of selectively collected glass waste.

The supernatant fraction delivered from the rotary sieve and waste packaging glass delivered from the town in bags or in bulk is unloaded from vehicles into one or more of the existing storage boxes. From the boxes, waste is loaded by a loader onto a horizontal sorting conveyor passing through a sorting cabin (6 sorting stations). From the waste is manually separated packaging glass by types, ferrous and non-ferrous metals, electrical and electronic waste (directed to the disassembly station) and hazardous waste (directed to the hazardous waste warehouse).

Residues from the sorting of glass and the residual fraction are sent to a plant for the production of alternative fuel or, if their energy value is too low, to landfill.

4.2.3. Installation for biological treatment of whitewater fraction and biodegradable waste

The installation for biological processing of waste consists of six lines of technological chambers grouped into two sets of 3 lines each. A single technological line consists of 4 chambers, i.e. chamber I, closed with a movable roof for intensive stabilization, with the volume of 340 m^3 and 3 open chambers (II-IV), with the volume of 300 m^3 each. The chambers have a floor with a system of channels covered with slotted panels, which are used for the aeration of waste and the removal of leachate. One non-aerated bunker for biologically stabilised waste is adjacent to each unit. The transfer of waste between the chambers in the trains is carried out by two gantry cranes equipped with grippers.

Between the two sets of chambers there is a fan room which ensures constant aeration of the mass of stabilised waste. The air sucked in by the waste bed is pumped to a biofilter filled with stabiliser. The active surface of the filter is approximately 220 m^2 . The active layer of stabiliser in the biofilter is 1.0 m thick. The gas flow intensity through the filter is approximately 33 m^3 /(h-m^2).

Five of the six biological treatment lines are used to stabilise the whitewater fraction. The retention time of the waste in Cell I and in each of the three subsequent cells is at least 14 days. After completion of the biological treatment the stabilised material is sent to a landfill or to a mechanical stabiliser treatment building.

4.2.4. Installation for composting selectively collected green waste and other bio-waste

Since January 2015, one of the six biological treatment lines has been used exclusively for the treatment of selectively collected green waste and bio-waste. It will produce compost or a plant growing aid.

The retention time of green waste and bio-waste in Chamber I and in each of the three subsequent chambers will be at least 14 days. After composting is completed, the product will be sent to the mechanical stabiliser treatment building

4.2.5. Mechanical stabiliser treatment building

The stabilised material from the biological treatment bunker of the whitewater fraction and the compost can be directed to the stabiliser treatment building for the mechanical treatment line. It consists of the following unit processes:

- separation into sieve fractions on a rotary sieve with a 40 mm opening and on a 20 mm sieve;
- recovery of ferrous metals;
- treatment of the fine fraction of stabilised glass in a hard particle separator,

The treatment of stabiliser and compost takes place separately - alternately. The stabiliser <20 mm fraction and the composting product are returned to the landfill for the initial restoration of landfill site A. Fraction >20 mm of stabilised material and residues from compost treatment are disposed of in the landfill.

4.3. Waste sorting plant

The sorting plant is a hall in a typical steel construction, mechanically ventilated (5 exchanges per hour), not heated. The hall includes:

- complete sorting line (10 stations) for household waste with baling press and
- strip import boxes for waste paper and plastics, storage of raw materials

sorted and textile waste with a station for a ballast shredder, separated by a manoeuvring area for waste collection and removal vehicles.

4.4. Landfill

The landfill has been in operation since 1960. Currently it covers an area of 19.20 ha. It is designed for storing non-hazardous and non-neutral waste. The location of the landfill meets the requirements set out in the Waste Act and in the Regulation on detailed requirements concerning the location, construction, operation and closure to which particular types of landfills should conform[2] .

The landfill consists of three storage fields A, B, C with areas:

- A - 3.70 ha
- B - 3.30 ha,
- C - 6.20 ha.

The equipment of the landfill includes: a weighbridge building with an entry and exit weighbridge, a disinfection mat in front of the exit weighbridge, a drainage under the "C" storage area, a landfill degassing system, a seepage water storage tank, a fuel storage area, garages and the equipment necessary for its proper operation.

The regional municipal waste landfill in Racula with a total capacity of 4.27 million m^3 (quarters A, B and C) was 91% full in 2017.

A new "D" landfill site with an area of about 4 ha and a capacity of about 500,000 m^3 was available.

The waste deposit is degassed, The installation commissioned in July 2001 consists of:

- 110 wells, including: in field A - 30, in field B - 48 and in field C - 32 wells,
- an overhead power line for energy transmission, transformer station, 350 kW generators, safety automation and measurement and control equipment.

The activity of biogas extraction and conversion into electricity is conducted by the company EKOENERGIA from Nowa Sól. The total amount of captured gas is approx. 150 m^3/h, electricity production - approx. 250 kWh.

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2 Regulation of the Minister of the Environment of 24 March 2003 on detailed requirements concerning the location, construction, operation and closure to which particular types of landfills should conform (Dz. U.03.61.549 of 10 April 2003)

4.5. Warehouse for hazardous waste

The Hazardous Waste Warehouse located within the ZZO area is the place where hazardous waste is accepted, segregated by the "at source" method from the municipal waste by the inhabitants and the hazardous waste coming from small industry, services, trade, public facilities and population services. Hazardous waste delivered to ZZO is stored in a warehouse for chemically hazardous waste or in a cold store for bacteriologically hazardous waste.

The Station's task is to accept waste, segregate it by assortment and transfer it to disposal after collecting enough waste to justify its transport to recipients. A period of one year was assumed as the maximum time span for storing particular types of waste.

5. Forecasts of the quantities of municipal waste collected and final products generated at the MBP installation

5.1. Data

The subject of the analysis is municipal waste from the city and municipality of Zielona Góra delivered to ZGK Waste Management Department in Racula near Zielona Góra.

The basis for forecasting changes in the amount of municipal waste generated is the data contained in the databases of the Central Statistical Office (2018), waste management plans (2002, 2006, 2014), reports of the Mayor of Zielona Góra (2016-2017) [13-15] and data obtained from ZZO Racula (2013 and 2015).

Table 4 shows the quantities of municipal waste delivered to the plant and treated in the mechanical part of the MBP plant in selected years of the period 1995-2018. Table 5 shows the quantities of municipal waste collected selectively in these years.

In 1995, 32245 Mg of municipal waste in total, including 30886 Mg from ZOK in the city of Zielona Góra, was directed to the DZO. Selectively collected were 17.8 Mg of waste paper, 41.0 Mg of plastics, 41.1 Mg of glass, 8.4 Mg of textiles and 10 Mg of bulky waste.

The MBP plant in Racula can treat 21.0 thousand Mg of waste with a bulk density of 500 kg/m^3 [16], running the stabilisation process for 8 weeks. Until the end of 2012, ZOK was aerobically stabilised in the installation. From 2013, after the construction of the mechanical part, the <80 mm fraction separated on a rotary sieve was subjected to stabilisation. The average mass of the whitewater fraction was 67.3% of that of ZOK. This means that the capacity of the MBP installation averages 31,000 Mg of ZOK.

Tabela 4. *Quantities of municipal waste delivered to the plant and treated in the mechanical part of the MBP plant*

Years	Total municipal waste		Municipal waste from the city of Zielona Góra		Municipal waste collected selectively		Municipal waste under biological treatment, Mg/a
	Mg/a	per 1 inhabitant, kg/(M-a)	Mg/a	per 1 inhabitant, kg/(M-a)	Mg/a	per 1 inhabitant, kg/(M-a)	
1995	32245	249	30886	266	118	0,9	-
2000	41859	315	40573	344	-	-	-
2002	46623	349	44367	375	5232	39,2	-
2006	50841	378	47868	405	5804	43,2	15786

2013	50815	368	46291	391	7797	56,5	18182
2015	505 40	364	45672	384	12008	86,6	35389
2016	51241	368	46165	385	10817	77,6	35389
2017	54935	393	49649	414	11852	84,8	36854
2018	55321	394	49822	415	11556	82,4	33229

Tabela 5. *Mass of municipal waste separately collected in 2018*

Waste components	Mass of waste in Mg/a								
	1995	2002	2006	2013	2014	2015	2016	2017	2018
Bio-waste	0,0	766,3	1376,5	2224,4	2587,2	2950,1	3879,1	2075,7	2721,8
Paper packaging	17,8	1724,2	1655,0	1613,2	1687,7	1762,3	2144,3	2817,5	2301,1
Multi-material packaging	0,0	0,0	0,0	0,0	84,9	169,9	254,8	339,8	304,6
Plastic packaging	41,0	330,5	527,5	1439,8	1570,1	1700,4	1805,7	1972,9	2084,7
Glass packaging	41,1	426,9	621,1	3,9	791,8	1579,7	735,5	1504,1	1549,0
Metals	0,0	263,2	318,9	290,1	789,3	1288,5	287,2	356,8	281,1
Clothing, textiles	8,4	8,7	8,1	3,5	8,4	13,3	4.79	29,7	37,8
Wood	0,0	15,9	3,0	3,0	3,0	3,0	3,0	3,0	3,0
Hazardous waste	0,0	0,0	0,0	0,0	28,1	56,2	60,0	4,8	5,8
Other	0,0	15,5	36,2	107,7	177,8	248,0	86,0	148,5	142,4
Bulky waste	10,0	1680,8	1258,2	2111,4	2174,2	2237,1	1561,0	2598,9	2125,1
Total	118	5232	5804	7797	9903	12008	10817	11852	11556

In 2015, the DZO received 50540 Mg of total municipal waste, including 38121.4 Mg of mixed municipal waste (ZOK). The "Report of the Mayor of the City of Zielona Góra" shows that 35389 Mg of ZOK were subjected to mechanical-biological processing, more than the capacity of the installation, which had to lead to a reduction in the time of waste stabilisation. Selectively collected 12008 Mg of waste 23.8% of total municipal waste.

In 2018, DZO received 55321 Mg of total municipal waste, including 43702 Mg of ZOK. ZOK accounted for 79%, of total municipal waste. Screening resulted in 29412 Mg of whitewater fraction. Selectively collected **11556 Mg** of waste 20.9% of total municipal waste.

5.2. Waste generation forecasts

Table 6 presents the values of unit indicators of municipal waste generation in Zielona Góra and Zielona Góra Municipality according to the data of the Central Statistical Office (2018), in the reports of the Mayor of Zielona Góra (2016-2017) [13-15] and data obtained from ZZO Racula (2013 and 2015).

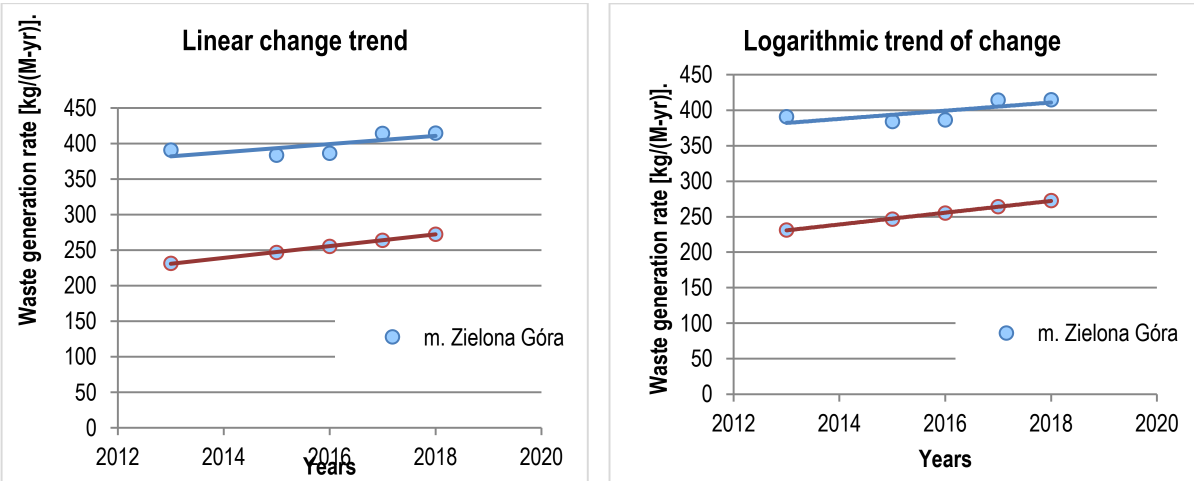
Tabela 6. *Municipal waste generated amounts (unit indicators)*

Years	Municipal waste, kg/(M-yr)	
	City of Zielona Góra	Zielona Góra Municipality
2013	391	231
2014	-	-
2015	384	247
2016	386	255
2017	414	264
2018	415	273

Available data from the years 2013-2018 were adopted. 2013 was assumed as the first year when the municipal waste management reform came into force, the main assumption of which was to transfer responsibility for municipal waste management to municipalities. It was assumed that these data are more reliable than data from previous years and can be the basis for forecasts. The GUS records do not include the part of waste which, e.g. is burnt in household cookers, illegally taken to wild dumps or abandoned, and is not recorded in waste management systems, e.g. to avoid landfill charges. The scale of these illegal activities is difficult to estimate unequivocally. It is believed that their range is not large and is systematically decreasing.

5.2.1. Data extrapolation - linear and logarithmic trend

The figure presents the trend of changes in the municipal waste generation index for the city and municipality of Zielona Góra based on data from Table 6.



Rys. 1st *Linear and logarithmic trend in municipal waste generation indicators for the city and commune of Zielona Góra*

Based on the determined trend equations (Figure 1), the projected values of the indicator for 2019-2030 were calculated (Table 7).

5.2.2. Extrapolation by geometric trend

The value of annual growth rates of the unit rate of waste generation is presented in Table 7. The average annual growth rate for Zielona Góra in 2013-2018 is 1.2% compared to the previous year. The total growth over the 5-year period is 6%. For the municipality of Zielona Góra, the average annual growth rate for is 3.3% from the previous year, and the total growth over the 5-year period is 17.9%.

5.2.3. Correlation with GDP growth trend

Numerous analyses by many authors show that the value of the waste generation rate is closely correlated with the economic level of a country, expressed by various indicators, the most common being GDP. Some models also adopt other indicators of socio-economic development, also called welfare indicators, such as the level of employment in services and agriculture, infant mortality rate, etc.

Tabela 7. *Projected municipal waste generation rates*

Years	Linear trend		Logarithmic trend		Geometric trend			
	Municipal waste, kg/(M-yr)		Municipal waste, kg/(M-yr)		Increase in year/year	Municipal waste, kg/(M-yr)	Increase in year/year	Municipal waste, kg/(M-yr)
	City of Zielona Góra	Zielona Góra Municipality	City of Zielona Góra	Zielona Góra Municipality	City of Zielona Góra		Zielona Góra Municipality	
2013	391	231	-	-	-	-	-	-
2014	-	-	-	-	-	-	-	-
2015	384	247	-	-	0,991	-	1,033	-
2016	386	255	-	-	1,007	-	1,035	-
2017	414	264	-	-	1,072	-	1,034	-
2018	415	273	-	-	1,001	-	1,033	-
2019	417	280	417	284	1,012	420	1,033	282
2020	422	288	423	292	1,012	425	1,033	291
2021	428	297	429	300	1,012	430	1,033	301
2022	434	305	434	309	1,012	436	1,033	311
2023	440	313	440	317	1,012	441	1,033	321
2024	445	322	446	325	1,012	446	1,033	332
2025	451	330	452	333	1,012	452	1,033	343
2026	457	338	457	342	1,012	457	1,033	355
2027	463	346	463	350	1,012	463	1,033	367
2028	469	355	469	358	1,012	469	1,033	379
2029	474	363	475	366	1,012	475	1,033	391
2030	480	371	480	375	1,012	480	1,033	405

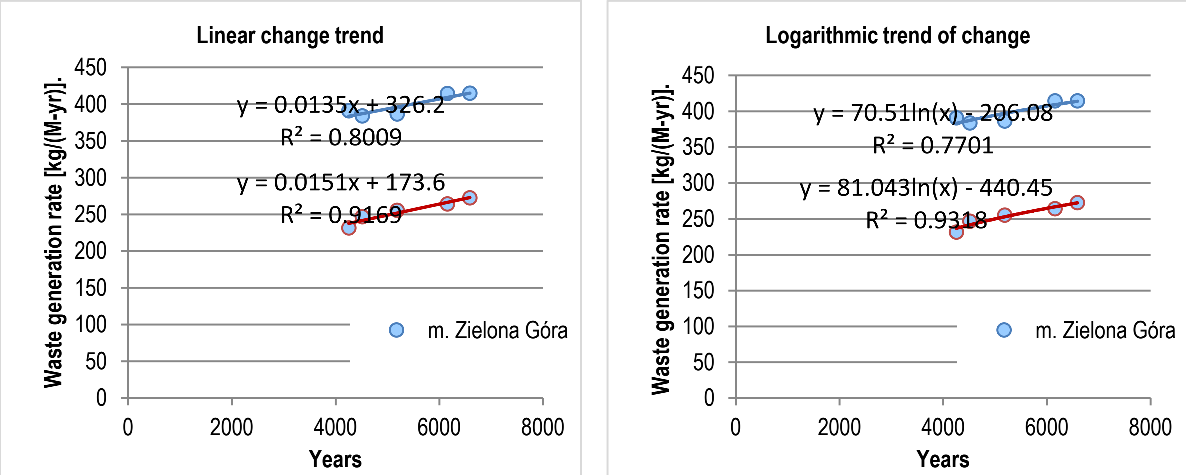
In this analysis, an attempt was made to correlate the value of the unit indicator of waste generation with the municipal budget income (DBG) per capita in 2013-2018 (Table 8) and to extrapolate the indicator on the basis of forecasts of DBG value growth, assuming its growth to be the same as GDP in Poland.

