Grant Agreement number: 101037031

Project acronym: FRONTSH1P

Project title: A FRONTrunner approach to Systemic circular, Holistic & Inclusive solutions for a new Paradigm of territorial circular economy

Type of action: Deployment of systemic solutions with the support of local clusters and the development of regional community-based innovation schemes

Deliverable Number: D5.1

Implementation plan of CSS3 and Citizens engagement Plan SOCIAL+ TECH

Delivery type:	**Report**
Lead beneficiary:	**LNEG**
Lead author:	**LNEG**
Contributions:	**ULODZ, STAM, K-FLEX, BZURA, PARZECZEW, VELTHA, OPUS, INL, NTUA**
Contractual delivery date:	**M12**
Delivery date:	**M16**
Dissemination level:	**PUBLIC**

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Partners

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HISTORY OF CHANGES			
Version	Date	Author/Contributor	Changes
V1. Non-technical state of the art & market conditions of CSS3	30.09.2022	UniLodz, OPUS, Bzura. (authors: Zbigniew Przygodzki, Justyna Trippner-Hrabi, Jacek Chądzyński, Marcin Feltynowski, Pamela Jeziorska-Biel, Ewa Szafrańska, Iwona Jażdżewska, Marcin Podgórski, Aneta Tylman, Dominik Drzazga, Dorota Sikora-Fernandez, Łukasz Waszak, Katarzyna Paździor, ...)	author's version
V2. Non-technical, technical state of the art & market conditions of CSS3	28.02.2023	LNEG (authors: Alberto Reis, Luísa Gouveia, Rafal Lukasik)	
V3.	30.04.2023	LNEG, UniLodz, OPUS, NTUA, VELTHA	

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1. Executive Summary

The deliverable was conceived with the aim to describe the starting point in the Łódzkie Region (Łódź voivodeship) before the design, development and implementation of the Circular Systemic Solution 3 Water and Nutrients, also providing a description of future activities, objectives, and success criteria for WP5. The objectives of the CSS3 Executive Implementation Plan are to set up a roadmap of practical implementation of CSS3 within the FRONTSH1P project, including operational objectives, activities, timelines, success criteria and means of verification. The main objectives are 1) draft the framework Technical and non-technical state of the art, requirements and success criteria to satisfy the implementation of the technological and non-technological solutions required in CSS3; 2) identify measures that have the strongest leverage for a sustainable-oriented improvement of products through Life cycle thinking and Ecodesign; 3) develop CSS3 community based innovation schemes to Reduce liquid and gaseous wastes through Microalgae Biotransformation towards upgraded biogas (biomethane) and bio-based products such as biofertilizers and biostimulants; 4) plan, design, develop, deploy and operate a CSS3 demo/pilot plant towards C biosequestration from GHG of anthropogenic origin and microalgae-mediated wastewater treatment towards microalgae bio-based products in Łódzkie region; 5) collect data in technological, economic, social and environmental dimensions and share them on the RCPB tool and support LifeCycle Assessment (LCA); 6) replicate successfully the best solution to other European regions (Italy, Greece, Pays Bas, Portugal)

The CSS3 Executive Implementation Plan is a tool to execute the CSS3 project efficiently, smoothly, and timely all the planned activities, towards the completion of the CSS3 FRONTSH1P project within the agreed time schedule and budget. The common approach and language adopted by all CSSs (from CSS1 to CSS4) will not only make certain coordination among all partners, but also facilitate the further replication phase of all CSSs in other territories, as highlighted in the FRONTSH1P proposal.

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2. Scope and Structure of the Deliverable

Definition of an implementation framework for CSS3. This deliverable will cover the following aspects:

1) Technical and non-technical state of the art, requirements, and success criteria to satisfy the implementation of the technological and non-technological solutions required in CSS3.

2) Identification, involvement, needs and expectations from regional stakeholders involved in CSS3.

3) Executive implementation plan of CSS3.

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3. About FRONTSH1P

A **FRONTrunner approach to Systemic circular, Holistic & Inclusive solutions for a new Paradigm of territorial circular economy (FRONTSH1P)** is a European circular economy project that started on November 1st, 2021. It is funded by the European Union under the Horizon 2020 programme.

The project is centred in the Polish region of Łódzkie. A region that on the one hand, traditionally heavily relies on coal extraction, and on the other hand, has pioneered circular (bio)economy since the early 2000s. The region has always been in the forefront of innovation and has become one of the leading regions in the field of circular economy. In the next 4 years, FRONTSH1P will contribute to further the green and just transition of the Łódzkie region away from its current linear economic foundation, towards the region's decarbonisation and territorial regeneration. It will do so by demonstrating four Circular Systemic Solutions. Each circular systemic solution targets an economic sector that is aiming towards decarbonisation: Wood Packaging, Food & Feed, Water & Nutrients, and Plastic & Rubber Waste. Each developed circular systemic solution will furthermore be highly replicable. A feat that will be proven during the project by their implementation in four other European regions: Campania (Italy), Sterea Ellada (Greece), Norte (Portugal), and Friesland (the Netherlands). Through the development of the circular systemic solutions, FRONTSH1P will create Circular Regional Clusters that involve a wide range of local, regional, and national stakeholders, both from the public and private spheres, guaranteeing that no one will be left behind. The CSS2, strictly interconnected with other CSSs, has key innovations in i) CO_2 assisted pre-treatment of agro-industrial waste combined with biotechnological treatments for the obtaining of Free Fatty Acids (FFAs) as component for foaming biomaterials ii) Establishment of innovative oil crops cultivations (i.e. sunflower, milk thistle) in marginal and abandoned agricultural areas to obtain vegetable oils that can be transformed in biodegradable biolubricants formulations, bio-oils for insulating materials and locally available animal feed supplements iii) production of biobased building blocks (diols and dicarboxylic acids) from second generation feedstock (from regional agro-industrial waste rich in sugars) for the formulation of new compostable bioplastics (compostable bags for OFMSW collection).

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4. Non-technical and technical state of the art: market and environmental conditions of CSS3

4.1. Market Analysis

4.1.1. Industrialization and urbanization of the Łódzkie Region

Łódzkie Region is in the centre of Poland. Apparently, the geometric center of Poland is located in the city of Piątek (Łęczyca poviat). It is adjacent to the following voivodeships: Świętokrzyskie, Śląskie, Opolskie, Wielkopolskie and Kujawsko-Pomorskie. In terms of area (18 219 km^2) (GUS, 2022a), it is on ninth place in Poland, and in terms of population (2 416 902 people 31.12.2021r.) (GUS, 2022b) on the sixth. Most people live in the city of Łódź (664 071), then in the Zgierz poviat (165 110). At the same time, it is a suburban zone of Łódź.

Łódzkie Region consists of:

– 21 land poviats and 3 cities with poviat status (Łódź, Piotrków Trybunalskich, Skierniewice) (TERYT-TERC, 2022a),
– 177 gminas, including 18 urban, 129 rural and 30 urban-rural (TERYT-TERC, 2022a),
– 527 cities and 4465 villages (TERYT-TERC, 2022b).

In 2020 year, the urbanization rate amounted to 63.28% (eRegion, 2022). The largest cities include: Łódź, Piotrków Trybunalski, Skierniewice, Kutno, Radomsko, Tomaszów Mazowiecki, Bełchatów, Zgierz, Pabianice and Zduńska Wola (GIOS, 2020). The population density of the voivodship in 2021 amounted to 133 people per km^2. However, there are large differences between individual counties (Table 1). The highest population density is characteristic of urban counties: Łódź 2265 people/km^2, Skierniewice 1359 people /km^2, Piotrków Trybunalski 1060 people / km^2 (Table 1). Outside the urban counties, the highest population density is observed in the following counties: Pabianice (241 people /km^2), Zgierz (193 people /km^2) and Zduńskowolski (178 people /km^2).

The industry of the Łódzkie Region has historically been dominated by textile industry. The situation changed radically in the last decade of the twentieth century. At that time, large textile factories collapsed, and the textile industry lost its dominant position. There has been an increase in the importance of the power industry, machinery, agri-food, metallurgy, pharmaceutical and construction (GIOS, 2020) The following operate in the province: Łódź Special Economic Zone, Bełchatów-Kleszczowski Industrial and Technological Park, Kutno Agro-Industrial Park, Łódzkie Regional Science and Technology Park and Boruta Zgierz Industrial Park. The differences in the degree of industrialization of individual counties are

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clearly marked. The counties of Łódź, Pabianice and Zgierz belong to industrial areas, while the counties of Łęczyca, Sieradz, Poddębice and Wieruszów belong to typically agricultural ones (GIOS, 2020).

Table 1. Basic data of the Łódź Voievodship for 2021, by poviats

Poviat	Population (persons)	Area (km^2)	Population density (people/km^2)	Population in cities (%)
Bełchatów	111 784	968	116	56,3
Brzeziny	30 560	359	85	40,33
Kutno	94 363	887	106	58,05
Łask	49 533	618	80	33,69
Łęczyca	48 715	773	63	31,28
Łowicz	76 820	988	78	35,71
Łódź East	72 856	500	146	31,92
Łódź city	664 071	293	2265	100
Piotrków Trybunalski city	71 252	67	1060	100
Skierniewice city	47 031	35	1359	100
Opoczno	74 867	1040	72	32,31
Pabianie	118 616	492	241	68,76
Pajęczno	50 461	804	63	24,1
Piotrków	90 727	1429	64	9,22
Poddębice	40 612	881	46	24,89
Radomsko	110 584	1443	77	45,92
Rawa	47 952	646	74	41,84
Sieradz	115 959	1491	78	42,53
Skierniewice	37 915	753	50	b.d.
Tomaszów Mazowiecki	114 620	1025	112	52,81
Wieluń	75 167	926	81	28,77

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Wieruszów	41 759	577	72	25,56
Zduńska Wola	65 568	369	178	64,99
Zgierz	165 110	855	193	68,26
Total	**2 416 902**	**18219**	**133**	**62,05**

Source: GUS – Local Data Bank, 2022.

Built-up and urbanized land accounts for 6.2% of all land in the Łódzkie Voivodeship, which gives the fifth place in the country (GUS – Local Data Bank, 2022). 7% of built-up and urbanized land is land used by industry, while 50% is occupied by communication routes, mainly roads (GUS – Local Data Bank, 2022).

Production of greenhouse gases (GHG) in the Łódzkie Region

Currently, the most important industries in the Łódzkie Region are: textile industry, energy industry, production of household appliances, pharmaceuticals, agri-food processing, production of medical equipment, packaging and construction ceramics. It is estimated that almost 70 percent of the Polish production of ceramic tiles and terracotta is produced in the Łódzkie Region. Developments are also observed in other areas, such as financial, billing and research services, and biotechnology. What's more, Europe's largest industrial cluster of household appliances has been established in the Łódzkie Region. It includes manufacturers such as B/S/H/, Whirpool, Indesit and Miele (PAIH, 2021).

At the end of December 2021, 1571 business entities operating in the field of industrial processing were entered in the REGON register in the Łódzkie Region (Statistical Office in Łódź, 2022). Most of them, as much as 29%, were in the Łódź city poviat, another 13.5% in the Łódź subregion – Zgierz and Pabianice counties. 7.5% of industrial entities had their headquarters in the Radomsko poviat the remaining counties had a much lower saturation of industrial activity (Fig. 1). Among all business entities operating in the field of industrial processing in the Łódzkie Region, the largest number were entities operating in the field of furniture production, manufacture of fabricated metal products and textiles (Table 2). However, considering the value of sold production, the dominant one was the production of food products (22% of the sum of values for all divisions, Table 2).

In the case of the Łódzkie Region, carbon dioxide has the predominant share in total greenhouse gas emissions. In 2012, it accounted for 99.75% of all greenhouse gas emissions, while methane emissions accounted for 0.235% and nitrous oxide only 0.015% (IOŚ-PIB, KOBiZE, 2014).

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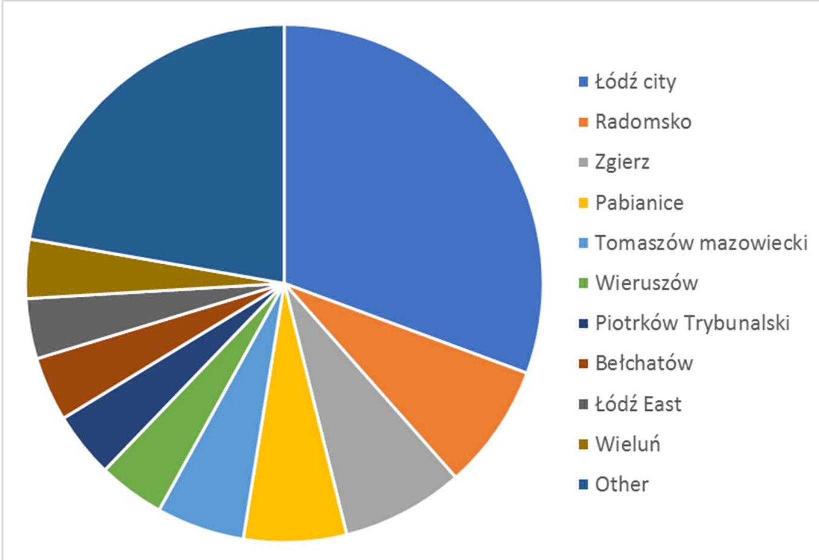

Figure 1. Industrial entities distribution by poviats

Source: GUS – Local Data Bank, 2022.