Tabela 8. *DBG values according to CSO and waste generation indicators*

Years	Municipal waste, kg/(M˙year)		DBG, PLN/M	
	City of Zielona Góra	Zielona Góra Municipality	City of Zielona Góra	Zielona Góra Municipality
2013	391	231	4 253	3 038
2014	-	-	4 571	3 117
2015	384	247	4 514	-
2016	386	255	5 187	-
2017	414	264	6 159	-
2018	415	273	6 590	-

Figure 2 shows the pattern of changes in the increase in waste generation rates with the increase in DBG and the linear and logarithmic trend characteristics of these changes.

The presented graphs show a high correlation between waste generation and DBG values. Therefore, they can be used to forecast the value of the waste generation indicator on the basis of forecasts of the GDP. Due to the lack of forecasts for growth of GDP for the city of Zielona Góra, it was assumed that its value will grow in proportion to GDP growth in Poland.



Rys. 2nd *Linear and logarithmic trends in municipal waste generation rates for the city and municipality of Zielona Góra as a function of DBG*

Different forecasts of Poland's GDP growth available from various national and international institutions

PwC report 'The world in 2050: Will the shift in the balance of power of global economies continue? "The average annual growth of Poland's GDP between 2021 and 2040 will be up to 2.8% per year.

Rating agency Fitch has upheld Poland's GDP growth forecasts for 2020 and 2021 at 3.3 percent and 2.9 percent, raising its 2019 forecast to 4.3 percent from 4.1 percent. - According to the agency's December 5, 2019 report.

The IMF's October 2019 autumn edition of the World Economic Outlook estimates Poland's GDP at 4% in 2019, 3.1% in 2020 and 2.5% in 2024.

Developed in July 2018, the OECD's growth forecast for economies that are members of the organisation assumes that Poland's GDP will grow:
- an average of 2.5% per annum between 2018 and 2030,
- an average of around 1.3% per year between 2030 and 2060.

All these forecasts have been disrupted by the coronavirus pandemic. No one knows how long it will last and how deep the wounds will be on people and businesses. Economists who try to forecast the future of the economy are spreading their arms: the models do not predict COVID-19. And the rationale for predicting what is next for the economy is changing in an instant. For now, the outlook is poor.

According to specialists from the Polish Economic Institute (PIE), the epidemic will have a very significant impact on the economic situation in 2020. They have presented a forecast of Poland's economic growth this year in three scenarios:

- Scenario one - a significant reduction in economic activity lasts until the end of April, from May the economy gradually returns to normal, but this process takes at least 1-2 months - economic growth in 2020 would be 1.1%;

- Scenario two - similar to the first, except that the peak of viral infections is later - the change in GDP in 2020 would be -0.7%;
- Scenario three - the spread of the virus is a continuous process that slows down slightly during the summer and accelerates significantly again in the autumn - the change in GDP in 2020 would be -4.7%.

The World Bank forecasts that Poland's GDP will decline by 4.2%. in 2020, according to the June report "Global Economic Prospects". Growth will return in 2021, however, and will then amount to 2.8%.

The European Commission has forecast for Poland (July) a 4.6% fall in GDP in 2020, and a 4.3% rise in 2021.

Table 9 presents projections of the growth of the waste generation rate for the assumed projected changes in the value of Poland's GDP for the years 2019-2030. In 2020 and 2021 no growth of GDP was assumed in the period from 2022 decreasing values of GDP growth were assumed from 2.8% in to 2.2% in 2030.

Data from Table 9 show that GDP growth in 2013-2018 was 28%, DBG growth was 55% and municipal waste generation rates were 6% for the city of Zielona Góra and 18% for the municipality of Zielona Góra. The growth of income per capita was higher than the growth of waste generation, which means that the principle of separating the growth rate of municipal waste generation from the rate of economic development was implemented.

The projected values of the municipal waste generation rate, for the linear rather than the logarithmic trend, are not significantly different from each other (by about 3% for 2035). Average values of the waste generation rate were calculated as arithmetic averages of the values calculated for both trends. The increase in the projected DBG values between 2019 and 2030 will be 29%, and the average values of the municipal waste generation rate will be about 5.2% for Zielona Góra and 9.1% for the New Town district of Zielona Góra. The assumption of separating the growth rate of municipal waste generation from the growth rate of DBG is, therefore, fulfilled.

Tabela 9. *Forecast of increase in municipal waste generation unit rates based on DBG growth*

Years	GDP forecast, PLN/M	Assumed GDP growth	DBG, PLN/M	Municipal waste, kg/(M˙year)					
				Linear trend		Logarithmic trend		Waste on average	
				City of Zielona Góra	Zielona Góra Municipality	City of Zielona Góra	Zielona Góra Municipality	City of Zielona Góra	Zielona Góra Municipality
2013	43034	-	4253	391	231	-	-	-	-
2014	44705	1,033	4571	-	-	-	-	-	-
2015	46814	1,039	4514	384	247	-	-	-	-
2016	48433	1,031	5187	386	255	-	-	-	-
2017	51776	1,050	6159	414	264	-	-	-	-
2018	55066	1,064	6590	415	273	-	-	-	-
2019	57324	1,041	6861	419	277	417	275	418	276
2020	59158	1,000	6861	419	277	417	275	418	276
2021	60815	1,000	6861	419	277	417	275	418	276

2022	62518	1,028	7053	421	280	419	278	420	279
2023	64143	1,026	7236	424	283	421	280	422	281
2024	65747	1,025	7417	426	286	422	282	424	284
2025	67325	1,024	7595	429	288	424	284	426	286
2026	68940	1,024	7777	431	291	426	286	428	288
2027	70526	1,023	7956	434	294	427	287	430	291
2028	72148	1,023	8139	436	297	429	289	432	293
2029	73735	1,022	8318	438	299	430	291	434	295
2030	75358	1,022	8501	441	302	432	293	436	297

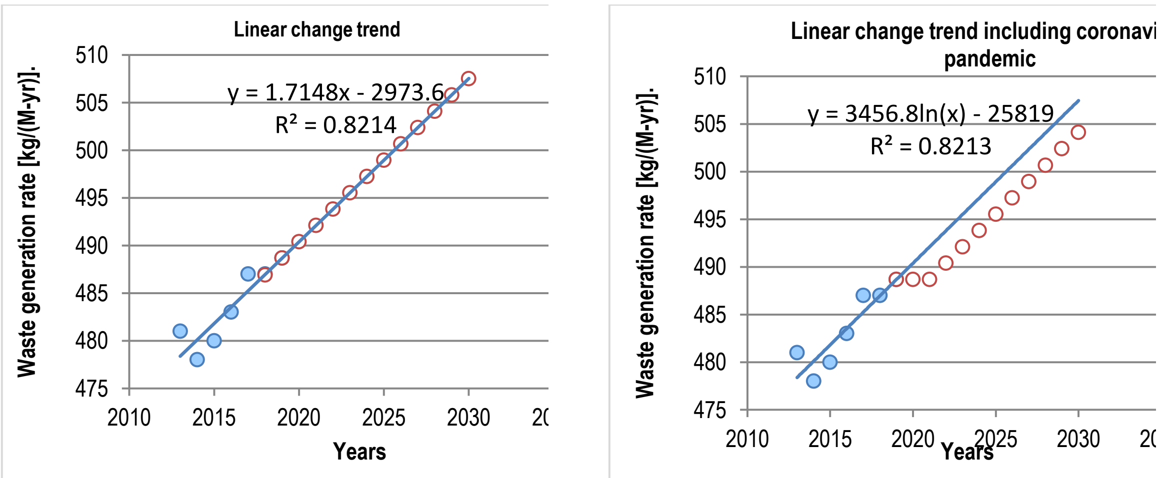
5.2.4. Trends in waste generation unit rates for the EU28

This chapter presents the trends in the municipal waste unit generation rate and its correlation with the average GDP (gross domestic product per capita) for the EU28. It is based on data from Eurostat in Table 10.

Tabela 10. *Average unit generation rate of ZOK and GDP in EU28*

Year	Waste [kg/(M-yr)].	GDP [Eur/(M-yr)].
2013	481	25 750
2014	478	26 140
2015	480	26 680
2016	483	27 130
2017	487	27 780

The growth trends of the waste generation rate determined by extrapolating a linear trend are shown in Figure 3.



Rys. 3rd *Linear trend in average waste generation rate in the EU28 from 2013 to 2017 and projected change to 2030 without and with coronavirus pandemic*

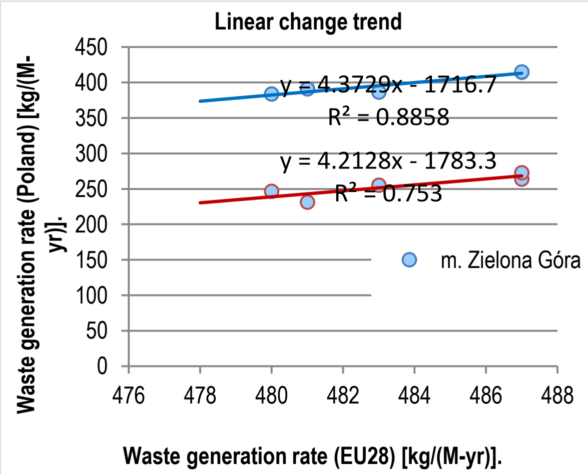
Projections of the growth of the unit waste generation rate in the EU for linear and logarithmic trends showed very little difference, and the increase in the value of the rate is relatively slow (about 5.5% between 2013 and 2030).

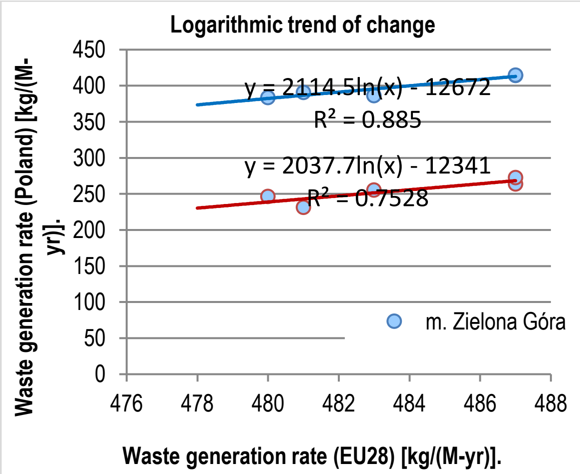
5.2.5. Trends in the rate of waste generation in Poland in relation to the rate for the EU28

The calculations are presented for the time period 2013-2018, although for 2018 there is still no value of the waste generation rate for the EU28 in the Eurostat data. The calculation uses the projected value from Table 11 (487 kg/M).

5.2.6. Trend calculations based on 2013-2018 data

The correlation trends of the waste generation rate in Poland and the EU28 are shown in Figure 4 (linear and logarithmic trend).





Rys. 4th *Linear and logarithmic correlation of municipal waste generation indicators for the city and municipality of Zielona Góra and the average indicator for the EU28*

Table 11 presents forecasts of the growth of the unit waste generation rate in the city and municipality of Zielona Góra for the linear and logarithmic trend (for data from 2013-2018).

5.2.7. Summary of forecasts

Tables 12 and 13 summarise the projected waste generation rates for 2019-2030 and the calculated average values for each year.

Tabela 11. *Forecasts of waste generation rate increase in the city and municipality of Zielona Góra for the linear and logarithmic trend (data from 2013-2018)*

Years	GDP forecast, PLN/M	Municipal waste, kg/(M˙year)			
		Linear trend		Logarithmic trend	
		City of Zielona Góra	Zielona Góra Municipality	City of Zielona Góra	Zielona Góra Municipality
2013	481	391	231	-	-
2014	478	-	-	-	-
2015	480	384	247	-	-
2016	483	386	255	-	-
2017	487	414	264	-	-
2018	487	415	273	-	-
2019	489	420	275	420,3	276

2020	490	420	275	420,3	276
2021	492	420	275	420,3	276
2022	494	428	283	427,7	283
2023	495	435	290	435,1	290
2024	497	443	297	442,5	297
2025	499	450	304	449,8	304
2026	501	458	311	457,1	311
2027	502	465	319	464,4	318
2028	504	473	326	471,6	325
2029	506	480	333	478,9	332
2030	507	488	340	486,1	339

The projected values vary quite strongly depending on the adopted benchmarks. Tables 12 and 13 show three average values of the indicator: the average of all projections, the average of projections based on Polish GDP and the average of projections made on the basis of correlation with the average waste generation rate for the EU28.

Considering the increase of the indicator value in the period of 11 years, the highest increase (16%) was recorded in the case of dependence on the EU28 indicator for waste from the city of Zielona Góra and for geometrical extrapolation (44%) for the municipality of Zielona Góra.

An increase of about 16% for a city with >100,000 inhabitants does not seem large. Already today, in some large cities with a high level of development, the value of this indicator exceeds 500 kg/(M-yr).

In rural areas there is a higher increase in the value of this indicator, on average by 23%, and in the forecast "geometric trend" even by 44%.

Tabela 12. *Comparison of waste generation rate forecasts for the city of Zielona Góra [kg/(M-yr)]*

Years	Extrapolation			Extrapolation in the DBG function		Extrapolation as a function of the EU28 waste indicator		Average	Average for DBG	EU28 average
	linear trend	log-linear trend	geome-tric trend	linear trend	log-linear trend	linear trend	log-linear trend			
2019	417	417	420	419	417	420	420	417	418	420
2020	422	423	425	419	417	420	420	419	418	420
2021	428	429	430	419	417	420	420	423	418	420
2022	434	434	436	421	419	428	428	429	420	428
2023	440	440	441	424	421	435	435	434	423	435
2024	445	446	446	426	422	443	443	439	424	443
2025	451	452	452	429	424	450	450	444	427	450
2026	457	457	457	431	426	458	457	449	429	457
2027	463	463	463	434	427	465	464	454	431	465
2028	469	469	469	436	429	473	472	460	433	472
2029	474	475	475	438	430	480	479	464	434	480
2030	480	480	480	441	432	488	486	470	437	487
quotient 2030/ 2019	1,15	1,15	1,14	1,05	1,04	1,16	1,16	1,13	1,04	1,16

Tabela 13. *Comparison of waste generation rate forecasts for the municipality of Zielona Góra [kg/(M-yr)*

Years	Extrapolation			Extrapolation in the DBG function		Extrapolation as a function of the EU28 waste indicator		Average	Average for DBG	EU28 average
	linear trend	log-linear trend	geome-tric trend	linear trend	log-linear trend	linear trend	log-linear trend			
2019	280	284	282	277	275	275	276	276	276	276
2020	288	292	291	277	275	275	276	280	276	276
2021	297	300	301	277	275	275	276	286	276	276
2022	305	309	311	280	278	283	283	293	279	283
2023	313	317	321	283	280	290	290	299	282	290
2024	322	325	332	286	282	297	297	306	284	297
2025	330	333	343	288	284	304	304	312	286	304
2026	338	342	355	291	286	311	311	319	289	311
2027	346	350	367	294	287	319	318	326	291	319
2028	355	358	379	297	289	326	325	333	293	326
2029	363	366	391	299	291	333	332	339	295	333
2030	371	375	405	302	293	340	339	346	298	340
quotient 2030/ 2019	1,33	1,32	1,44	1,09	1,07	1,23	1,23	1,25	1,08	1,23

In further balancing of waste generation in the city and municipality of Zielona Góra, forecasts of changes in the average waste generation rate were adopted according to the forecast determined on the basis of the projected changes in the EU28 waste rate.