Table 2. Value of sold production of industrial processing and number of business entities according to NACE Rev. 2

Nr	Manufacturing divisions according to NACE Rev. 2	Sold production (PLN milion)	Number of bussiness entities	Poviats with the largest number of business entities
10	Manufacture of food products	14372	132	Łódź city, Pabianice, Zgierz
11	Manufacture of beverages	965	5	Łódź city, Wieruszów, Tomaszów Mazowiecki
13	Manufacture of textiles	2992	83	Łódź city, Pabianice, Zgierz
14	Manufacture of wearing apparel	2044	182	Łódź city, Pabianice, Zgierz
15	Manufacture of leather and related products	50,4	11	Łódź city, Zgierz, Kutno
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture	1121	109	Łódź city, Radomsko, Zduńska Wola

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Nr	Manufacturing divisions according to NACE Rev. 2	Sold production (PLN milion)	Number of bussiness entities	Poviats with the largest number of business entities
	of articles of straw and plaiting materials			
17	Manufacture of paper and paper products	2618	19	Łódź city, Tomaszów Mazowiecki, Radomsko
18	Printing and reproduction of recorded media	1149	48	Łódź city, Pabianice, Zgierz
20	Manufacture of chemicals and chemical products	2147	12	Łódź city
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	1470	4	Łódź city, Pabianice
22	Manufacture of rubber and plastic products	6748	30	Tomaszów Mazowiecki, Łódź city, Zgierz
23	Manufacture of other non-metallic mineral products	4898	60	Łódź city, Zgierz, Tomaszów Mazowiecki
24	Manufacture of basic metals	831	3	Piotrków Trybunalski city, Zgierz, Pabianice
25	Manufacture of fabricated metal products, except machinery and equipment	4261	266	Łódź city, Bełchatów, Piotrków Trybunalski

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Nr	Manufacturing divisions according to NACE Rev. 2	Sold production (PLN milion)	Number of bussiness entities	Poviats with the largest number of business entities
26	Manufacture of computer, electronic and optical products	1511	12	Łódź city
27	Manufacture of electrical equipment	6706	9	Łódź city, Wieluń, Pabianice
28	Manufacture of machinery and equipment n.e.c.	2121	32	Łódź city, Pabianice, Sieradz
29	Manufacture of motor vehicles, trailers and semi-trailers	2041	4	Wieluń, Zgierz, Łódź city
30	Manufacture of other transport equipment	301,4	5	Łódź city
31	Manufacture of furniture	1709	273	Radomsko, Łódź city, Wieruszów
32	Other manufacturing	b.d.	91	Łódź city, Zgierz, Kutno
33	Repair and installation of machinery and equipment	b.d.	181	Łódź city, Wieluń, Tomaszów Mazowiecki
	Total	65427	1571	Łódź city, Pabianice, Zgierz

Source: GUS – Local Data Bank, 2022.

Greenhouse gas emissions come from sources:

- point (heat and power plants and other industrial plants),
- line (transport),
- area (home hearths, agriculture).

In the Łódzkie Region, point sources have the largest share in carbon dioxide emissions – in 2012 it was almost 86% of total CO_2 emissions and amounted to 40.84 Tg_{CO2} (IOŚ-PIB, KOBiZE, 2014; GUS – Local Data Bank, 2022). Point sources related to industrial production are located mainly in the Łódź Agglomeration and in the cities of Piotrków Trybunalski,

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Tomaszów Mazowiecki and Skierniewice (GIOS, 2012). The most important emitters are the main producers of electricity and heat: PGE GiEK SA (about 77% of the total point emission of the voivodeship in 2012 (GIOS, 2012)) and Veolia Energia Łódź S.A. (formerly Dalkia Łódź S.A., about 8% of total emissions in 2012 (GIOS, 2012)). Analyzing Table 3 (presenting emissions of greenhouse gases from point sources in the Łódzkie Region in 2021 by poviat), it can be noted that point sources in the Bełchatów poviat are responsible for 85% of carbon dioxide emissions in the Łódzkie Region, in the poviat Łódź city for 5.6% of total carbon dioxide emissions, and over 4% of carbon dioxide emissions fall on the Pajęczno poviat, in which the main emitter is Cementownia Warta S.A. (cement plant).

Table 3. Point emissions of greenhouse gases from the Łódzkie Region, by poviats

Poviat	carbon dioxide	methane	nitrous oxide
	2021	2021	2021
	[Mg/a]	[Mg/a]	[Mg/a]
Bełchatów	33 212 206	0	0
Kutno	141 277	8	2
Łask	19 600	0	0
Łowicz	77 811	0	0
Łódź East	13 214	0	0
Opoczno	178 997	0	0
Pabianice	55 850	0	0
Pajęczno	1 709 337	21	7
Piotrków Trybunalski	15 044	0	0
Radomsko	86 398	47	0
Rawa	4 495	0	0
Sieradz	88 656	0	0
Skierniewice	489	0	0
Tomaszów Mazowiecki	451 987	0	0
Wieluń	56 659	0	0
Wieruszów	124 620	0	0
Zduńska Wola	84 580	0	0
Zgierz	225 395	0	0
Brzeziny	14 154	0	0
Łódź city	2 183 406	2	0
Piotrków Trybunalski city	137 120	0	0
Skierniewice city	84 544	0	0
Total	38 965 839	78	9

Source: GUS – Local Data Bank, 2022.

On the basis of Table 4, it can be noted that the combustion of fuels in the Łódzkie Region constitutes a much higher percentage of total carbon dioxide emissions (99.6%) than in the whole country (93%). What is more, the energy industry in the Łódzkie Region was responsible for 83% of CO_2 emissions, while in the whole of Poland it was responsible for

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53%. It is also worth noting that carbon dioxide emissions from industrial processes have a negligible share in its total emissions in the Łódzkie Region (smaller than in the whole country).

Table 4. Carbon inventory in 2012 (excluding Agriculture and Land Use, Land Use Change and Forestry)

	Poland		**Łódzkie Region**	
	($GgCO_2$)	(%)	($GgCO_2$)	(%)
Fuel combustion	**298403,8**	**93,0**	**47333,9**	**99,6**
Energy industries	168641,7	52,6	39567,4	83,2
Manufacturing Industries and Construction	30635,5	9,5	1120,4	2,4
Transport	46148,2	14,4	3032	6,4
Other Sectors	52978,4	16,5	3614	7,6
Fugitive Emissions from Fuels	**3723,8**	**1,2**	**0,1**	**0,0**
Solid Fuels	1869,4	0,6	0	0
Oil and Natural Gas	1854,4	0,6	0,1	0,0
Industrial processes	**17819,6**	**5,6**	**126**	**0,3**
Mineral Industry	10064,1	3,1	92,7	0,2
Chemical Industry	4316,5	1,3	0	0
Metal Industry	2297,1	0,7	2,1	0,0
Other Production	9,5	0,0	0	0
Other	1132,4	0,4	31,2	0,1
Use of solvents and other products	**635,7**	**0,2**	**42,9**	**0,1**
Waste (incineration)	**278,7**	**0,1**	**35,9**	**0,1**
Total emissions	**320861,7**	**100**	**47538,7**	**100**

Source: IOŚ-PIB, KOBiZE, 2014.

Carbon sequestration is obtained only through plants. Only forest land has a negative carbon dioxide emission balance. For the Łódzkie Region in 2012 it was - 3 Tg_{CO2} (IOŚ-PIB, KOBiZE, 2014). It should be emphasized that in the same year, the power plant in Bełchatów emitted 31 $Tg_{of\ CO2}$, which is ten times more than was absorbed by forests throughout the

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Łódzkie Region. It was planned to build an installation for the capture, transport and geological storage of CO_2 (PGE, 2012) for the newest unit of the Bełchatów Power Plant, but for economic reasons this project was not implemented (URE, 2022a).

In 2019, a sharp decrease in carbon dioxide accumulation in Polish forests was noticeable throughout the country (Figure 2). The authors of the National Inventory Report 2022 (KOBiZE, 2020) explain the decrease in greenhouse gas absorption through the collapse of the growth dynamics of the wood resources volume as a long-term result of natural disasters – droughts affecting Poland since 2014 and hurricane winds.

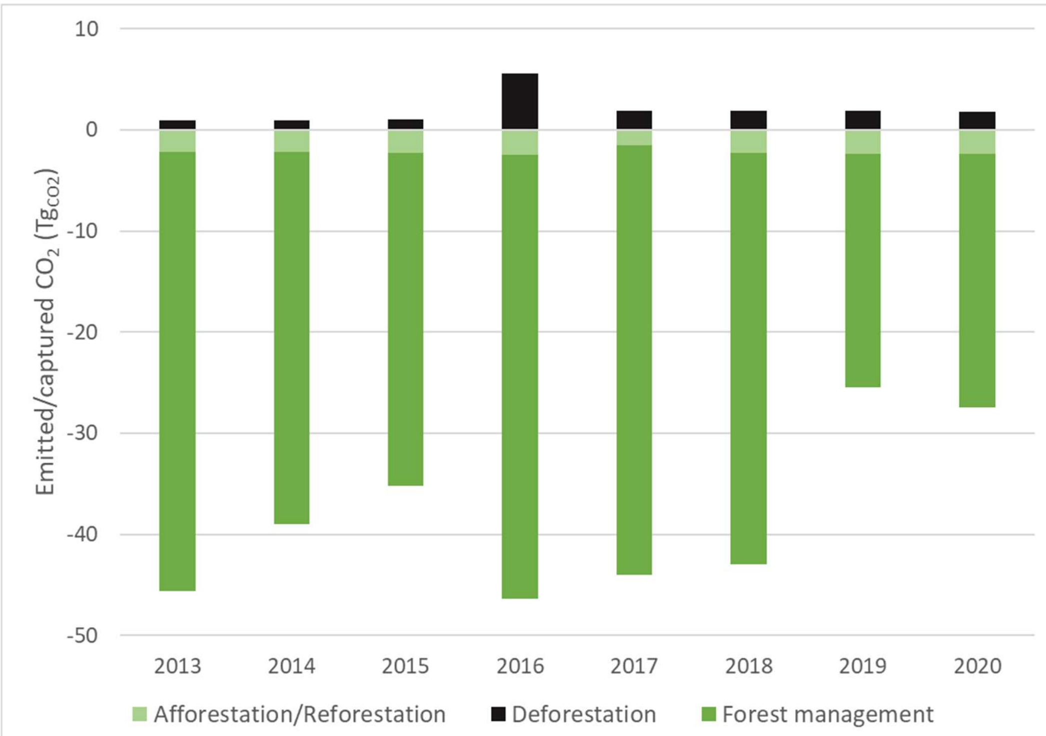

Figure 2. Balance of greenhouse gas emissions and removals in the period 2013-2020 according to the LULUCF activity of the Kyoto Protocol

Source: KOBiZE, 2020.

There have also been reported that as the temperature rises, the rate of respiration by plants (which is associated with the emission of carbon dioxide into the atmosphere) increases, and the rate of photosynthesis (responsible for the absorption of carbon dioxide by plants) decreases drastically (Duffy et al., 2021). Considering both global warming and the accompanying violent atmospheric phenomena, we can expect an additional deterioration in the ability of Polish forests to absorb carbon dioxide from the atmosphere in the coming years.

According to the Territorial Just Transition Plan of the Łódzkie Region (ZWŁ, 2021) the Bełchatów Power Plant should be gradually phased out – by 2030, gross electricity

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production would be reduced from 27.4 TWh (2020) to 6.9 TWh while reducing carbon dioxide emissions by about 80%. The complete decommissioning of the power plant would take place in 2036. It is planned to replace the production of electricity from lignite in favor of nuclear energy and renewable energy sources. Assuming an optimistic option – elimination of carbon dioxide emissions from the Bełchatów Power Plant through the use of zero-emission energy production technologies – CO_2 emissions in the Łódzkie Region should fall to approx. 17.5 Tg_{CO2} in 2036, while from point sources to approx. 9 Tg_{CO2}.

In the case of methane emissions, the largest shares in it (for the Łódzkie Region in 2012) were:

- landfilling of solid waste: 32%;
- agriculture – intestinal fermentation: 29%;
- wastewater management: 14% (Table 5).

On a national scale, fugitive emissions of fuels were responsible for over 28% of methane emissions, while this source was much less important in the Łódzkie Region (Table 5). Methane capture has not been reported.

As for the last of the analyzed greenhouse gases – which is the least important in terms of quantity – nitrous oxide, the source of the largest emissions, both in the whole country and in the Łódzkie Region, were agricultural soils (responsible for over 60% of total emissions), manure management (over 15%), fuel combustion in the energy industry (7% on a national scale, almost 12% in the Łódzkie Region) and sewage management (below 4%, Table 6). In the case of nitrous oxide, also no methods of its absorption were observed.

Table 5. Methane emissions in 2012

	Poland		Łódzkie Region	
	(Gg)	(%)	(Gg)	(%)
Fuel combustion	**149,46**	**7,25**	**9,69**	**8,44**
Energy industries	5,07	0,25	0,54	0,47
Manufacturing industries and construction	4,49	0,22	0,16	0,14
Transport	4,89	0,24	0,32	0,28
Other sectors	135,01	6,55	8,67	7,55
Fugitive emissions from fuels	**585,38**	**28,39**	**6,02**	**5,24**
Solid fuels	359,33	17,43	0,51	0,44

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Oil and natural gas	226,06	10,96	5,5	4,79
Industrial processes	**14,47**	**0,70**	**0,01**	**0,01**
Chemical industry	13,21	0,64	0	0,00
Metal industry	1,25	0,06	0,01	0,01
Total agriculture	**545,79**	**26,47**	**43,47**	**37,84**
Enteric fermentation	427,48	20,73	33,68	29,32
Manure management	117,43	5,69	9,72	8,46
Field burning of agricultural residues	0,88	0,04	0,07	0,06
Land use, land use change and Forestry	**108,21**	**5,25**	**3,3**	**2,87**
Forest land	1,49	0,07	0,13	0,11
Grassland	0,07	0,00	0,01	0,01
Wetlands	106,65	5,17	3,17	2,76
Total waste	**658,83**	**31,95**	**52,38**	**45,60**
Solid waste disposal	407,64	19,77	36,56	31,83
Wastewater treatment and discharge	251,2	12,18	15,83	13,78
Total emissions	**2062,14**	**100,00**	**114,87**	**100,00**

Source: IOŚ-PIB, KOBiZE, 2014.