The high level of correlation between municipal waste generation indicators for the city and municipality of Zielona Góra and the average indicator for the EU28, as well as the low level of waste generation in Poland in relation to other EU countries, allow the assumption that the forecast of waste generation on the basis of changes in the indicator for the EU28 may be the most reliable.

The values of the unit indicators established for the years 1995-2015 and assumed for the projected amounts of waste generated in 2020-2030 are presented in Table 14.

Tabela 14. *Values of waste generation rates 1995-2030*

Area	Waste generation rate [kg/(M-yr)]									
	1995	2000	2004	2005	2010	2014	2015	2020	2025	2030
m. Zielona Góra (within the limits until 2014)	265	344	379	381	388	388	384	*420*	*450*	*487*
m. Zielona Góra (Nowe Miasto District)	105	135	164	173	212	238	246	*276*	*304*	*340*
City and municipality of Zielona Góra	249	320	354	356	364	366	364	*399*	*428*	*464*

Italics - forecast values

5.3. Masses of waste generated

The masses of waste produced in 1995-2015 in the area of the city and municipality of Zielona Góra and the total forecast quantities of waste produced calculated on the basis of average unit indicators from Table 14 and the demographic forecast from Table 2 are presented in Table 15.

Tabela 15. *Masses of municipal waste generated*

Area	Waste quantities [Mg]									
	1995	2000	2004	2005	2010	2014	2015	2020	2025	2030
m. Zielona Góra (within the limits until 2014)	30861	40573	44915	45047	46104	46083	45694	*50824*	*54298*	*58429*
Municipality of Zielona Góra (Nowe Miasto District)	1383	1984	2603	2786	3914	4663	4845	*5634*	*6413*	*7347*
City and municipality of Zielona Góra	32245	42557	47517	47834	50019	50746	50539	*56458*	*60710*	*65776*

Italics - forecast values

5.4. Material composition of waste

The material (morphological) composition of municipal waste generated in rural areas of Zielona Góra is shown in Tables 16 and 17.

Material compositions (morphological) of municipal waste generated in urban (large cities) and rural areas until 2014 were adopted from national waste management plans [17, 18], from own studies and from information obtained from the DZO in Racula.

Tabela 16. *Material composition of municipal waste produced in the area of the city of Zielona Góra*

Area	Share [%]									
	1995	2000	2004	2005	2010	2014	2015	2020	2025	2030
Kitchen waste	25,5	23,5	22,4	22,2	21,6	21,1	20,9	*19,6*	*17,6*	*16,0*
Green waste	4,2	5,1	6,7	7,4	8,0	8,0	8,1	*8,7*	*8,2*	*7,8*
Paper and cardboard	21,2	18,9	18,6	18,8	19,7	19,7	19,2	*16,7*	*18,3*	*19,4*
Multi-material packaging	0,5	1,9	2,7	2,8	2,7	2,8	3,1	*4,8*	*5,2*	*5,5*
Plastics	13,5	15,7	16,0	15,9	15,8	15,8	15,8	*15,7*	*14,6*	*14,3*
Glass	7,7	8,1	8,8	9,0	9,8	10,0	9,9	*9,3*	*10,1*	*10,8*
Metal	3,4	3,7	3,3	3,0	2,7	2,6	2,5	*2,3*	*2,5*	*2,7*
Clothing, textiles	2,6	3,2	3,6	3,7	3,5	3,5	3,7	*4,3*	*4,7*	*5,0*
Wood	1,8	0,7	0,6	0,7	0,8	0,8	0,8	*0,9*	*1,0*	*1,1*
Hazardous waste	0,6	0,6	0,5	0,4	0,3	0,3	0,3	*0,2*	*0,2*	*0,2*
Ash fraction <10 mm	12,5	10,6	8,1	7,2	5,0	4,1	4,1	*4,2*	*3,7*	*2,9*
Mineral wastes	3,6	3,4	3,2	3,2	3,1	3,1	3,0	*2,5*	*2,8*	*2,9*
Other	0,9	1,1	1,9	2,3	3,1	3,6	3,9	*5,4*	*5,9*	*6,2*
Bulky waste	2,1	3,5	3,6	3,5	3,8	4,3	4,5	*5,3*	*5,1*	*5,0*
Total	100,0	100,0	100,0	100,0	100,0	100,0	100,0	*100,0*	*100,0*	*100,0*

Tabela 17. *Estimated material composition of municipal waste produced in the area of the commune of Zielona Góra*

Area	Share [%]									
	1995	2000	2004	2005	2010	2014	2015	2020	2025	2030

Kitchen waste	12,6	11,7	18,0	18,9	21,1	20,9	20,3	*18,1*	*16,2*	*14,7*
Green waste	7,4	2,2	4,0	4,9	7,1	6,9	6,6	*5,6*	*5,3*	*5,0*
Paper and cardboard	6,4	13,8	12,0	11,4	9,6	9,5	9,5	*9,8*	*11,3*	*12,7*
Multi-material packaging	0,0	0,9	3,0	3,4	4,3	4,3	3,7	*1,6*	*1,9*	*2,1*
Plastics	3,8	14,7	12,0	11,7	10,8	10,9	11,8	*15,2*	*14,1*	*13,8*
Glass	9,6	10,5	8,0	8,7	10,4	10,4	10,2	*9,5*	*11,0*	*12,4*
Metal	6,3	3,5	5,0	4,3	2,5	2,5	2,7	*3,5*	*4,1*	*4,6*
Clothing, textiles	1,9	2,5	1,0	1,3	2,2	2,2	2,2	*2,4*	*2,7*	*3,1*
Wood	2,5	1,8	2,0	1,6	0,7	0,7	0,6	*0,1*	*0,2*	*0,2*
Hazardous waste	1,0	1,1	1,0	1,0	0,9	0,9	0,7	*0,2*	*0,2*	*0,2*
Ash fraction <10 mm	23,3	21,3	19,7	19,1	17,5	17,4	17,9	*19,2*	*16,6*	*13,2*
Mineral wastes	14,0	7,0	6,9	6,7	6,4	7,0	7,1	*8,0*	*9,2*	*10,4*
Other	5,0	1,1	3,2	3,1	2,9	3,1	3,1	*3,2*	*3,7*	*4,2*
Bulky waste	6,0	7,9	4,0	3,9	3,5	3,4	3,5	*3,5*	*3,4*	*3,3*
Total	100,0	100,0	100,0	100,0	100,0	100,0	100,0	*100,0*	*100,0*	*100,0*

Italics - forecast values

In recent years, very few studies have been conducted on the material composition of waste in Poland. The forecast of changes in waste composition in 2018-2039 was based on the results of annual studies conducted in Wielkopolska and Lower Silesia, in 2017 and 2018.

The assessment of quantitative changes of particular waste streams has taken into account the observed trends resulting from changes in people's lifestyles, increase in the level of prosperity, evolving changes in regulations regarding restriction or elimination of certain products (e.g. single-use plastic items), growing environmental awareness, implementation of anti-smog programmes in cities, changes in the area and use of green areas in cities and in individual gardens, development of residential buildings, etc.

Based on the data from Tables 16-17, waste streams from the city of Zielona Góra and the municipality of Zielona Góra were determined (Table 18).

Tabela 18. *Estimated streams of municipal waste produced in the area of the city and municipality of Zielona Góra*

Area	Waste quantities [Mg]									
	1995	2000	2004	2005	2010	2014	2015	2020	2025	2030
Kitchen waste	8042	9749	10530	10510	10766	10705	10557	11001	10592	10403
Green waste	1395	2106	3115	3458	3965	4030	4037	4724	4811	4921
Paper and cardboard	6628	7959	8673	8770	9436	9524	9240	9055	10649	12297
Multi-material packaging	149	806	1278	1368	1432	1513	1611	2517	2951	3396
Plastics	4231	6663	7514	7485	7709	7790	7776	8827	8839	9373
Glass	2496	3477	4142	4318	4939	5114	5014	5255	6213	7215
Metal	1132	1574	1597	1473	1343	1314	1289	1370	1629	1903
Clothing, textiles	822	1328	1631	1704	1723	1734	1817	2328	2737	3159
Wood	599	339	335	371	400	411	411	490	573	657
Hazardous waste	207	268	236	207	187	193	183	114	135	156
Ash fraction <10 mm	4168	4735	4165	3756	2984	2709	2760	3240	3058	2676
Mineral wastes	1312	1519	1625	1609	1702	1749	1714	1739	2095	2484
Other	342	450	945	1130	1539	1811	1918	2906	3419	3949
Bulky waste	721	1585	1732	1674	1893	2148	2211	2892	3010	3188

Total	32245	42557	47517	47834	50019	50746	50539	56458	60710	65776

Italics - forecast values

5.5. Selective collection of municipal waste

The achieved levels of municipal waste recycling in 1995-2015 in the area of the city and municipality of Zielona Góra and the levels resulting from the law in force, in 2020-2030, are presented in Table 19.

Legal obligations for the management of municipal waste (household and similar waste) are set out in the Waste Framework Directive. Such obligations include, inter alia, the target of preparing 50% of municipal waste for re-use/recycling by 2020 (Article 11(2)(a))[3] . This Article has been further clarified in the Commission Decision of 18 November 2011 which established the principles and methods for the calculation of the recycling and preparation for reuse rates (RPM) of these municipal waste fractions[4] .

Tabela 19. *Estimated levels of recycling of municipal waste collected selectively in the area of the city and municipality of Zielona Góra*

Area	Level of PdPU and recycling of COC components [%].									
	Achieved values							Legally required values		
	1995	2000	2004	2005	2010	2014	2015	2020	2025	2030
Bio-waste	0,0	4,6	7,9	8,8	12,6	17,6	20,2	25,0	60,0	65,0
Paper and cardboard	0,2	2,0	17,5	17,2	15,6	15,9	17,2	50,0	80,0	85,0
Multi-material packaging	0,0	0,0	0,0	0,0	0,0	1,0	1,8	10,2	30,0	45,0
Plastics	0,6	1,1	3,4	3,8	8,2	12,1	13,1	50,0	55,0	55,0
Glass	1,5	5,9	11,4	11,9	4,9	13,9	28,4	50,0	70,0	75,0
Metal	0,0	11,3	17,3	19,7	21,4	20,9	21,3	50,0	75,0	80,0
Clothing, textiles	0,9	0,8	0,4	0,4	0,3	0,4	0,6	15,3	50,0	70,0
Wood	0,0	3,0	2,5	1,5	0,7	0,7	0,7	7,5	25,0	30,0
Hazardous waste	0,0	0,0	0,0	0,0	0,0	12,4	26,1	20,2	60,0	70,0
Ash fraction <10 mm	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Mineral wastes	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Other	0,0	2,5	2,7	2,7	5,0	9,8	12,9	5,1	5,0	5,0
Bulky waste	1,4	76,0	84,8	81,5	80,0	83,7	85,5	80,8	95,0	95,0
Total level of PdPU and ZOK recycling	**0,3**	**5,5**	**10,6**	**10,7**	**11,9**	**15,5**	**18,4**	**39,8**	**55,5**	**60,5**

Italics - levels required by law.

Poland has chosen, through the provisions in the new Act on Maintaining Cleanliness and Order in Municipalities (Article 3b(1))[5] and in the Regulation on Recycling of Waste[6] , option

3 Directive 2008/98/EC of the European Parliament and of the Council on waste and repealing certain Directives (OJ L 312, 22.11.2008, p. 3).

4 Commission Decision of 18 November 2011 laying down the rules and calculation methods for verifying compliance with the targets set out in Article 11(2) of Directive 2008/98/EC of the European Parliament and of the Council (notified under document C(2011) 8165) (OJ L 310/11, 25.11.2011) (2011/753/EU).

5 Act of 13 September 1996 on maintaining cleanliness and order in communes (Journal of Laws of 2012, item 391).

6 Regulation of the Minister of Environment of 29 May 2012 on the levels of recycling, preparation for reuse and recovery by other methods of certain municipal waste fractions (Journal of Laws 2012 No. 0 item 645).

2 of accounting for recycling and PdPU of paper, metals, plastics and glass. The required Level of recycling and PdPU of these fractions of municipal waste, set out in the Regulation of the Minister of Environment, in 2017 was 20%, in 2018 - 30%, in 2019 - 40% and 50% in 2020[7] .

The recent revision of the Waste Framework Directive introduced new, more ambitious recycling targets for municipal waste. 55% of municipal waste should be recycled by 2025, 60% by 2030 and 65% by 2035[8] . New targets have also been set for the recycling of packaging waste[9] (Table 19):

- for plastics 50% by weight for 2025 and 55% for 2030;
- for wood, 25% by weight for 2025 and 30% for 2030;
- for ferrous metals 70% by weight for 2025 and 80% for 2030;
- for aluminium 50% by weight for 2025 and 60% for 2030;
- for glass 70% by weight for 2025 and 75% for 2030;
- for paper and board 75% by weight for 2025 and 85% for 2030

Taking into account that separately collected waste requires after-treatment to remove contaminants and non-recyclable waste, more of each type of waste must be collected than the required recycling levels in order to achieve the required recycling levels after treatment at the sorting plant and taking into account material losses during treatment processes (the values of these losses are 1-50% and their equivalent are the purity indicators of the individual waste fractions given in Table 20).

Table 20 shows the quantities of waste that need to be separately collected and treated to achieve the required recycling levels.

Tabela 20. *Streams of selectively collected municipal waste in the area of the city and municipality of Zielona Góra*

Area	Cleanliness index	Waste quantities [Mg]									
		1995	2000	2004	2005	2010	2014	2015	2020	2025	2030
Bio-waste	0,95	0	547	1071	1224	1861	2587	2950	7405	9712	10486
Paper and cardboard	0,90	18	180	1690	1672	1631	1688	1762	5030	9466	11614
Multi-material packaging	0,80	0	0	0	0	0	18	36	321	1107	1910
Plastics	0,60	41	117	429	478	1049	1570	1700	7356	8102	8592
Glass	0,90	41	227	524	573	268	792	1580	2920	4832	6013
Metal	0,95	0	188	291	305	302	289	289	721	1286	1602
Clothing, textiles	0,85	8	13	8	8	5	8	13	419	1610	2601
Wood	0,90	0	11	9	6	3	3	3	41	159	219
Hazardous waste	0,85	0	0	0	0	0	28	56	27	95	129
Ash fraction <10 mm	1,00	0	0	0	0	0	0	0	0	0	0

7 Regulation of the Minister of the Environment of 14 December 2016 on levels of recycling, preparation for reuse and recovery by other methods of certain fractions of municipal waste (D.U. of 27 December 2016, Item 2167).
8 Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (Text with EEA relevance) (OJ L. 150/109, 14.6.2018).
9 Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste (OJ EU. L. 150.141, 14.6.2018.).

Mineral wastes	1,00	0	0	0	0	0	0	0	0	0	0
Other	1,00	0	11	26	31	77	178	248	147	171	197
Bulky waste	1,00	10	1203	1470	1364	1515	1798	1890	2336	2860	3028
Total	-	**118**	**2498**	**5518**	**5661**	**6712**	**8960**	**10528**	**26723**	**39400**	**46392**
Share of selectively collected waste in the mass of WEEE [%]		0,4	5,9	11,6	11,8	13,4	17,7	20,8	47,3	64,9	70,5

Italics - forecast values

The total weights of the waste streams that need to be separately collected to ensure the required recycling levels for 2025 and 2030 are very high at 64.9% and 70.5% of the total waste generated respectively.

Table 21 shows the masses of residual waste remaining after separate collection and the masses of biased waste sorting residues.

The mass of residual waste is in 2015 79.2% of the total mass of waste generated and will be 52.7, 35.1 and 29.5% in 2020, 2025 and 2030 respectively.

It appears that such levels are not achievable in practice and that it is impossible to separate the missing quantities for recycling from residual mixed waste as the quality of this waste will not allow it to be sent for recycling, especially biowaste and paper and cardboard.

5.6. Mechanical-biological treatment of waste

Until 2012, mixed municipal waste and part of the sewage sludge from the sewage treatment plant in Zielona Góra were composted. Waste brought to the composting plant was unloaded directly into storage tanks, which constitute the first element of the technological sequence. The time of waste storage in chamber I and in each of the three subsequent chambers was at least 14 days, usually 3 weeks or even longer.

Tabela 21. *Streams of residual municipal waste (waste after separate collection) from the area of the city and municipality of Zielona Góra and residues from sorting of waste*

Area	Waste quantities [Mg]									
	1995	2000	2004	2005	2010	2014	2015	2020	2025	2030
Bio-waste	9437	11308	12573	12744	12870	12148	11644	*8320*	*5690*	*4838*
Paper and cardboard	6611	7779	6983	7098	7805	7836	7477	*4024*	*1183*	*683*
Multi-material packaging.	149	806	1278	1368	1432	1495	1575	*2196*	*1844*	*1486*
Plastics	4190	6546	7085	7006	6660	6220	6076	*1471*	*737*	*781*
Glass	2455	3250	3618	3745	4670	4322	3435	*2336*	*1381*	*1203*
Metal	1132	1386	1306	1168	1041	1025	1001,0	*649*	*343*	*300*
Clothing, textiles	814	1315	1623	1696	1717	1726	1803	*1909*	*1127*	*557*
Wood	599	328	325	365	397	408	408	*449*	*414*	*438*
Hazardous waste	207	268	236	207	187	165	127	*87*	*40*	*28*
Ash fraction <10 mm	4168	4735	4165	3756	2984	2709	2760	*3240*	*3058*	*2676*
Mineral wastes	1312	1519	1625	1609	1702	1749	1714	*1739*	*2095*	*2484*
Other	342	439	919	1099	1462	1633	1670	*2759*	*3248*	*3751*
Bulky waste	711	381	262	310	378	350	321	*556*	*151*	*159*
Total	**32126**	**40059**	**41999**	**42173**	**43307**	**41786**	**40012**	***29735***	***21310***	***19385***

Share of selectively collected waste in the mass of WEEE [%]	99,6	94,1	88,4	88,2	86,6	82,3	79,2	*52,7*	*35,1*	*29,5*
Residues from waste sorting [Mg].	24	144	495	531	775	1075	1219	*4234*	*5699*	*6619*
Share of selectively collected waste in the mass of WEEE [%].	0,1	0,3	1,0	1,1	1,5	2,1	2,4	7,5	9,4	10,1

Italics - forecast values

Assuming:

- 6 - process lines with 4 chambers per line,
- working volume of chamber I approx. 320 m^3 ,
- 52 working weeks per year;
- bulk density of municipal waste in the chamber - 460 kg/m^3 (average value);

the capacity of the installation will be - 22963 Mg for the stabilisation time in the first step of 2 weeks (320-6-52/2-460/1000) and 15309 Mg for the stabilisation time in the first step of 3 weeks (320-6-52/3-460/1000). This is confirmed by the amounts of mixed municipal waste sent to the installation in 2000, 2001, 2012 and 2013. According to available data, 15275, 15294, 18973 and 15164 Mg of waste were sent for composting. It was therefore assumed that in 1995-1999 and 2002-2011 an average of 15204 Mg of mixed municipal waste was accepted.

Since 2013, after the construction of the mechanical part, the chamber composting plant has been processing the <80 mm fraction separated from the ZOK on a drum sieve in 5 technological lines and bio-waste in 1 line.

Assuming:

- 5 - process lines with 4 chambers per line (1 line is dedicated to composting of selectively collected bio-waste),
- bulk density of biofraction in the chamber - 508 kg/m^3 (average value);

the capacity of the installation will be - 21 133 Mg of whitewater fraction (320-5-52/2-508/1000).

The share of biofraction in ZOK is on average 71.3%. This means that an average of 29,639 Mg of ZOK (21,133 -100/71.3)≅ 30 thousand Mg can be processed annually at the MBP installation in Racula.

According to the available data, 353891, 36854, 33229 and 37931 Mg of waste were consecutively sent for composting between 2015 and 2018. This means that the waste in the chambers was kept for less than 2 weeks.

Table 22 shows the masses of residual waste remaining after separate collection and directed to mechanical-biological treatment (MBP).

Tabela 22. *Mixed municipal waste streams destined for mechanical-biological treatment (MBP) and their morphological composition*

Area	Waste quantities [Mg]									
	1995	2000	2004	2005	2010	2014	2015	2020	2025	2030
Bio-waste	4592	4353	4604	4653	4582	11121	10382	*8320*	*5690*	*4838*

Paper and cardboard	3216	2994	2557	2591	2779	7173	6667	*4024*	*1183*	*683*
Multi-material packaging.	72	310	468	499	510	1368	1404	*2196*	*1844*	*1486*
Plastics	2038	2520	2594	2558	2371	5694	5418	*1471*	*737*	*781*
Glass	1195	1251	1325	1367	1663	3957	3062	*2336*	*1381*	*1203*
Metal	551	534	478	426	371	938	892	*649*	*343*	*300*
Clothing, textiles	396	506	594	619	611	1580	1608	*1909*	*1127*	*557*
Wood	291	126	119	133	141	373	363	*449*	*414*	*438*
Hazardous waste	101	103	87	76	67	151	113	*87*	*40*	*28*
Ash fraction <10 mm	2028	1823	1525	1372	1062	2480	2461	*3240*	*3058*	*2676*
Mineral wastes	638	585	595	587	606	1601	1528	*1739*	*2095*	*2484*
Other	166	169	336	401	521	1495	1489	*2759*	*3248*	*3751*
Total	**15284**	**15275**	**15284**	**15284**	**15284**	**37931**	**35389**	***29179***	***21160***	***19225***

Italics - forecast values

Table 23 shows the masses and morphological composition of the supernatant fractions produced in the MBP plant and Table 24 shows the masses and composition of the stabilisers produced. The masses of stabilisers have been estimated assuming that the moisture content of the waste components remains unchanged during the process.

Tabela 23. *Streams of the supernatant fractions produced in the MBP installation*

Area	Waste quantities [Mg]									
	1995	2000	2004	2005	2010	2014	2015	*2020*	*2025*	*2030*
Bio-waste	-	-	-	-	-	1309	1254	*896*	*613*	*521*
Paper and cardboard	-	-	-	-	-	2627	2506	*1349*	*397*	*229*
Multi-material packaging.	-	-	-	-	-	525	553	*771*	*648*	*522*
Plastics	-	-	-	-	-	2436	2380	*576*	*289*	*306*
Glass	-	-	-	-	-	1514	1203	*818*	*484*	*421*
Metal	-	-	-	-	-	336	328	*213*	*112*	*99*
Clothing, textiles	-	-	-	-	-	788	823	*871*	*514*	*254*
Wood	-	-	-	-	-	121	121	*133*	*122*	*130*
Hazardous waste	-	-	-	-	-	45	34	*24*	*11*	*7*
Ash fraction <10 mm	-	-	-	-	-	0	0	*0*	*0*	*0*
Mineral wastes	-	-	-	-	-	441	432	*438*	*528*	*626*
Other	-	-	-	-	-	412	421	*696*	*819*	*946*
Total	**-**	**-**	**-**	**-**	**-**	**10552**	**10056**	***6785***	***4537***	***4062***

Italics - forecast values

Tabela 24. *Masses and morphological composition of stabilisers produced in the MBP plant*

Area	Waste quantities [Mg]									
	1995	2000	2004	2005	2010	2014	2015	*2020*	*2025*	*2030*
Bio-waste	2618	2488	2641	2673	2638	5645	5243	*4223*	*2882*	*2453*
Paper and cardboard	2797	2604	2224	2253	2416	3953	3618	*2326*	*684*	*395*
Multi-material packaging.	72	310	468	499	510	843	851	*1425*	*1196*	*964*

Plastics	2038	2520	2594	2558	2371	3258	3038	*895*	*448*	*475*
Glass	1195	1251	1325	1367	1663	2443	1859	*1518*	*897*	*781*
Metal	551	534	478	426	371	602	564	*436*	*230*	*202*
Clothing, textiles	379	485	569	593	585	759	752	*994*	*587*	*290*
Wood	278	120	114	127	135	241	232	*302*	*278*	*295*
Hazardous waste	101	103	87	76	67	106	79	*63*	*29*	*20*
Ash fraction <10 mm	2028	1823	1525	1372	1062	2480	2461	*3240*	*3058*	*2676*
Mineral wastes	638	585	595	587	606	1160	1096	*1300*	*1567*	*1858*
Other	166	169	336	401	521	1083	1068	*2063*	*2429*	*2806*
Total	12861	12991	12957	12934	12945	22573	20860	*18785*	*14286*	*13214*

Italics - forecast values

5.7. Waste disposed of in landfill

Table 25 presents the masses of WEEE generated in the city and municipality of Zielona Góra and the masses of waste subjected to PdPU and recycled, processed in the MBP installation and disposed of in the landfill.

Tabela 25. *Masses generated in the MBP plant*

Area	Waste quantities [Mg]									
	1995	2000	2004	2005	2010	2014	2015	*2020*	*2025*	*2030*
Total mass of waste generated in the region, of which:	32245	42557	47517	47834	50019	50746	50539	*56458*	*60710*	*65776*
• weight of waste from the city of Zielona Góra	30861	40573	44915	45047	46104	46083	45694	*50824*	*54298*	*58429*
• weight of waste from the municipalities of Zielona Góra	1383	1984	2603	2786	3914	4663	4845	*5634*	*6413*	*7347*
PdPU and recycled waste	95	2354	5023	5130	5937	7885	9308	*22490*	*33701*	*39773*
ZOK processed in installation. MBP	15284	15275	15284	15284	15284	37931	35389	*29179*	*21160*	*19225*
Waste disposed of in landfill, including:	29727	37920	40167	40353	41743	38055	36759	*30360*	*24672*	*24054*
• sorting residues	24	144	495	531	775	1075	1219	*4234*	*5699*	*6619*
• bulky waste	711	381	262	310	378	350	321	*556*	*151*	*159*
• ZOK without bulky waste without treatment at the MBP plant	16131	24403	26453	26579	27645	3505	4302	*0*	*0*	*0*
• off-set fraction	0	0	0	0	0	10552	10056	*6785*	*4537*	*4062*
• stabiliser	12861	12991	12957	12934	12945	22573	20860	*18785*	*14286*	*13214*
Loss of mass in the biostabilisation process in an installation. MBP	2423	2283	2327	2350	2339	4805	4472	*3609*	*2337*	*1950*

Italics - forecast values

5.8. Landfill biogas production

The projected quantities and temporal variability of biogas produced at the landfill were developed based on the Rattenberger/Tabasaran methodology (Krümpelbeck 2000).

The assumptions used are given in Table 26.

Tabela 26. *Assumptions made*

Area	ZOK +Superfraction +Sorting residues		Stabilizat	
Deposit temperature [ºC]	30			
Carbon content of organic matter [kg/Mg].	181,0		55,0	
Total gas production from waste [m3/Mg].	236,8		71,9	
Share of degradable fraction [%]:				
• easily (bio-waste, green waste)	53,9		43,7	
• medium (paper, wood)	35,0		41,2	
• difficult to decompose	11,1		15,1	
Fractional half-life values [years]:	Min. half-life	Max half-life	Min. half-life	Max half-life
• easily (bio-waste, green waste)	3	6	3	6
• medium (paper, wood)	6	25	6	25
• difficult to decompose	12	40	12	40
Volume flow of gas that can be released [%].	60			

The calculation of potential methane emissions from the landfill in mass units was calculated by multiplying the resulting volume of biogas produced by its concentration (50%) and by its molar mass (16 g) and dividing by the molar volume (22.4 l/mol).

Tabela 27. *Estimated landfill biogas and methane emissions*

Area	Values in years									
	1995	2000	2004	2005	2010	2014	2015	2020	2025	2030
Waste disposed to landfill [Mg], of which:	29727	37920	40167	40353	41743	38055	36759	*30360*	*24672*	*24054*
Biogas production [thousand m3/a].	3856	4793	5548	5690	6204	6187	5928	*4996*	*3872*	*3427*
Biogas production [m^3 /h]	440	547	633	650	708	706	677	*570*	*442*	*391*
Biogas emissions [m^3 /h]	264	328	380	390	425	424	406	*342*	*265*	*235*
Biogas emissions [kg CH_4 /h]	94,3	117,3	135,7	139,2	151,8	151,3	145,0	*122,2*	*94,7*	*83,8*
Biogas emissions [Mg CH_4 /a]	826	1027	1189	1219	1329	1326	1270	*1071*	*830*	*734*

Italics - forecast values

6. Literature

1. Act of 14 December 2012 on waste (Journal of Laws 2013, item 21).
2. Directive 2008/98/EC of the European Parliament and of the Council on waste and repealing certain Directives (OJ L 312, 22.11.2008, p. 3).
3. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Closing the loop - An EU roadmap for a circular economy. Brussels, 2.12.2015. COM(2015) 614 final. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016AE0042 (4.07.2020).
4. Population forecast of municipalities for 2017-2030 (experimental study)". Retrieved from: https://stat.gov.pl/obszary-tematyczne/ludnosc/prognoza-ludnosci/prognoza-ludnosci-gmin-na-lata-2017-2030-opracowanie-eksperymentalne,10,1.html (7.07.2020).
5. Projections for counties and cities with county rights for 2014-2050. Retrieved from: http://stat.gov.pl/obszary-tematyczne/ludnosc/ (14.07.2020).

6. Update of the Provincial Waste Management Plan together with the Municipal Waste Investment Plan. Draft. Zielona Góra, 2018. Retrieved from: https://bip.lubuskie.pl/system/obj/39447_AWPGO_zmiana.pdf (12.07.2020).
7. Janka W.; Waste management plan for the city of Zielona Góra. THE "PREKO ZG" SYSTEM. Annex to the Resolution No. XVI/152/03 of the City Council of Zielona Góra of November 4, 2003. Retrieved from: https://bip.zielonagora.pl/system/obj/1914_0152r03-z01.pdf (22.07.2020).
8. Jędrczak A.; Composting of waste in open composting chambers with aeration in Zielona Góra, Gas, Water and Sanitary Technology, 1995, No. 2, pp. 37-40.
9. Council Directive of 18 March 1991 amending Directive 75/442/EEC on waste. Official Journal L 078, 26/03/1991 P. 0032 - 0037.
10. Waste management plan for Zielona Góra district for years 2009-2012 with perspective for years 2013-2020. Zielona Góra, 2010. Annex to the Resolution XXXIX/305/10 of the Zielona Góra District Council of 26th August 2010. Retrieved from: https://bip.powiat-zielonogorski.pl/system/obj/3618_XXXIX_305_10_Zal.pdf (14.07.2020).
11. Sudnik R. Thesis "Selective collection of secondary raw materials for the city of Zielona Góra", Zielona Góra, 1996.
12. Waste management plan 2012 for the city of Zielona Góra - Draft. Zielona Góra, June 2008.
13. Report of the Mayor of the City of Zielona Góra on the implementation of municipal waste management tasks for 2017. Retrieved from: https://bip.zielonagora.pl/542/13831/Reports_dot_of_waste_management_for_year_2017/ (14.07.2020).
14. Analysis of the state of municipal waste management of the city of Zielona Góra in 2016. Retrieved from: https://bip.zielonagora.pl/system/obj/49330_Roczna_analiza_za_2016_r.PDF (14.07.2020).
15. Report of the Mayor of Zielona Góra on the implementation of municipal waste management tasks for 2015. Document obtained from ZZO Racula.
16. Jędrczak A. Assessment of technological efficiency of the MBP Installation in Racula. Zielona Góra, September 2014. research commissioned by the Department of Public Utilities and Housing in Zielona Góra.
17. Resolution No. 219 of the Council of Ministers of 29 October 2002 on the National Waste Management Plan. M.P. 2003 nr 11 poz. 159. Retrieved from: http://isap.sejm.gov.pl /isap.nsf/DocDetails. xsp?id=WMP20030110159 (17.07.2020).
18. Resolution No. 217 of the Council of Ministers of 24 December 2010 on the "National Waste Management Plan 2014". M.P. 2010 nr 101 poz. 1183. Retrieved from: http://isap.sejm.gov.pl/ isap.nsf/ DocDetails xsp?id=WMP20101011183 (12.07.2020).
19. Jędrczak A. Ecological review of the landfill site in Racula, near Zielona Góra. Zielona Góra, 2002.