Table 6. Nitrous oxide emissions in 2012

	Poland		**Łódzkie Region**	
	(Gg)	(%)	(Gg)	(%)
Fuel combustion	**6,768**	**6,96**	**0,794**	**11,73**
Energy industries	2,757	2,84	0,568	8,39
Manufacturing industries and construction	0,555	0,57	0,018	0,27
Transport	1,85	1,90	0,124	1,83
Other sectors	1,605	1,65	0,084	1,24
Fugitive emissions from fuels	**0,001**	**0,00**	**0**	**0,00**

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Oil and natural gas	0,001	0,00	0	0,00
Industrial processes	**3,39**	**3,49**	**0**	**0,00**
Chemical industry	3,39	3,49	0	0,00
Use of solvents and other products	**0,4**	**0,41**	**0,03**	**0,44**
Total agriculture	**81,265**	**83,60**	**5,611**	**82,87**
Manure management	15,709	16,16	1,29	19,05
Agricultural soils	65,52	67,40	4,318	63,77
Field burning of agricultural residues	0,036	0,04	0,003	0,04
Land use, land use change and forestry	**1,759**	**1,81**	**0,095**	**1,40**
Forest land	1,065	1,10	0,045	0,66
Arable land	0,674	0,69	0,049	0,72
Grassland	0,001	0,00	0	0,00
Wetlands	0,019	0,02	0,001	0,01
Total waste	**3,627**	**3,73**	**0,241**	**3,56**
Wastewater treatment and discharge	3,575	3,68	0,234	3,46
Waste incineration	0,052	0,05	0,007	0,10
Total emissions	**97,21**	**100,00**	**6,771**	**100,00**

Source: IOŚ-PIB, KOBiZE, 2014.

4.1.2. Wastewater treatment in the Łódzkie Region

In 2021, there were 61 industrial sewage treatment plants and 273 municipal wastewater treatment plants in the Łódzkie Region (GUS – Local Data Bank, 2022) In 6 industrial treatment plants, only mechanical wastewater treatment processes were used, in 5 mechanical and chemical processes, and in the others mechanical and biological processes. 4 treatment plants provided increased biogen removal (Table 7). Most of the industrial sewage treatment plants are in the Bełchatów poviat, while in the Poddębice, Rawa and Łódź city poviats there is no such treatment plant (GUS – Local Data Bank, 2022). At the same time, the largest wastewater treatment plant in the Łódzkie Region is in the Łódź city poviat – the Wastewater Treatment Plant of Łódź (GOŚ ŁAM), which ensures the treatment of 36%

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of all municipal sewage from areas inhabited by approx. 34% of all residents of the Łódzkie Region (GOŚ ŁAM, 2017; GUS – Local Data Bank, 2022).

All municipal wastewater treatment plants use mechanical and biological processes to treat wastewater (Table 7). Of these, 46 use technologies that enable increased biogen removal. At the same time, these are mostly large wastewater treatment plants – therefore, almost 81% of all municipal wastewater is effectively treated from biogenic compounds. The methods of wastewater treatment used in municipal treatment plants will be described in this study on the basis of the largest treatment plant – GOŚ ŁAM, which belongs to facilities using mechanical and biological processes ensuring increased biogen removal (GOŚ ŁAM, 2017) Wastewater flowing to the treatment plant is first subjected to mechanical treatment using coarse screenings with openings of 100 mm, fine hook-slot screenings with openings of 6 mm or disc sieves with a ground clearance of 5 mm. The separated screenings are crushed and directed to combustion in the GOŚ ŁAM Thermal Sludge Conversion Installation (ITPO). Wastewater from the screening hall flows into four aerated grit chambers. The sand collected in them is flushed and directed (as a mineral with a content of organic compounds below 3%) to a separate Landfill of GOŚ-Laguna. The final stage of mechanical purification are primary settling tanks. The sludge formed in them is directed to the fermentation chambers. Then, the wastewater flows by gravity to seven activated sludge tanks, where biological wastewater treatment is carried out using a three-phase activated sludge process called MUCT (Modified method University of Cape Town). This method involves the use of anaerobic, anoxic and aerobic zones together with external recirculation of sludge between the secondary settling tank and the anoxic zone, internal recirculation of sludge from the anoxic to anaerobic zone and internal recirculation of sewage and sludge between the oxygen and anoxic zones. At the end of the biological part of the treatment plant there are secondary settling tanks, from which sewage is discharged through a collection channel into the Ner River. Excessive sludge from secondary settling tanks after compaction on belt thickeners is directed to the fermentation chambers. Fermentation chambers ensure stabilization of pre- and excessive sludge in the process of mesophilic methane fermentation (35 – 38°C). The resulting biogas is desulfurized and can be directed to combustion in combined energy aggregates (3 pcs. with an electrical capacity of 0.933 MW and a thermal capacity of 1.165 MW each), combustion in oil and gas boilers (3 pcs. with a thermal capacity of 1.4 MW each), combustion as an additional fuel in ITPO, retention in a membrane tank, flaring (emergency). Fermented sludge after degassing and dehydration on belt presses is directed to ITPO, where it is first dried on disc dryers. Then it is combined with shredded screenings and directed to fluidized bed furnaces. Fly ash and dust from waste gas treatment are disposed of by storage (GOŚ ŁAM, 2017).Table 7. Wastewater treatment plants in the Łódzkie Region – number and capacity in 2021