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ANNEX No. 2

Balance and nitrogen emissions from wastewater treatment systems in the Zielona Góra agglomeration in 2007 -2020

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Balance and nitrogen emissions from wastewater treatment systems in the Zielona Góra agglomeration for the years 2007-2020

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1. National Programme for Municipal Waste Water Treatment, applicable law

When acceding to the European Union, Poland undertook to meet the requirements of Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment (Official Journal of the European Communities L 135 of 30 May 1991, pp. 40-52, as amended; Official Journal of the European Communities Polish special edition, Chapter 15, Volume 002, p. 26) in accordance with the deadlines and transition periods determined in the negotiations and enshrined in the Accession Treaty. In the pre-accession talks, adjustment transition periods were negotiated for the implementation of the provisions of the above mentioned Directive until the end of 2015. Therefore, the National Programme of Municipal Wastewater Treatment (KPOŚK) was established in order to identify the actual needs in terms of wastewater management and to prioritise their implementation in such a way as to meet the Treaty obligations. The Programme was adopted by the Council of Ministers on 16 December 2003. KPOŚK provides a list of agglomerations which must be equipped with collective sewage systems and treatment plants by the deadlines set out in the Programme. Since the accession of the Republic of Poland to the European Union there has been a significant progress in wastewater management. The reduction of pollutant loads discharged into waters has translated into a noticeable improvement in water quality in rivers and lakes.

To date, there have been five updates to the KPOŚK in: 2005, 2009, 2010, 2015 and 2017, and between 2003 and 2018:

- 87,500 km of sewerage network was constructed, of which 2727 km of network was constructed in 2018,
- 416 new municipal wastewater treatment plants were built (2018 - 13 plants),
- 1,732 investments were carried out for the modernisation and/or expansion of municipal wastewater treatment plants (in 2018 - 157 investments),
- approximately PLN 69.5 billion was spent on investments (in 2018 - PLN 3.7 billion).

31 July 2017. The Council of Ministers adopted the fifth update of the KPOŚK with a list of tasks planned by local governments for implementation in 2016-2021. AKPOŚK 2017 concerns 1587 agglomerations with an equivalent population of 38.8 million, in which 1769 municipal wastewater treatment plants are located. The agglomerations included in the update have been prioritised according to the importance of investments and the urgency of providing resources. According to the investment intentions presented by the agglomerations, 116 new wastewater treatment plants are planned to be constructed and other investments are planned in 1010 wastewater treatment plants in the fifth update. It is also planned to construct 14 661 km of new sewage network and modernise 3 506 km of the existing network. Financial needs for the implementation of the above mentioned undertakings amount to PLN 27.85 billion. As a consequence of approving the fifth update of the KPOŚK, a new version of the Master Plan for the Wastewater Directive was created. The Master Plan contains a summary of the most important planning information in the field of wastewater management shown in the update. The document was approved by the Management of the Ministry of Environment on 8 September 2017. In order to stimulate and enforce as well as coordinate the activities of

municipalities and water and sewerage companies in the expansion, construction and modernisation of sewerage systems and municipal wastewater treatment plants, the Minister responsible for water management prepares and updates the National Programme for Municipal Wastewater Treatment. This document is approved by the Council of Ministers. The National Programme for Municipal Waste Water Treatment, of which the list of agglomerations and the list of necessary undertakings for the construction and modernisation of sewage systems is an integral part, should include in particular

- the material and financial scope of these projects,
- the completion dates for the planned projects.

The economic and financial instruments stimulating implementation of the KPOŚK include EU aid funds, loans and grants from ecological funds, as well as fees fees and penalties for specific use of the environment, including increased fees if the communes do not implement the provisions of the KPOŚK on time.

In the Polish legal system, issues related to wastewater management, rational shaping and protection of water resources are regulated through the provisions of the Act of 20 July 2017. **Water Law** (Dz. U. 2020.310). The legal, organisational and economic solutions contained in the Act, addressed to both water owners, users and public administration bodies, are intended to serve water protection, which aims to maintain or improve water quality and biological relations in the aquatic environment and wetlands. For the purposes of programming, coordinating and reporting on waste water collection and treatment activities resulting from the fulfilment of Poland's obligations assumed in the Treaty of Accession to the European Union concerning the implementation of the provisions of Council Directive 91/271/EEC on urban waste water treatment, the term "agglomeration" was introduced in the Water Law Act, denoting an area where population or economic activity is sufficiently concentrated for urban waste water to be collected and forwarded to a waste water treatment plant or to the final waste water discharge point. It is assumed that the minimum concentration ratio is 120 persons per 1 km of built network. Exceptions are e.g. areas of nature conservation, protection of water intakes, etc., where the concentration factor may be 90 people per 1 km of built network. The concentration ratio may be 90 persons/1 km. The manner of determining the area and boundaries of agglomerations is set out in the Regulation of the Minister of Maritime Affairs and Inland Navigation of 27 July 2018 on the manner of determining the areas and boundaries of agglomerations (Journal of Laws of 2018, item 1586).

The concept of agglomeration and the technical and economic rationale for determining the extent of the collective sewage system in the commune constitute the basis for the delimitation of areas and boundaries of agglomerations. In areas where construction of collective sewerage systems would not benefit the environment or would cause excessive costs, individual systems or other solutions ensuring the same level of environmental protection as collective sewerage systems should be applied, in accordance with Article 88(4) of the Water Law (transposing Article 3(1) of Council Directive 91/271/EEC). The area of an agglomeration may include one or more settlement units (city, rural settlement) or only part thereof. The limits of an agglomeration therefore do not coincide with the administrative borders of the communes but should run along the borders of the registered parcels. The municipality with an agglomeration or the municipality with the largest population equivalent (where the agglomeration is located on the territory of more than one municipality) is responsible for implementing waste water collection and treatment programmes for the area of the agglomeration.

The conditions to be met when discharging waste water to waters or to the ground, including for waste water from treatment plants in agglomerations, are set out in the **Regulation of the Minister for Maritime Affairs and Inland Navigation** on substances that are particularly harmful to the aquatic environment and the conditions to be met when discharging waste water to waters or to the ground, and when discharging rainwater or snowmelt to waters or to water facilities (Journal of Laws 2019, item 1311). According to the regulations contained in the regulation, domestic wastewater from wastewater treatment plants in agglomerations and municipal wastewater from wastewater treatment plants in agglomerations, discharged to waters or to the ground, must not contain pollutants in quantities exceeding the maximum permissible values, or should meet the minimum percentage reduction of pollutants which ensures that the maximum permitted values for polluting substances are not exceeded (Annex 3 of the Regulation), and the quantity of waste water discharged into waters or onto land is measured continuously or, if not discharged continuously, it is measured during periods of waste water discharge in such a way as to make it possible to determine the actual quantity of waste water discharged.

Tabela 1. *Maximum limit values for polluting substances or minimum percentage of reduction of polluting substances for waste water from waste water treatment plants in an agglomeration discharged into water or into the ground [1)]*

Lp.	Name of the substance [2)]	Unit	Maximum limit values of pollutant indicators or minimum percentage of reduction of pollutants for domestic or urban waste water entering waters or the ground: for the p.e. of the agglomeration[3)] : since 2000 up to 9999	10000 to 14999	from 15000 to 99999	100000 and above
1	Five-day biochemical oxygen demand (BOD_5 at 20° C), determined with the addition of a nitrification inhibitor	mgO_2 /l min. % reduction	25 or 70-90	25 or 70-90	15 or 90	15 or 90
2	Chemical oxygen demand (COD_{Cr}), determined by the bichromate method	mgO_2 /l min. % reduction	125 or 75	125 or 75	125 or 75	125 or 75
3	Total suspended solids	mg/l min. % reduction	35 or 90	35 or 90	35 or 90	35 or 90
4	Total nitrogen (sum of Kjeldahl nitrogen (N_{Norg} + N_{NH4}), nitrite nitrogen and nitrate nitrogen)	mgN/l min. % reduction	15[4)] -	15 or 70- 80[5)]	15 or 70-80	10 or 70-80
5	Total phosphorus	mgP/l min. % reduction	2[4)] -	2 or 80[5)]	2 or 80[5)]	1 or 80[5)]

Explanations:
[1)] (1) The maximum levels or minimum percentage reductions of polluting substances set out in the Annex: (a) biochemical oxygen demand (BOD5), chemical oxygen demand determined by the bichromate method (CODr) and total suspended solids - refer to their values in average daily samples, except that in the case of urban waste water treatment plants with periodic daily discharges, the authority in the permit may prescribe a simplified method of waste water sampling if it can be demonstrated that the results of the determinations will be representative of the amount of pollution discharged,

(b) total nitrogen - refer to the annual average value in the waste water, calculated from daily average samples taken over a period of one year. Alternatively, nitrogen removal requirements may be determined on the basis of daily average samples if it can be demonstrated that the same level of protection of the water bodies against pollution is achieved. In this case, the daily average sample must not exceed 20 mg/l total nitrogen for all samples with an outlet temperature in the biological reactor greater than or equal to 12 °C. Temperature conditions may be replaced by a limit on the duration of the operation in order to take account of regional climatic conditions, (c) total phosphorus - concerning the annual average value in the effluent;

(2) The minimum percentage of reduction of pollutants shall be determined in relation to the load of pollutants in the waste water entering the treatment plant in the agglomeration.

[2)] Analysis shall be performed on homogenised, undecanted and unfiltered samples, except in the case of pond drains, where determination of BOD5, CODCr, total nitrogen and total phosphorus shall be performed on filtered samples. Samples taken from the biological pond outlet shall be filtered beforehand, however, the content of total suspended solids in unfiltered samples shall not exceed 150 mg/l, irrespective of the size of the treatment plant.

[3)] During the start-up of newly constructed, expanded or rebuilt treatment plants and in the event of failure of facilities essential for the implementation of the water permit, the maximum limit values for polluting substances shall be increased to a maximum of 50% and the required reduction of polluting substances shall be reduced to a maximum of 50% compared to the values in the Annex.

[4)] Values required only for waste water entering lakes and their tributaries and directly into artificial bodies of water situated on running water.

[5)] The minimum percentage of reduction of polluting substances shall not apply to waste water discharged into lakes and their tributaries, directly into artificial bodies of water situated on running water, or into the ground.

The issues concerning the management of municipal and domestic sewage are the own tasks of the municipality and are regulated in the Act of 7 June 2001. **On collective water supply and collective sewage disposal** (Journal of Laws of 2019, item 1437) and the Act of 13 September 1996 **On the maintenance of cleanliness and order in municipalities (**Journal of Laws of 2019, item 2010). The municipalities' own tasks include the issues of water supply and supply, sewerage and municipal sewage disposal and treatment - in accordance with the Act of 8 March 1990 on municipal self-government (Journal of Laws of 2019, item 506). The municipality may entrust its tasks in the field of water supply and sewage disposal to specialised entities - water supply and sewage companies. They are obliged to ensure the capacity of their water supply and sewerage facilities to supply water in the required quantity and under appropriate pressure, and in a continuous and reliable manner
They are also obliged to ensure that their water supply and sewerage facilities are capable of delivering sewage in the required quantity and at the required pressure, in a continuous and reliable manner,
in a continuous and reliable manner, as well as ensure adequate quality of supplied water and discharged wastewater.
and discharged sewage. Collective water supply and sewage disposal services and sewage disposal are basic services ensuring an adequate standard of living and sanitary conditions for the population and should be provided by the municipality simultaneously.

2. Characteristics of the study area

The subject of the analysis is the management of wastewater from the Zielona Góra agglomeration established by Resolution NR XXI/252/16 of the Sejmik of the Lubuskie Voivodeship of 20 June 2016. The agglomeration area includes: The City of Zielona Góra, part of the sołectvos located in the area of the New City District and the village of Wilkanowo located in the area of the municipality of Świdnica (Official Journal of the Lubuskie Voivodeship 2016, item 1314).

2.1. Geographical location, area

2.1.1. Zielona Góra

Zielona Góra and the adjacent municipalities are located in western Poland, and is part of the Lubuskie Province. The city lies almost on the crossroads of international road and rail routes connecting Scandinavia with the south of Europe and Warsaw with Berlin.
Zielona Góra is entirely surrounded by forests, forming a forest glade.

Total area of the town before the merger with the municipality: 58.3 km^2 , of which: agricultural land accounts for - 9.3%, built-up and urbanised areas - 28.8% (built-up, residential areas - 5.7 km^2 , built-up, industrial areas - 2.0 km^2 , roads - 5.66 km^2), green, recreational and leisure areas - 3.2%, forests and forest land - 46.1%, land under water - 0.34%, wasteland - 0.09% and other areas - 15.4%.

2.1.2. Municipality of Zielona Góra

The Zielona Góra Commune was a rural municipality, one of the 10 municipalities of the Zielona Góra district. From the north, east and south, it surrounded its area and was directly adjacent to the city of Zielona Góra. From the west, it bordered the Czerwieńsk and Sulechów municipalities.

Total area of the municipality: 220.45 km^2 , of which: agricultural land accounted for - 33.1%, built-up and urbanized areas - 6.9%, forests and forest land - 57.9%. land under water - 0.43%, wasteland - 0.28% and other areas - 1.3%. The commune consists of 18 solectwos (Table 2) and 4 villages without the status of solectwos: Barcikowiczki, Krępa Mała, Przydroże and Stożne.

2.2. Merger of the City of Zielona Góra and the Municipality of Zielona Góra

On 1 January 2015 there was a merger of two units of local government - the City of Zielona Góra - on the rights of the county and the municipality of Zielona Góra into one unit of local government - the City of Zielona Góra - on the rights of the county, covering the administrative borders of both combined units of local government. These actions are to be the fastest way to increase the spatial and demographic potential of the city, affecting the whole Lubusz region and to create a strong medium-sized agglomeration centre. The inhabitants of the city and commune expressed their consent to the creation of a joint local government unit in a communal referendum.

2.3. Demographic situation

Zielona Góra. The population of Zielona Góra was at the end of 1995. - 116329 people (Table 1), the natural growth rate was equal to about 3%, and the population density per 1 km^2 - 1995. In 2015 the population of Zielona Góra (within the limits of 2014) was - 118975 people, and the natural growth rate was equal to about 0.2%. In 2030 the city of Zielona Góra will be inhabited by 141612 people and the population density per 1 km^2 will be 508.

The basis for this forecast is data from two studies:

- Population projection of municipalities for 2017-2030 [CSO, 2017];
- Projections for counties and cities with county rights for 2014-2050 [CSO, 2014].

Tabela 2. *Population forecast*

Area	Population on 31.12.									
	1995	2000	2004	2005	2010	2014	2015	2020	2025	2030
m. Zielona Góra (within the limits until 2014)	116329	118103	118516	118221	118950	118920	118975	*120937*	*120662*	*120002*
m. Zielona Góra (Nowe	13 167	14 728	15 834	16 128	18 434	19 592	19736	*20451*	*21094*	*21610*

Miasto District)										
City of Zielona Góra (within the limits from 2015)	-	-	-	-	-	-	138711	*141388*	*141756*	*141612*

Italics - forecast values

The municipality of Zielona Góra in 1995 had 13 167 inhabitants (as of 31.12.1995). The average population density per 1 km^2 was 59.7. The natural growth rate was equal to 1.1%. In 2015, the population of the now defunct Zielona Góra Municipality was - 19736 people and the natural growth rate was equal to about 0.7%. In 2030, the population of the Nowe Miasto District will be 21610.

2.4. Sewage collection and treatment system in the Zielona Góra agglomeration

The sewage collection and treatment system had been operating in the town since the 1920s, in 1921 the construction of the town sewage system began and the Łącza stream was rebuilt into the main collector carrying sewage from the town. In the years 1929-1938 the main collector was rebuilt and the town was sewered, and in 1934 a municipal sewage treatment plant with a capacity of 19500 m^3 /d at Foluszowa Street was opened. In the 1950s the distribution sewerage system was extended and in 1971 the length of the network reached 100km.
As soon as the main sewer was put into operation, the sewage treatment plant was shut down.