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	Mechanical		Chemical		Biological				With increased biogen removal			
	Industrial		Industrial		Industrial		Municipal		Industrial		Municipal	
	(pcs)	(m^3/d)	(pcs)	(m^3/d)	(pcs)	(m^3/d)	(pcs)	(m^3/d)	(pcs)	(m^3/d)	(pcs)	(m^3/d)
ŁÓDZKIE REGION	6	5 875	5	7 184	46	39	227	113	4	9 120	46	482 865
Bełchatów	0	0	1	1 300	7	27	28	34 341	0	0	1	13 000
Brzeziny	0	0	0	0	1	560	3	900	0	0	1	6 600
Kutno	2	1 359	0	0	2	530	13	3 930	1	300	3	25 050
Łask	0	0	1	24	4	340	10	9 109	0	0	2	369
Łęczyca	0	0	0	0	1	386	9	1 228	0	0	2	6 475
Łowicz	0	0	0	0	0	0	6	2 222	1	4 000	2	25 000
Łódź East	0	0	1	2 760	5	1 039	10	7 119	0	0	3	5 625
Opoczno	1	300	0	0	0	0	11	4 974	0	0	1	5 500
Pabianice	0	0	1	400	0	0	4	1 317	0	0	0	0
Pajęczański	0	0	0	0	4	429	11	4 362	0	0	1	2 000
Piotrków	0	0	0	0	4	981	13	5 889	0	0	4	2 716
Poddębice	0	0	0	0	0	0	6	1 106	0	0	2	4 008
Radomsko	0	0	1	2 700	3	577	21	7 399	0	0	2	30 700
Rawa	0	0	0	0	0	0	5	1 147	0	0	1	7 000
Sieradz	0	0	0	0	0	0	16	4 045	1	3 360	3	18 490
Skierniewice	0	0	0	0	1	400	7	1 890	0	0	2	14 120
Tomaszów	1	6	0	0	3	2 148	17	6 255	0	0	1	18 000
Wieluń	0	0	0	0	2	600	9	2 105	1	1 460	5	10 087
Wieruszów	0	0	0	0	2	11	8	2 919	0	0	2	3 055
Zduńskowola	0	0	0	0	2	290	6	844	0	0	1	9 500
Zgierz	1	60	0	0	3	2 952	11	6 277	0	0	5	44 270
Łódź city	0	0	0	0	0	0	0	0	0	0	1	215 300
Piotrków Trybunalski city	1	4 150	0	0	0	0	1	4 150	0	0	1	16 000
Skierniewice city	0	0	0	0	2	8		8	0	0	0	0

Source: GUS – Local Data Bank, 2022.

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Table 8. Characteristics of municipal sewage and tariffs for the wastewater discharge into the sewage system and for the wastewater discharge into waters or into the ground

	Unit	Minimum	Maximum	Mean value
Characteristics of wastewater				
BOD_5	(mgO_2/dm^3)	216	900	431
COD	(mgO_2/dm^3)	740	2392	1100
BOD_5/COD	( )	0,29	0,50	0,41
Total suspension	(mg/dm^3)	291	611	387
Total nitrogen	(mgN/dm^3)	43	106	67
BOD_5/Total nitrogen	(mgO_2/mgN)	3,54	9,73	6,54
Total phosphorus	(mgP/dm^3)	6,32	15	10,41
BOD_5/Total phosphorus	(mgO_2/mgP)	24,40	60,40	43,13
Tariffs of fees (net) for the discharge of sewage into the sewage system by:				
Households	(PLN/m^3)	4,06	12,07	6,78
Industry & Services	(PLN/m^3)	4,95	12,58	7,83
Charges for the introduction of wastewater into water or into the ground				
BOD_5	(PLN/kg)			4,28
COD	(PLN/kg)			1,71
Total suspension	(PLN/kg)			0,52

Source: JL, 2017; GOŚ ŁAM, 2018; Starostwo Powiatowe w Łowiczu, 2020; Rada Miasta Łowicz, 2014; Solecka et al., 2018; Wierzbicki, 2016; Wody Polskie, 2022.

Municipal wastewater, which is a mixture of wastewater from households and of industrial origin, is characterized by relatively high variability of pollution indicators. For the largest wastewater treatment plants in the Łódzkie Region, the indicators of organic carbon content, i.e., the five-day Biochemical Oxygen Demand (BOD_5) and the Chemical Oxygen Demand (COD) fluctuated, respectively, between 216 and 900 mgO_2/dm^3 and between 740 and 2392 mgO_2/dm^3 (Table 8). The nitrogen load was relatively high – it ranged between 43

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and 106 mgN/dm^3. Considering the ratio of BOD_5 to total nitrogen, it can be concluded that the analyzed wastewater contained a sufficient amount of nitrogen compounds for the needs of aerobic microorganisms (this ratio should be 10:1 (Winkler, 2016)), but also that the nitrogen content in the wastewater exceeded the metabolic needs of microorganisms. Similarly, the load of phosphorus compounds exceeded the metabolic needs of microorganisms – the optimal ratio of BOD_5 to total phosphorus is 100:1(Winkler, 2016). It is therefore appropriate to use techniques that allow increased biogen removal.

In 2021, 94.95% of all wastewaters requiring treatment in the territory of the Łódzkie Region was treated (GUS – Local Data Bank, 2022) More than 90% of wastewater was treated in municipal wastewater treatment plants. The rates of fees for wastewater discharge to sewage systems are approved by the State Water Holding Polish Waters. These fees cover the costs of collecting, treating, and discharging of wastewater into waters and ground, as well as the costs of maintaining the entities responsible for the aforementioned activities. In 2021, households paid between PLN 4.06 and PLN 12.07 per m^3 for sewage disposal (on average PLN 6.78 / m^3, Table 8). The rates of fees for business entities were in most cases slightly higher and ranged between 4.95 and 12.58 PLN / m^3 (Table 8).

Analyzing Figure 3, already since 2003, more than 90% of all wastewaters discharged into water or into the ground has been treated. Within the first decade of the twenty-first century the existing treatment plants operating based on biological purification processes have been modernized towards increased biogen removal. Since 2015, the amount of sewage discharged into water and ground from the Łódzkie Region has remained constant – between 96,000 and 98,000 dam^3. The share of treated wastewater in the total volume of discharged wastewater, as well as the volume of chemically and biologically treated wastewater, including increased biogen removal, was also stabilized. Only the amount of mechanically treated wastewater decreased significantly between 2105 and 2017 (Figure 3).

On the other hand, analyzing the changes in the volume of wastewater discharged after treatment (separately for municipal and industrial wastewater treatment plants) and the sludge masses resulting from wastewater treatment processes (Figure 4), both the volumes of wastewater leaving municipal wastewater treatment plants and the sludge generated in them have remained at a constant level since 2015. It can be assumed that they will also not undergo significant changes soon. However, the situation is completely different in the case of industrial wastewater treated in on-site wastewater treatment plants. Significant changes in the volume of treated industrial wastewater can be observed – an increase from 27,000 $dams^3$ in 2003 to about 40,000 $dams^3$ in 2011, and then a decrease to approx. 6,000 dam^3 in 2020. Significant fluctuations occurred also in the amount of sludges – an increase from 37,000 Mg in 2003 to 49,000 Mg in 2009, followed by a sharp decrease to 16,320 Mg in

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2011 and also a surprising increase to almost 25,000 Mg in 2021. Moreover, changes in the mass of formed sludges are not proportional to changes in the volume of wastewater treated (Figure 4). Therefore, it is very difficult to predict how the amount of waste generated in the industrial wastewater treatment plants will change both in the near and distant future.