From 1945, the water supply and sewage infrastructure was managed by the Gasworks and Municipal Waterworks Company, and in 1956 the Municipal Water Supply and Sewage Company was established. In connection with the administrative reform, in 1975, the State Water Supply and Sewage Company was established by merger. In 1991, the enterprise was transformed into a budgetary entity named Zakład Wodociągów i Kanalizacji (Waterworks and Sewage System Company). On 1 July 2004, the budgetary entity was transformed into a single-member limited liability company of the Municipality, registered in the National Court Register under the following KRS number: 0000211506, under the name of "Zielona Góra Waterworks and Sewage System Company". On 31 March 2007 a merger took place between the "Łącza" Water Treatment Plant and the Company "Zielonogórskie Wodociągi i Kanalizacji".
After the closure of the sewage treatment plant at Foluszowa Street, Zielona Góra did not have a sewage treatment plant until 1997. After the sewage treatment plant at Foluszowa Street was closed down, Zielona Góra did not have a sewage treatment plant until 1997. As a result of the pollution, the watercourses of the Laka and Zimna Woda turned into open sewers. The average values of the indices in the Laka watercourse were as follows: BOD_5 411mg/dm^3 , COD 1250 mg/dm^3 , and total suspended solids 339 mg/dm^3 . The inflow of sewage from the Laka River

to the Zimna Woda watercourse caused complete degradation of the waters of this river. In 1997, the waters of these rivers were classified, on the basis of the following indicators: physico-chemical to the III quality class, hydrobiological and bacteriological
and bacteriological indicators as not meeting the standards, excessively polluted. The opening of the sewage treatment plant in the Laka River has improved the quality of the waters of the Laka and Zimna Woda Rivers (Table 3). In 1999 an improvement in the physico-chemical parameters of the waters of the Ziemna Woda River in the estuarial section and of the Laka River along its whole length was noted. The assessment of hydrobiological parameters has also improved. No improvement was found in the sanitary condition of both rivers.

Table 3. *Classification of the waters of the Zimna Woda and Laka rivers before and after commissioning of the Laka sewage treatment plant*

Indicator pollution	Location of selected cross-sections of measurement and control points and classification of waters of the Zimna Woda and Łącza Rivers							
	River Coldwater, above the mouth of the Lia River		River Link in the Przylep area		River Łącza before its confluence with the Cold Water		River Zimna Woda, before it enters the Oder	
	1997r.	1999r.	1997r.	1999r.	1997r.	1999r.	1997r.	1999r.
BOD_5	III	II	n.o.n.	I	n.o.n.	III	n.o.n.	II
COD_{Cr}	II	I	n.o.n.	II	n.o.n.	II	n.o.n.	II
Suspension og.	I	I	n.o.n.	I	n.o.n.	II	n.o.n.	II
Ammoniacal nitrogen	II	I	n.o.n.	I	n.o.n.	I	n.o.n.	I
Nitrite nitrogen	III	I	n.a.[3)]	III	n.o.n.	n.o.n.	n.o.n.	n.o.n.
Total nitrogen	I	I	n.a.	I	III	II	III	II
Phosphates	II	II	n.o.n.	II	n.o.n.	n.o.n.	n.o.n.	II
Phosphorus og.	II	III	n.a.	III	n.o.n.	n.o.n.	n.o.n.	III
Saprobity	III	II	n.a.	II	n.o.n.	III	n.o.n.	III
Cola titer	n.o.n.[2)]	II	n.a.	n.o.n.	n.o.n.	n.o.n.	n.o.n.	n.o.n.
Total								
Physical and chemical indicators	III	III	n.o.n.	III	n.o.n.	n.o.n.	n.o.n.	n.o.n.
Hydrobiological indicators	n.o.n.	II	n.a.	II	n.o.n.	III	n.o.n.	III
Bacteriological indicators	n.o.n.	II	n.a.	n.o.n.	n.o.n.	n.o.n.	n.o.n.	n.o.n.

1) I, II, III - water purity classes
2) n.o.n. - substandard, excessively polluted waters
3) n.a. - no data, analysed as waste water

2.5. Zielonogórskie Wodociągi i Kanalizacji sp. z o.o.

Currently, in the area of the agglomeration of Zielona Góra, the services in the area of water intake and treatment, water supply, sewage disposal, collection and treatment of sewage, construction of water and sewage systems, in particular water and sewage services in the area of the city of Zielona Góra and in the village of Wilkanowo in the commune of Świdnica are provided by Zielonogórskie Wodociągi i Kanalizacji Sp. z o.o. Zielonogórskie Wodociągi i Kanalizacja Sp. z o.o. is a company with 100% share of the City of Zielona Góra. The company was established for a strictly defined purpose - the fulfilment of own tasks of the city of Zielona Góra. On the basis of a natural monopoly it is the only entity able to provide services in the field of collective water supply and collective sewage removal in Zielona Góra.

The water supply network in the agglomeration area amounts to 508.2 km, and the degree of water supply covers 99% of the area of the Zielona Góra agglomeration. The sewerage networks cover 98% of the agglomeration area with a total length of 386.1 km, including 7.7 km in the Świdnica Commune.
From the non-channelised area of the Zielona Góra agglomeration wastewater is transported to the treatment plants by means of septic tankers. For the needs of the whole agglomeration there is one sewage treatment plant in Łężyca.

In the area of the Zielona Góra agglomeration, projects have been carried out successively in order to improve water quality and to protect groundwater from pollution by domestic sewage, to eliminate deficiencies in the poor technical condition of sewers, to modernise the water production process and to prevent ecological damage. Since 2004, the company has been carrying out large investments with co-financing from the European Union, thanks to which it has been possible to construct a sewage system in Przylep, Stary and Nowy Kisielin, and a water supply system in Wilkanowo. Then, between 2007 and 2013, the company completed two major sewage projects in Racula and Drzonkowo. In the next stage, a sewage system was built in the villages of Łężyca, Krępa and Zawada. In the current EU perspective two projects are being implemented. One concerns the sewage system and water supply in the New Town district - a sewage system in Zatoń, water supply system in Krępa and Łężyca. The Waste Water Treatment Plant for Zielona Góra in Łężyca is also being extended. The Water Treatment Station for the city will be modernised. Thanks to these investments it can already be said that Zielona Góra will be 100% supplied with water, the percentage of sewerage of the whole agglomeration will increase. The investments carried out in the first three stages between 2004 and 2015 cost almost PLN 310 million, of which the EU subsidy amounted to PLN 173 million. The remaining money is the company's own funds, including preferential loans from the National Fund for Environmental Protection and Water Management and the Voivodeship Fund for Environmental Protection and Water Management. Stage IV is a project worth PLN 62.2 million, EU co-financing amounted to PLN 39.7 million. Stage V is an investment worth PLN 70.8 million. Other investments include providing water and sewage infrastructure for the Industrial and Technological Park in Nowy Kisielin and constructing a storm water drainage system in the Czarkowo settlement in Łężyca. Both worth over PLN 10 million. The implemented projects realise the main objective of the OPI&E Priority Axis 1: Water and sewage management, which is equipping (by the end of 2020) agglomerations above 10,000 p.e. with sewage systems and sewage treatment plants. The project will ensure among others - reduction of external environmental costs for the economy, ensuring proper treatment of municipal sewage, increasing accessibility to the collective sewage system.

2.6. Area served by ZWiK Sp. z o.o.

The water supply of the city of Zielona Góra is based on:

- surface water intake from the Obrzyca River in Sadowa,
- groundwater intake from the Odra Proglacial Valley in the vicinity of Zawada,
- local groundwater intakes located in the city (7 wells),
- local intakes within the New Town district (Jany, Jarogniewice, Łężyca, Ochla, Stary Kisielin, Zatonie, Zawada).

The water supply networks operated by the Company are located in the area of Zielona Góra, in the municipality of Zielona Góra (Przylep, partly in the town of Zawada and Nowy Kisielin) and part of Wilkanowo in the municipality of Świdnica.

Wastewater from households, industrial plants, services and public utilities from the Zielona Góra agglomeration and from the village of Wilkanowo - Świdnica commune are treated in the wastewater treatment plant Łącza. The number of inhabitants served by the treatment plant at the time of establishing the Zielona Góra agglomeration (2016) is presented in Table 4., while the current number of p.e. (equivalent population) of the agglomeration is 198,087.

Table 4: *Area of the agglomeration of Zielona Góra served by ZWiK Sp. z o.o.*

Lp.	Municipality	Number of inhabitants
1	City of Zielona Góra	117699
2	Nowe Miasto District	
	Przylep	3035
	Krępa	697
	Zawada	1697
	Racula	2367
	New Kisielin	1204
	Old Kisielin	1724
	Drzonków	1589
3	Świdnica Municipality	
	Wilkanowo	1098
LM together:		**131 110**

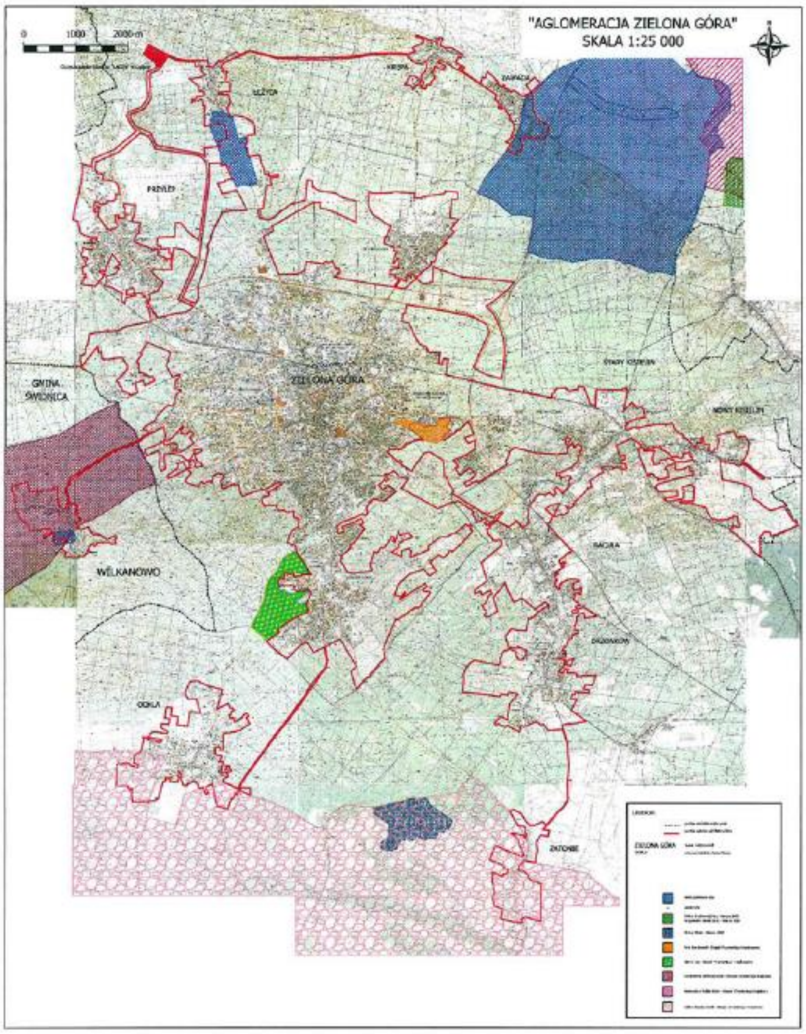

Fig. 1. Borders of the agglomeration Zielona Góra (Dz. Urz. Woj. Lub. 2016, item 1314)

3. Sewage treatment plant "Łącza"

The "Łącza" sewage treatment plant was built by the "Łącza" Water and Sewage Company, which was established in 1985 as a special purpose vehicle for the construction of a sewage treatment plant for Zielona Góra and the construction of an inflow channel and sewage outlet to the reception tank. Implementation of the task began in 1989. In 1993, PASSAVANT WERKE AG was chosen as the supplier of wastewater treatment technology and equipment. A year later, P.B.P. EKOSYSTEM was selected as the general designer of the plant. In August 1998, the technological start-up began and in December 1998 the plant was put into operation. After the completion of construction works, the "Łącza" Water and Wastewater Company started to operate the plant and changed its name to "Łącza" Water Company. Since March 2007. Wastewater Treatment Plant "Łącza" merged with the Company "Zielonogórskie Wodociągi i Kanalizacji".

3.1. Description of the technological line of mechanical and biological wastewater treatment "Łącza"

The "Łącza" sewage treatment plant was put into operation in December 1998 as the central treatment plant for Zielona Góra. It is situated about 7 km north of Zielona Góra in an area west of the village of Łężyca, 2 - 3 km from the Czerwieńsk - Wysokie and Zielona Góra - Wysokie roads.

Photo 1. Sewage treatment plant "Łącza" in Zielona Góra - Łężyca (www.zwik.zgora.pl)

The Łącza WWTP with a capacity of $Q_{śrd}$ = 51 225 m^3 /d (310 500 p.e., dry weather: Q_{dmax} =2 880 m^3 /h, rainy weather: Q_{dmax} = 5 760 m^3 /h) has been designed with a mechanical, biological and chemical wastewater treatment system. Wastewater is fed to the treatment plant through an open channel equipped with damming structures forming 5 retention tanks with a total capacity: 84 000 m^3 . At the moment, due to the high hydraulic capacity, all municipal wastewater is directed to the treatment plant: sanitary, rain, infiltration, accidental and delivered.

The Łącza WWTP covers an area of 8.17 ha and is equipped with the following facilities:

- inflow channel with a venturi to measure the amount of wastewater entering the treatment plant,
- a combined sewage collection point equipped with flow measurement and magnetic card readers,
- overflow separation chamber for the removal of excess rainwater (technological bypass of the treatment plant)
- grilles, main screen pumping station,
- blow-through sandblasters,
- sand separators,

- primary settling tank,
- activated sludge chambers,
- secondary settling tanks,
- press and sludge thickener,
- sludge drying and incineration plant,
- administrative and social buildings and a workshop.

The treatment plant operates in a 3-stage biological wastewater treatment system with biological defosfatation, denitrification and nitrification (Figure 2).

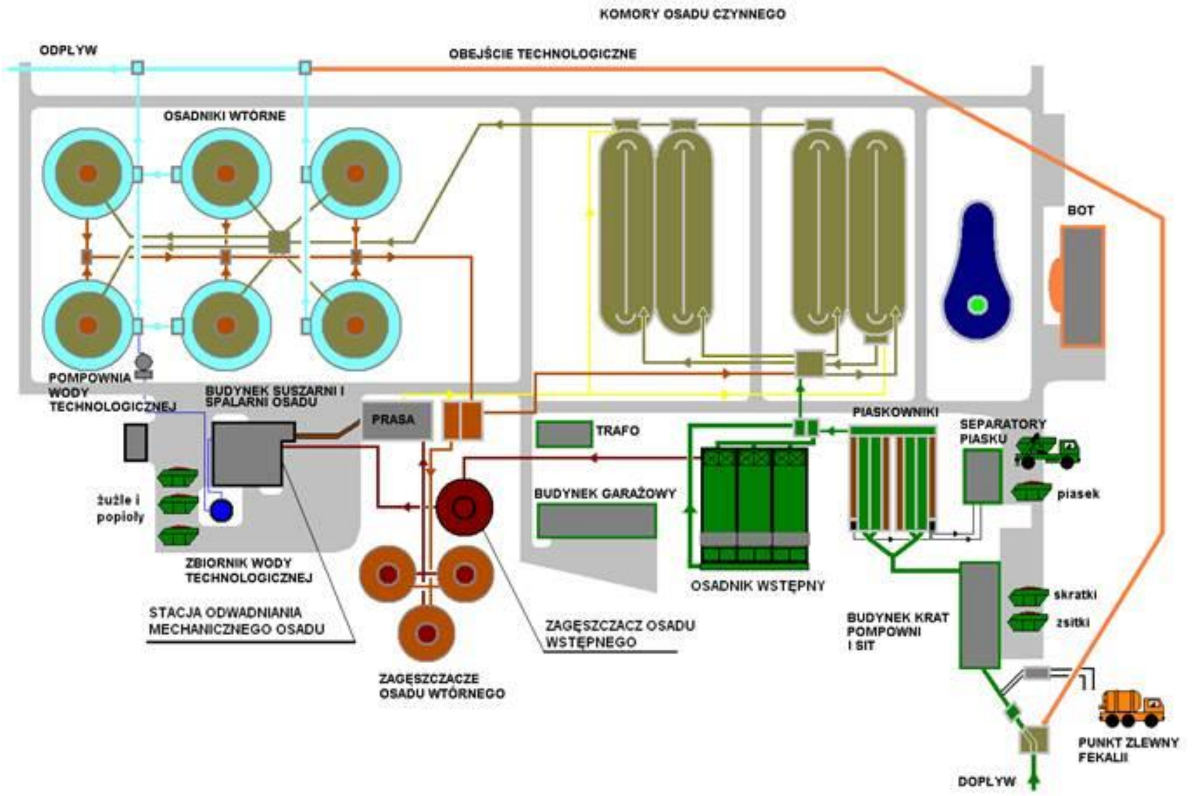

Fig. 2 Technological scheme of the sewage treatment plant "Łącza" (www.zwik.zgora.pl)

The threshold values of pollutants in treated wastewater according to the water permit are summarised in Table 5.