Comparing the amount of sewage sludges generated in the Łódzkie Region with the amount of sludge subjected to recovery processes (Table 9), about 60% of municipal sludge and about 90% of industrial sludge were not subjected to any recovery process in 2021. This indicates a high demand for new installations enabling the recovery of sewage sludge in the Łódzkie Region. These sludges could be used, for example, to biogas production in the anaerobic digestion process.

Table 9. Quantities of sewage sludges, together with methods of their management (in Mg per year)

	2005	2010	2015	2020	2021
Municipal					
Total	35 654	38 687	41 774	41 792	41 197
Applied in agriculture	6 611	6 378	8 525	7 108	7 864
Applied in land reclamation	3 229	1 132	1 324	1 435	1 376
Applied in cultivation of plants intended for compost production	600	2 178	12	660	149
Thermally transformed	0	4 302	12 250	12 591	6 917
Landfilled	21 204	6 889	4 665	823	926
Industrial					
Total	41 764	16 881	14 880	25 980	24 872
Applied in agriculture	1 789	662	390	405	512
Applied in land reclamation	7 484	1 682	669	842	753
Applied in cultivation of plants intended for compost production	2	0	0	448	438
Thermally transformed	0	1	593	563	791
Landfilled	17 776	591	350	420	384

Source: GUS – Local Data Bank, 2022.

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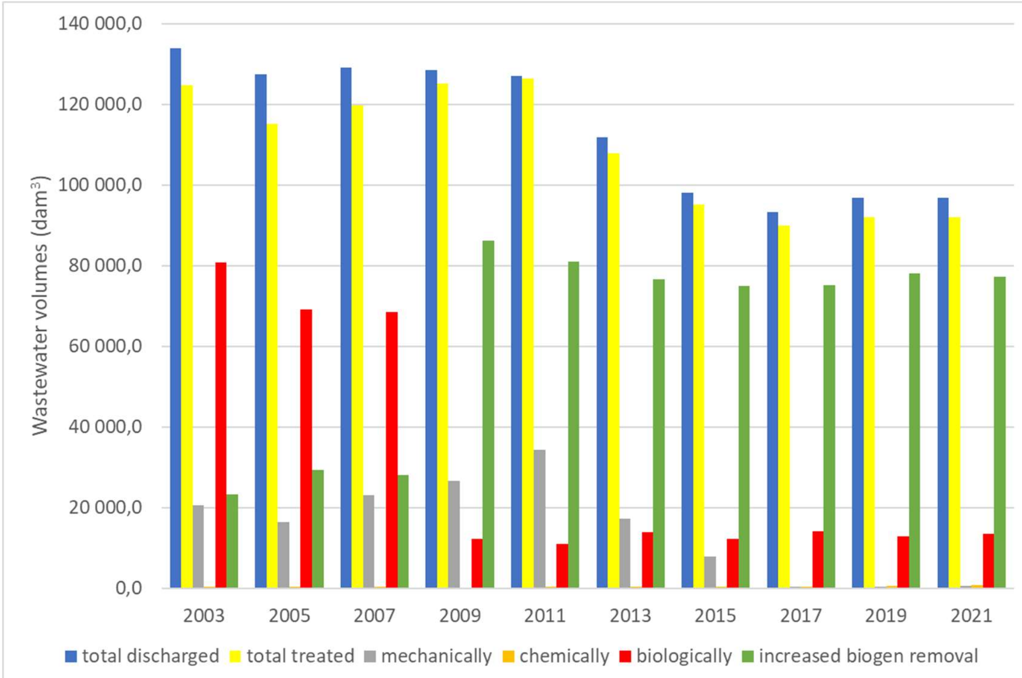

Figure 3. Changes in the volumes of wastewater discharged, including those treated by various methods, between 2003 and 2021

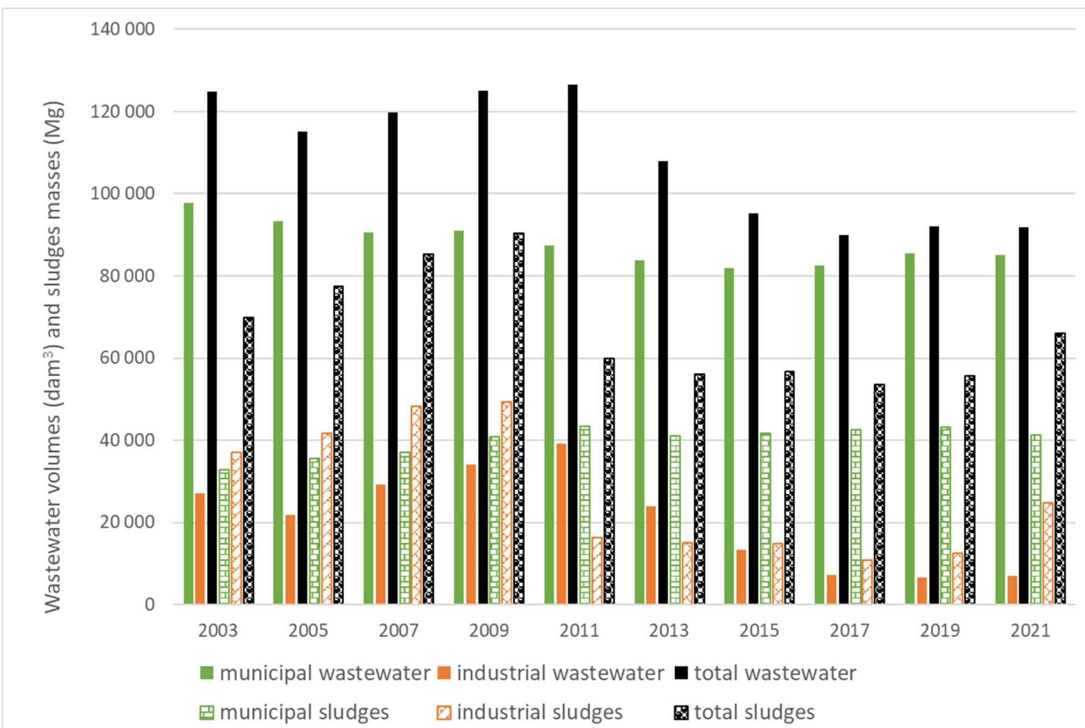

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Figure 4. Changes in the volume of wastewater and the mass of sludges generated in municipal and industrial wastewater treatment plants between 2003 and 2021