Table 5. *Threshold values of pollutants in treated sewage discharged from sewage treatment plant Łącza*

parameter mg/dm^3	COD	BOD_5	N-NH_3	$N_{tot.}$	$P_{tot.}$	TSS	Cl^-	SO_4^{2-}	Cd	Ni	Pb	Cr
	125	15	10	10	1	35	1000	500	0.2	0.5	0.5	0.1

3.1.1. Mechanical part

The first stage of wastewater treatment is the so-called mechanical treatment - wastewater is fed to screens, further on to sand traps, from where it goes to the primary settling tanks.

Wastewater from the overflow separating chamber flows through the open inflow channel, in which a measuring venturi has been built, to the grit chamber building. In order to allow the reception of sewage transported by septic tankers, a reception point equipped with flow measurement and magnetic card readers was built.

Photo 2. Sink point (www.zwik.zgora.pl)

Wastewater from the catchment point is discharged into the influent channel upstream of the metering equipment. Raw sewage entering the facility is directed to two mechanically cleaned screens with a clearance of 50 mm, and then flows into the main pumping station equipped with five submersible pumps, from where it is pumped to five rotary dense screens with a clearance of 2.5 mm. The retained screenings are discharged by belt conveyor to a container, then hygienised with chlorinated lime and taken to a landfill.

	
thin gratings with a clearance of 50 mm	2.5 mm thick rotary sieves

Photo.3 Screenings separation equipment (www.zwik.zgora.pl)

Wastewater treated on the screens flows into two double sand traps with floating matter removal, working in parallel. Sand with an equivalent diameter of more than 0.16 mm is retained in the sand traps at a rate higher than 95%. Air for aeration of sand traps is supplied by blowers installed in the grit chamber, main pumping station and screens. Mixture of wastewater and sand settling in the sand traps is conveyed by means of submersible pumps installed on mobile platforms to the troughs located along the grit chamber from where it is conveyed to two grit pulp pumping stations. Separated sand pulp is dewatered in sand separators and washed in sand washes located in a separate building.

	
sandblasters	sand separators

Photo.4 Sand traps and sand separators (www.zwik.zgora.pl)

The dewatered, washed sand is transported to containers by means of screw conveyors and then taken to the landfill. Similarly, floating bodies are scraped by scrapers into collection chambers. From the sand traps wastewater is fed to the primary settling tanks consisting of three parallel chambers. In order to evenly distribute the wastewater to the individual settling tanks, manually and electrically operated weirs with adjustable overflow edge position and channel valves opening downwards were used in the distribution channels. The settling tanks have been equipped with chain scrapers for removal of bottom sludge and floating matter and with rotary gutters for floating matter. The wastewater from the settling tanks flows through 60 cm wide reinforced concrete overflow chutes with stainless steel pilaster overflows.

3.1.2. Biological part

In the second stage, wastewater from the mechanical part flows through the collection and distribution chamber, where after mixing with recycled sludge from secondary settling tanks, it feeds the defosfatation chamber equipped with 4 submerged mixers causing the circulation movement of wastewater and sludge mixture, preventing sedimentation. The effluent is then distributed to 3 aeration chambers supplied in parallel, made in a circular shape. Oxygen is supplied to the system by aeration rotors that simultaneously force the circulation of activated sludge in the tanks. The operation of the rotors is controlled automatically, making it possible to create alternating aerobic and anaerobic zones, and thus to carry out the nitrification and denitrification processes in a common chamber, not requiring additional internal recirculation. Such a technological system - the anaerobic defossification chamber preceding the system of alternating aerobic and anaerobic zones - creates preferential conditions for the development of bacterial species able to accumulate in their cells increased amounts of phosphorus.

	
aeration and defosfatation chambers	secondary settling tanks

Fig.5. Equipment in the biological part of the treatment plant (www.zwik.zgora.pl)

The effluent level in the aeration chambers is maintained at a constant level, irrespective of the inflow volume, by means of automatically controlled overflow weirs. This allows for constant control of the immersion depth of rotor blades and the related aeration efficiency. The entire technological process is controlled by oxygen probes installed in the activated sludge chambers and alternative devices for constant control of ammonium nitrogen content in the outflowing wastewater. Thanks to this duplicated system it is possible to choose the option of controlling the process according to aerobic parameters or ammonium nitrogen content in the activated sludge chambers. Iron salts in the form of $Fe_2(SO_4)_3$ -PIX 113 are also added to the mixture of sludge and treated wastewater flowing out of the aeration chambers to precipitate the remaining phosphorus. Wastewater from the aeration chambers of the activated sludge flows into the distribution chamber, where it is evenly divided into six parallel working secondary radial settling tanks. In the settling tanks the activated sludge is sedimented and the treated effluent is clarified. Treated wastewater flows into the receiving channel. Activated sludge is transported from the bottom of the secondary settling tanks into the settling funnels by means of sludge scrapers, from where it flows into the pumping station of recycled and surplus sludge. The floating matter accumulated on the surface of the settling tanks is conveyed to the floating matter pumping station, from where it is pumped into the main sewage pumping station and separated in the mechanical part of the treatment plant.

3.1.3. Treatment of sewage sludge

Sludge thickening and dewatering installation

Preliminary sludge is removed separately from each sludge hopper to the sludge pumping station and further to the gravitational thickener of preliminary sludge. Before passing the sludge to the thickener, the dry matter content of the sludge is measured. The thickened sludge goes to the dewatering installation (chamber or belt press). Then it should undergo thermal processing in the sludge drying and incineration installation. This installation is currently not in operation due to economic and technological reasons. Excess sludge is pumped to three gravitational sludge thickeners. After approximately 3 days of storage, the gravitationally thickened sludge undergoes the process of chemical conditioning and dewatering. Iron salts Fe^{+3} and a cationic polyelectrolyte emulsion are used for conditioning. Thus prepared sludge is subjected to the dewatering process in a chamber filter press with the capacity of 10.5 m^3 . After about 3 hours of filtration a hydration of sludge within the range of 72-75% (28-25% of dry mass) is achieved. After being crushed, the dewatered surplus sludge is placed in a container from where it is transported for further agricultural use.

	
gravity sludge thickeners	chamber press

Fig. 6. Sludge thickening and dewatering equipment (www.zwik.zgora.pl)

Installation for thermal treatment of **sludge**

The installation consists of a sludge dryer and incinerator with parameters:

	
drying installation • throughput 3.4 m^3 /h raw sludge (850 kg s.m.o/h) • operating time 8000 h/y • evaporated water volume 2422kg/h • volume of dried sludge 20.7 m^3 /d • hydration of dried sludge 15%	**combustion installation** • capacity: 850 kg s.m.o/h • process temperature in the chamber: 850°C • hearth area: 5 m^2 • return air and flue gas flow: 12 000 kg/h • residence time in the adiabatic chamber: 2 s

Figure 3 shows the technological layout of the dryer and incinerator.

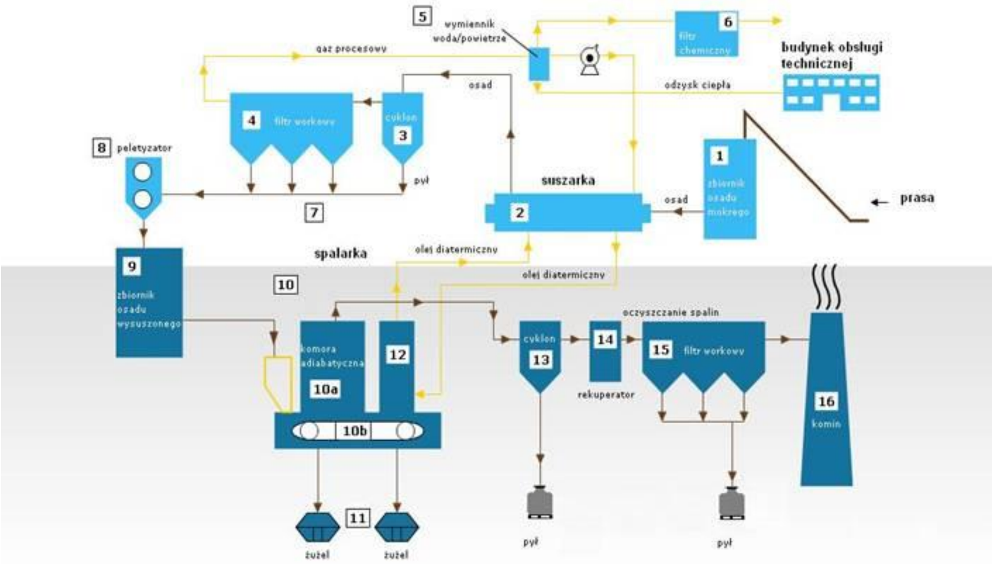

Fig 3. Technological layout of the sludge drying and incineration plant (www.zwik.zgora.pl)

Description of drying technology

The technology used, called a turbo dryer by the manufacturer VOMM, is based on the production of three phases of material (wet, dense, dry) in the dryer. The sludge inside the dryer is in constant motion created by the turbulence induced by a high speed rotating shaft with blades installed on it inside a cylinder with a heating jacket. When a thin layer of sludge adheres to the walls of the cylinder, it is possible to carry out a heat exchange with high thermal efficiency. The drying process is an indirect process and does not affect the modification of the sludge. In fact, the heat treatment consists in the flow of hot process gas and maintaining the product at a temperature of 80°C÷90°C and under a vacuum of 30÷35mbar. The residence time of the sludge inside the dryer is about 2÷5 minutes. Sludge after dewatering is transported by a conveyor to the wet sludge tank (1) with capacity of 80 m^3 . The tank is equipped with a mobile unloading device. Next, the raw sludge is transported to the batching tank before the dryer and further to the turbo dryer (2). After passing through the dryer, the dried sludge dust mixed with process gas goes to the cyclone (3) and further to the bag filter (4) where the dust is separated from the gas. After the separation the dried sludge is transported further to the pelletizer (8) from where, after separation from the remaining dust on the shaker, it is delivered in the form of pellets to the tank for dried sludge (9) with an active volume of 100m^3 . The process gas is recirculated from the bag filter to the dryer through a system of pipelines and a process fan with a capacity of 25 000 m^3 /h. A damper is installed on the suction line to remove excess gas from the system to the condensate column and the air-water exchanger (5) for heat recovery. An oil-to-process gas heat exchanger is installed in the delivery pipeline downstream of the fan to maintain the correct process gas temperature. After cooling in the condensation column, excess gas is cleaned in a chemical filter (6) and discharged into the atmosphere. Diatermic oil heated to 280°C÷ 300°C is used as a heating medium. An oil-fired boiler with a capacity of 2326 kW was installed to generate the heat required for the sludge drying process (in the case of operation without the use of a tanner). In order to provide an appropriate amount of water, the sludge drying room is equipped with the technological water installation with the capacity of 120 m^3 /h taken from the secondary settling tank and subjected to filtration and disinfection using an ultraviolet head.

Description of combustion technology

The moving grate of the furnace is equipped with a system controlling the speed of movement inside the combustion chamber and an oil burner modulating the temperature level to the required values. The installation is equipped with a system for the selective non-catalytic reduction of NOx to N_2 molecules using a 35 % urea solution. An exhaust gas/oil heat exchanger recovers combustion heat for the sludge drying plant. The flue gas after leaving the flue gas/oil heat exchanger is directed to the flue gas/air heat exchanger for cooling to a useful temperature for the incinerator reactor. A sorbent (sodium bicarbonate and activated carbon) is dosed into the reaction column to neutralise acids and to absorb heavy metals and dioxins. After leaving the reaction tower, the purified flue gases pass through a bag filter and further through the chimney into the atmosphere. An installation for continuous measurement of flue gas emissions is mounted on the chimney. Dried sludge stored in the dried sludge hopper (9) is fed to the incinerator charging hopper (10). Then it goes to the moving grate (10b) where the sludge is burnt. The flue gases flow through the adiabatic chamber (10a) where they are kept for 3 seconds. The moving furnace grate is equipped with a speed control system, an adjustable air dosage system and a fuel layer adjustment in order to optimise the combustor operation. The adiabatic chamber is equipped with an oil burner and a urea solution dosing system. From the chamber, the flue gases pass to the flue gas/oil heat exchanger (12) heating the diathermy oil to 280°C, which is the heat source for the sludge dryer. The flue gas cleaning section consists of a cyclone, a reaction tower, a bag filter, a fan and a chimney. Flue gases after escaping from the flue gas/oil exchanger (12) are transferred to the cyclone (13) where the separation of powdery substances takes place and further through the recuperator (14)-flue gas/air exchanger where the heating of the blast air and flue gas cooling to 180°C takes place - to the bag filter (15). Before the bag filter, the flue gases pass through a reaction tower where the process of mixing with sorbent takes place in order to eliminate hazardous volatile substances (heavy metals, dioxins, acid substances) from the flue gases. After leaving the filter, the flue gases are transferred by a fan to the chimney (16) and further to the atmosphere. During the process in the combustion chamber, generated slags are automatically removed from under the grate, cooled down with water and transferred into a container. Dust from the cyclone and the bag filter is collected in big bags and manually transported to the temporary storage area.

3.1.4. Discharge of treated waste water

The treated wastewater is received by the Laka Canal, a left-bank tributary of the Zimna Woda stream. The water quality of the receiver is systematically tested by an accredited ZWiK laboratory.

4. Characteristics of the municipal wastewater fed to the Łącza WWTP, treated wastewater and the amount of sewage sludge in the years 2007-2020

Table 6 shows the amount of municipal sewage entering the sewerage network and brought to the sewage treatment plant in Łącza in the years 2007-2020. In 2020, 10509 thousand m^3 were brought to the sewage treatment plant. The average volume of sewage in the period 2007-2020 was
10287 thousand m^3 /year. The amount of inflow sewage has been decreasing in recent years from 1.5 to 0.3 %.
The agglomeration does not keep records of no-outflow tanks or the type of technology used for domestic sewage treatment plants. On the basis of data from the National Programme of Sewage Treatment (2007-2020) and data from the operator, the number of individual sewage treatment systems has been determined, which is 110, which corresponds to 12 000 m^3 of sewage discharged to the ground per year. The utilisation rate of the sewage network is over 98% of the p.e.

Table 6. *Quantities of municipal sewage delivered to the sewage treatment plant in Łącza*
M- residents, P- industry

Year	Agglomeration Zielona Góra		of which: individual treatment systems			% of p.e. benefiting:		
	RLM_{rz} Agglomeration	Sewage quantity	Number of treatment	Population	Sewage quantity	Sewage network	Slurry tank vehicles	Individual treatment

		total	plants					systems
	M	thousand m³ /year	pcs.	M	thousand m³ /year			
2020	198087 M:136 970+4100 P:56937	10509 kan. 10648 command.41	110	330	12	98,10	1,70	0,17
2019	198087 M:136 970+4100 P:56937	10477,5 kan.10362,8 command.26,7	110	330	12	98,13	1,70	0,17
2018	198087 M:136 970+4100 P:56937	10031 kan.9986,1 dow.32.9	110	330	12	98,09	1,74	0,17
2017	198087 M:136 970+4180 P:56937	11796 Kan.11 747.6 dow.36,4	110	330	12	98,01	1,82	0,17
2016	198087 M:136 970+4180 P: 56937	10434 Kan.10 381,4 dow.40.6	110	330	12	98,53	1,30	0,17
2015	180956 M:133 978+3870 P:43108	9945,6 channel:9867.6 dow:66.0	110	330	12	98,7	1,13	0,17
2014	180956 M:133 978+3870 P:43108	9947 channel:9870 dow:65	110	330	12	95,7	4,13	0,17
2013	180956 M:133 978+3870 P:43108	10 569 channel:10487.3 dow:78.7	110	330	12	95,0	4,83	0,17
2012	180956 M:133 978+3870 P:43108	10 593 channel:10483 dow:98	110	330	12	94,0	5,83	0,17
2011	199876 M:137841+3700 P:58335	11076 channel:10891 dow:113	500	1979	72	91	8,01	0,99
2010	169341 M:137841+1378 P:31500	11286 channel:11116 proof:118	bd	5225	52	82	bd	bd
2009	M:137 000 P:bd	10421 channel:10275 Dow:146	bd	bd	bd	85	bd	bd
2008	M:125827 P:bd	10315 channel:10157 Dow:158	bd	bd	bd	93	bd	bd
2007	M: 133667 P:bd	6622 channel:5863 Dow:bd Nocz:759	bd	bd	bd	84	bd	bd

Figure 4 shows the structure of wastewater suppliers from 2011 to 2017. More than 70 % of the wastewater entering the Łącza WWTP comes from households and about 10 % from industry.

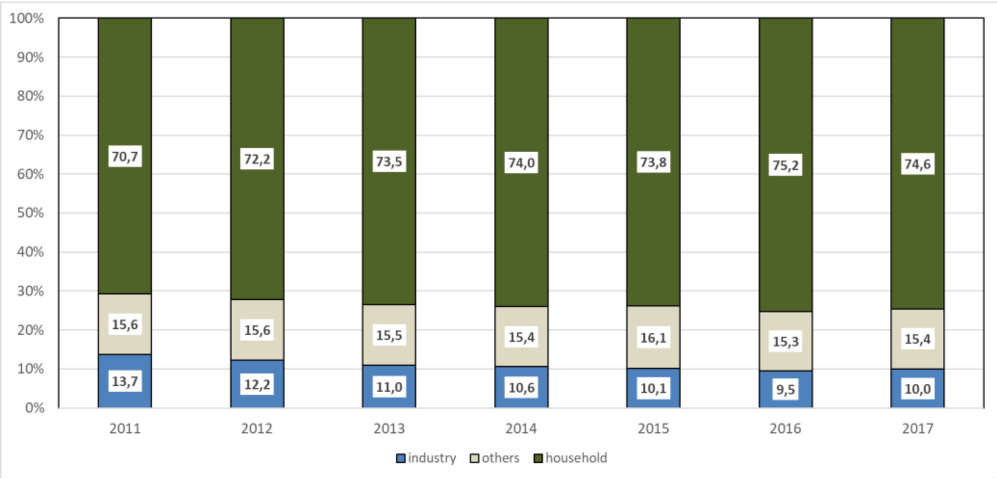

Fig. 4 Structure of wastewater suppliers to the Laka WWTP in 2011-2017

Table 7 presents the quality characteristics of raw and treated wastewater at the Zielona Góra WWTP. In the years 2007-2020 the average concentration of total nitrogen in raw wastewater was 57 g N/m^3 , while in treated wastewater it was 7 g N/m^3 .

Table 7 Quality characteristics of raw and treated wastewater for the period 2007-2020

Year	waste water	BOD_5	COD	Suspension og.	Nog	Pog
		mg/l	mg/l	mg/l	mg/l	mg/l
2020	raw	411	942	560	62	9
	cleared	7	41	8	6	0,2
2019	raw	291	718	423	54	8
	cleared	5	32	8	7	0,1
2018	raw	406	898	466	54	8
	cleared	5	34	8	6	0,4
2017	raw	370	816	456	54	7
	cleared	5	33	9	6	0
2016	raw	348	788	418	52	7
	cleared	6	38	11	4	0
2015	raw	422	815	463	55	8
	cleared	3	26	8	4	0
2014	raw	425	730	431	53	7
	cleared	5	25	7	6	0
2013	raw	400	754	446	48	8
	cleared	4	28	9	4	0
2012	raw	467	887	473	56	7
	cleared	5	30	7	4	0
2011	raw	405	925	446	59	8
	cleared	5	31	6	7	0
2010	raw	396	854	458	68	8

	cleared	8	39	11	7	0
2009	raw	460	981	445	57	8
	cleared	7	32	13	9	0
2008	raw	489	1049	50	61	10
	cleared	8	32	13	13	0
2007	raw	483	1006	510	61	5
	cleared	7	28	13	12	1

The sludge arising from the wastewater treatment process after gravity thickening and mechanical thickening is used for growing non-food and fodder crops, used for land reclamation, including land for agricultural purposes. As of 2018, the thermal treatment plant (drying and incineration) is not kept in continuous operation. Between 2007 and 2020, the WWTP generated an average of 3023 Mg s.m./year.

Table 8 *Quantity of sewage sludge from sewage treatment plant Łącza and methods of its management*

Sediments Mg s.m./year	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007
Total plant permission* . thermally	3083 3083 0	3356 2326 +723** 307	3448 3201 247	3162 2499 663	3402 3060 342	2802 2316 486	3086 2102 984	3180 2178 1000	2912 2912 -	3208 3208 -	2328 2328 -	2668 2668 -	2961 2961 -	2732 2732 -

* used to grow non-food and feed crops, used to rehabilitate land, including agricultural land

** intended for compost production

5. Nitrogen balance and emissions from wastewater treatment systems in the Zielona Góra agglomeration

The balance and nitrogen emissions from wastewater treatment systems in the Zielona Góra agglomeration do not take into account the share of nitrogen contained in water treated for drinking purposes due to the low concentrations of nitrogen compounds in waters abstracted and treated for household purposes. Ground water abstracted in Zawada is characterised by ammonium nitrogen concentrations of 0.50-0.30 mg/dm^3 ; nitrate nitrogen (V) from 0.2 to 0.3 mg/dm^3 ; nitrate nitrogen (III) from 0.005-0.047 mg/dm^3 . Water abstracted from the Obrzyca river contains: ammonium ion 0,46 - 0,23 mg/dm^3 ; nitrate ion (V) 0,078-3,60 mg/dm^3 ; nitrate ion (III) 0,002-0,044 mg/dm^3 . The content of nitrogen compounds in treated water for the city of Zielona Góra is, respectively: concentration of ammonium ion < 0.05 mg/dm^3 ; nitrate ion (V)< 2 mg/dm^3 ; nitrate ion (III) <0.005 mg/dm^3 . The limit values in water intended for human consumption are for ammonium ion 0.5 mg/dm^3 ; nitrate ion (V) 50 mg/dm^3 ; nitrate ion (III) 0.50 mg/dm^3 . Therefore, there is no need to remove nitrogen during water treatment and unconventional water treatment methods need not be used.

In the Zielona Góra agglomeration 330 inhabitants discharge wastewater to individual systems - household treatment plants. Nitrogen emissions from this source are respectively:

a. losses to atmosphere during transport and treatment - **0.58 Mg** N/year (1767 g **N/PE/year**), including **9.33 kg N_2 O-N/year** (0.016 kg N_2 O-N/kg N);
b. nitrogen emission from soil - **0.14 Mg** N/year (438 g **N/PE/year**), including **1.44 kg N_2 O-N/year** (0.01 kg N_2 O-N/kg N).

The calculation of nitrogen emissions from sewage sludge treatment and utilisation has been included in the balance of the Łącza WWTP, as sludge is periodically transported to it.

The nitrogen balance and emissions for the Łącza WWTP are presented in Figure 5.
Nitrogen emissions from this source are respectively:

a. losses to atmosphere during transport and treatment - **539 Mg** N/year, including **1, 94 Mg N_2 O-N/year** (0.0036 kg N_2 O-N/kg N); the calculated emission factor is 9.79 g N_2 O-N/PE/year;
   Assuming an emission factor for aerobic biological treatment plants reported in the literature of 7 g N_2 O-N/PE/year, the N_2 O emission for the Łącza WWTP is 1.39 Mg N_2 O-N/year .
b. nitrogen emission from aquatic receiving environment (water channel Łącza) **-1.65 kg N_2 O-N/year** (0.019 kg N_2 O-N/kg N);
c. sewage sludge to utilization - **170 Mg N/year.**

The individual nitrogen loads were calculated taking into account the parameters and indicators as summarised in Table 9.

Table 9 *Calculation of nitrogen load flow for 198 087 PE*

point	description	value	parameters
1.1	Input	795 Mg N/year	4.015 g N/PE/year, 11 g N/PE/day
		669 Mg N/year	annual inflow 1 1.79 6,000 m^3 /year, average nitrogen concentration 57 g N/m^3
1.2	Mechanical treated wastewater	702 Mg N/year	3,546 g N/PE/year
1.3	Input to biological treatment	782 Mg N/year	3,948 g N/PE/year
1.4	Output	87 Mg N/year	10 g N/m^3 , 120 dm^3 /PE/day, 1 .2 gN/PE/day
		80 Mg N/year	annual inflow 1 1.79 6,000 m^3 /year, average nitrogen concentration 7 g N/m^3
2.1	Primary sludge	93 Mg N/year	469 g N/PE/year, 28 g DM /PE/day, 3 .8% N in dry matter
2.2	Waste Activated Sludge	157 Mg N/year	1,723 g N/PE/year, 32 g DM /PE/day, 4 % N in dry matter
2.C	Sludge liquids	80 Mg N/year	402 g N/PE/year, 10% increase of nitrogen load compared to the load in raw sewage
3.1	N_2 , N_2 O losses to atmosphere during transport and treatment	539 Mg N /year incl. 1.94 Mg N_2 O/year	0.0036 kg N_2 O/kgN 4.3kg NH_3 /PE/year

		0.85 Mg NH_3 /year	
3.2	Nitrogen emission from wastewater and aquatic receiving environments	1.65 Mg N_2 O/year	0.019 kg N_2 0/kg N

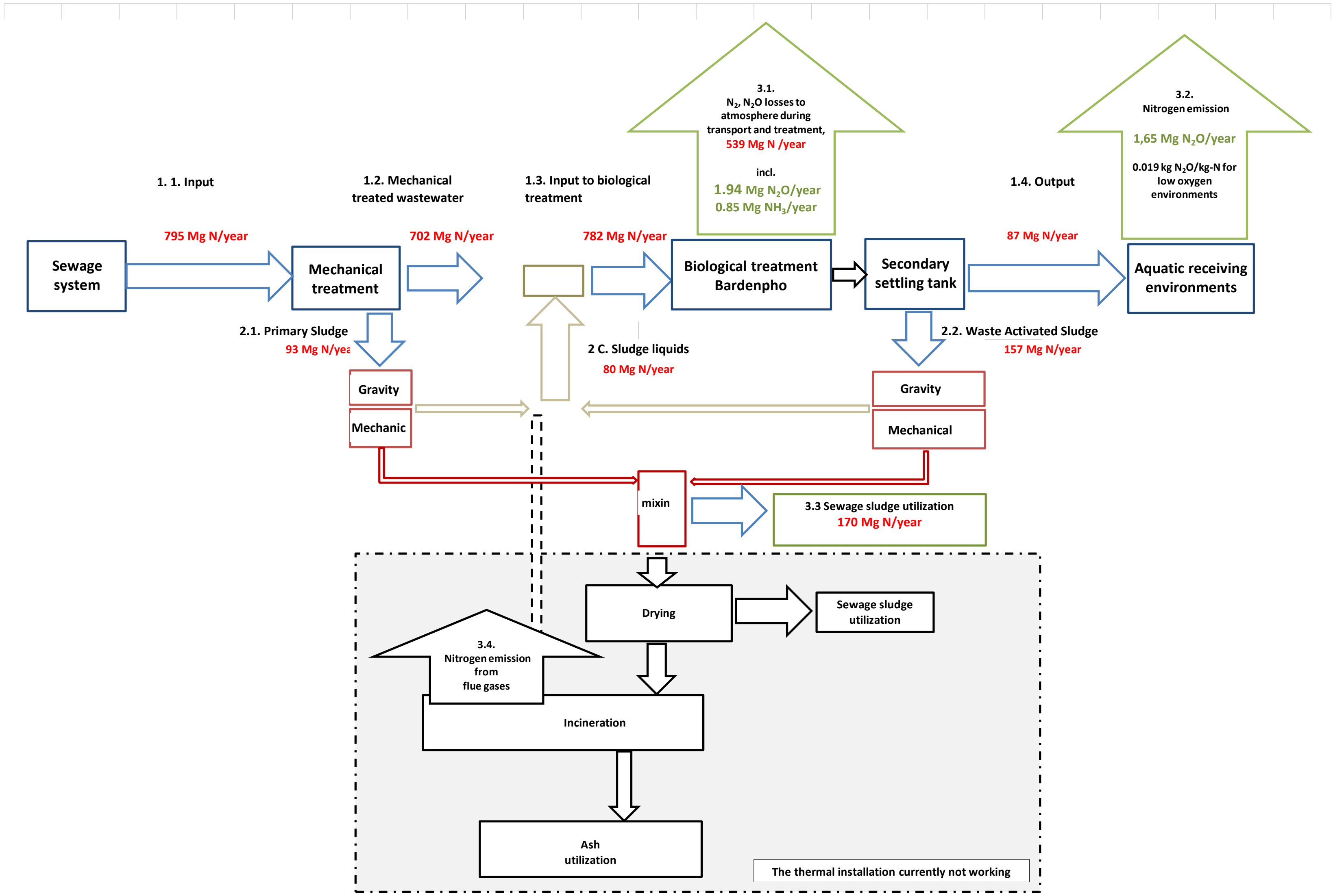

Fig. 7 Nitrogen balance at sewage treatment plant Łącza for the city and municipality of Zielona Góra

6. Forecast

The Zielona Góra agglomeration within the designated boundaries is characterised by a very high level of sewerage, exceeding 98%. In order to achieve the assumptions of AKPOŚK2017 in the spatial development plan of Lubuskie voivodeship till 2030 in the scope of water and sewage management further activities are planned within the area of Zielona Góra agglomeration that will contribute to improvement of water quality and protection of groundwater from pollution by domestic sewage.

The first project is the expansion of the collective sanitary sewerage system:
Within the framework of OPI&E Priority Axis 1: Water and sewage management, equipping by the end of 2020 the agglomerations above 10 thousand p.e. with sewage systems and sewage treatment plants, it is planned to renovate about 4.17 km of sanitary sewage system, modernize about 10 km of sewage system and design and build about 27.0 km of sanitary sewage system, 4.30 km of pumping pipelines - (increase of $p.e._{rz}$ by 3604) and 4 sewage pumping stations.

The second project is the expansion of the Łącza wastewater treatment plant:
At the wastewater treatment plant in Łężyca, which receives wastewater from the Zielona Góra agglomeration, a sewage sludge digestion installation will be constructed. It will include: an installation for thermal hydrolysis of sludge, two closed fermentation chambers, cogeneration units and accompanying facilities. The installation will be adapted to process 4,700 Mg of dry sludge per year. The final utilisation of the sludge will not change. As at present, the sludge will be incinerated. In order to increase the retention of domestic sewage in the inflow channel, the construction of retention tanks for sewage after the storm overflow is planned, together with pre-treatment and metering. Projected p.e. of the treatment plant is 310500.
Implementation of the projects will ensure increased accessibility to the collective sewerage system, eliminate deficiencies in the poor technical condition of sewers, ensure proper treatment of sewage and prevent environmental damage.

7. **Literature**

1. Act of 7 June 2001 on collective water supply and collective sewage disposal. (consolidated text Dz. U. of 2019, item 1437).
2. Act of 20 July 2017. - Water Law (consolidated text Dz. U. of 2020, item 284i 310).
3. Act of 8 March 1990 on municipal self-government (consolidated text Dz. U. of 2019, item 506).
4. Act of 13 September 1996 on the maintenance of cleanliness and order in municipalities (consolidated text Dz. U. of 2019, item 2010).
5. Ordinance of the Minister of Maritime Affairs and Inland Navigation of 12 July2019 on substances particularly harmful to the aquatic environment and on conditions to be met when introducing sewage into waters or into the ground, and when discharging rainwater or snowmelt into waters or into water facilities (Journal of Laws 2019, item 1311)

6. Regulation of the Minister of Maritime Affairs and Inland Navigation of 27 July2018 on the method of determining the areas and boundaries of agglomerations (Journal of Laws 2018, item 1586).
7. Prognoza ludności gmin na lata 2017-2030 (opracowanie eksperymentalne). CSO, Warsaw, August 2017. retrieved from: https://stat.gov.pl/obszary-tematyczne/ludnosc/prognoza-ludnosci/prognoza-ludnosci-gmin-na-lata-2017-2030-opracowanie-eksperymentalne,10,1.html (29.01.2021).
8. Projections for counties and cities on the right of county for 2014-2050. CSO, December 2014. Retrieved from: https://stat.gov.pl/obszary-tematyczne/ludnosc/prognoza-ludnosci/prognoza-dla-powiatow-i-miast-na-prawie-powiatu-oraz-podregionow-na-lata-2014-2050-opracowana-w-2014-r-,5,5.html (29.01.2021).
9. Update of the National Programme for Municipal Waste Water Treatment - AKPOŚK 2017