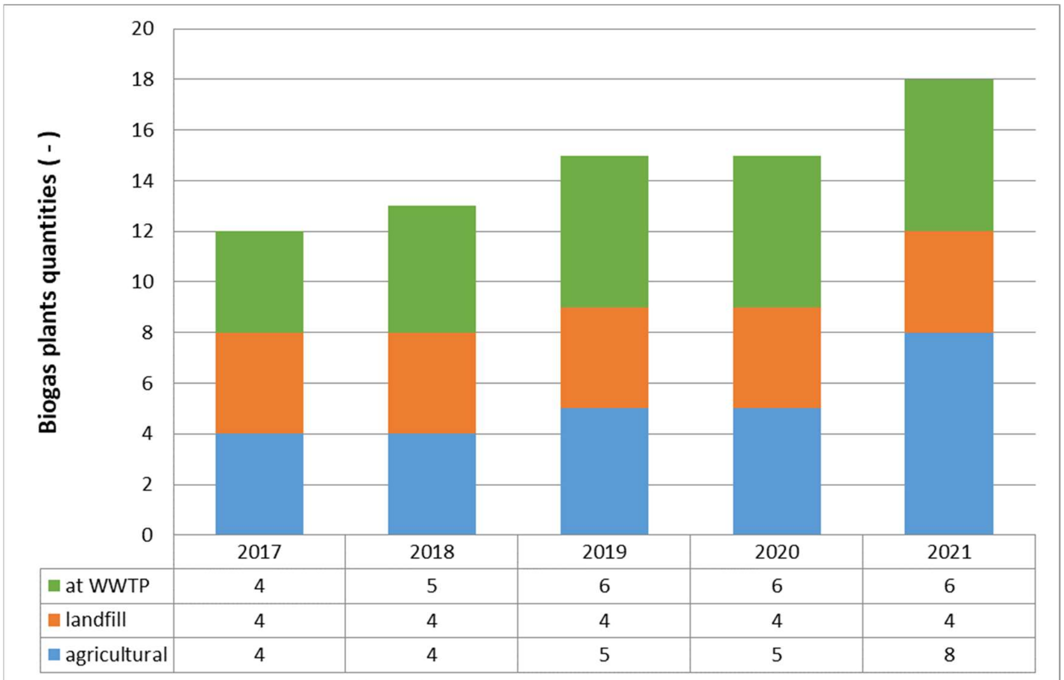

Figure 5. Changes in the number of biogas plants in Łódzkie Region from 2017 to 2021

Source: URE, 2022b.

Table 10. List of biogas plants operating in the Łódzkie Region

Poviat	Locality	Installed capacity	Biogas
Kutno	Dobrzelin	0,776	Agricultural
	Krzyżanówek	0,100	Landfill
	Franki	0,716	Landfill
	Kutno	0,999	Agricultural
	Kutno	0,499	Agricultural
Łask	Łask	0,124	at WWTP
Łowicz	Łowicz	0,600	at WWTP
	Kocierzew	0,999	Agricultural
Łódź city	Łódź	3,640	at WWTP
Opoczno	Opoczno	0,860	Agricultural
Radomsko	Ruszczyn	0,999	Landfill
	Jadwinówka	0,090	Landfill
	Masłowice	1,200	Agricultural
Rawa	Konopnica	1,998	Agricultural
	Rawa Mazowiecka	0,600	Agricultural
Skierniewice	Mokra Prawa	0,190	at WWTP
Wieluń	No data	0,250	at WWTP
Zduńska	Tymienice	0,365	at WWTP

Source: URE, 2022b.

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In 2021, there were 18 biogas plants in the Łódzkie Region enabling the use of biogas to produce electricity (Table 10). 8 of them were classified as agricultural biogas plants (Krajowy Ośrodek Wsparcia Rolnictwa, 2022) 4 were biogas plants at landfills, and 6 were identified as anaerobic digesters at wastewater treatment plants (WWTP). The highest installed capacity had cogenerators at GOŚ ŁAM. Among agricultural biogas plants, the biogas plant in Konopnica had the largest installed capacity. Most agricultural biogas plants were in the Kutno poviat. Analyzing Figure 5, between 2017 and 2019 there was one new biogas plant at WWTP each year. In 2019, one agricultural biogas plant was put into operation. The largest increase in the number of agricultural biogas plants occurred between 2020 and 2021.

On a national scale, it can be stated that the share of the biogas sector in ecological energy sources is significantly below the European average (3.2% in Poland, 7.3% European average (GUS, 2020). Analyzing the development of the installed capacity in biogas plants since 2005 (Figure 6), one can notice a significant slowdown in investments in the years 2017 – 2019. It was associated with low prices of green certificates. The production of electricity from biogas was unprofitable. It was only from 2020 that the situation has improved and a significant increase in investments has been observed – visible in Figure 5 for the Łódzkie Region. On a national scale, 23 agricultural biogas plants were built in 2021. This is almost as much as in the previous 5 years together. This is related to the need to decarbonize the national energy structure and increase interest in green energy sources. The current crisis related to the war in Ukraine has further increased the importance of renewable energy sources. A well-developed agricultural economy, along with an increase in energy prices, is conducive to investments in agricultural biogas plants. The trend observed between 2020 and 2021 should continue and even accelerate. However, a factor inhibiting the development of the industry may be social protests related to the construction of biogas plants, especially using municipal or slaughter waste.

The further development of biogas plants may be influenced by the fact that biogas is envisaged as one of the important elements of the Energy Policy of Poland until 2040 (PEP 2040) (Rada Ministrów, 2021) According to the assumptions of this document, the increase in the use of biogas will, among other things, be a consequence of the increase in the amount of bio-waste.

Capital expenditures on biogas technologies in cogeneration are at an average level (1800-3500 thousand €/MWnet) and are much higher than the lowest value for natural gas heating boiler technology, amounting to 150 thousand€/MWnet. It is worth emphasizing that PEP 2040 forecasts a probable decrease in costs for agricultural biogas, which may contribute

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to the development of this sector. According to the list, biogas technologies are included in the group with the lowest technical lifetime of 25 years.

Biomass and biogas heat and power plants are expected to receive 8.3 billion PLN – which is only 2.42% of all capital expenditures presented in PEP 2040 for the expansion of generation capacities in the years 2021-2040. On the other hand, the forecast capital expenditures in the power sector in 2016-2040 according to fuels estimate the share of biogas at the level of 4.88%, which is the fifth highest value after wind, nuclear, photovoltaic and gas units.

According to Annex 2 of the Energy Policy of Poland until 2040, OVN's capital expenditures for a biogas plant operating in combination with electricity and heat generation (cogeneration; CHP) (the launch in the time range 2016-2040 in the distinction between the type of biogas) are (Rada Ministrów, 2021):

- agricultural: 3250-2750 thousand EUR/ MW net,
- at WWTP: 3500 thousand EUR/ MW net,
- landfill: 1800 thousand EUR/ MW net.

Fixed costs, on the other hand, are:

- agricultural: 220 thousand EUR/ MW net,
- at WWTP: 135 thousand EUR/ MW net,
- landfill: 80 thousand EUR / MW net.

However, there is no information on variable costs, mainly due to the different conditions of the biogas plant.

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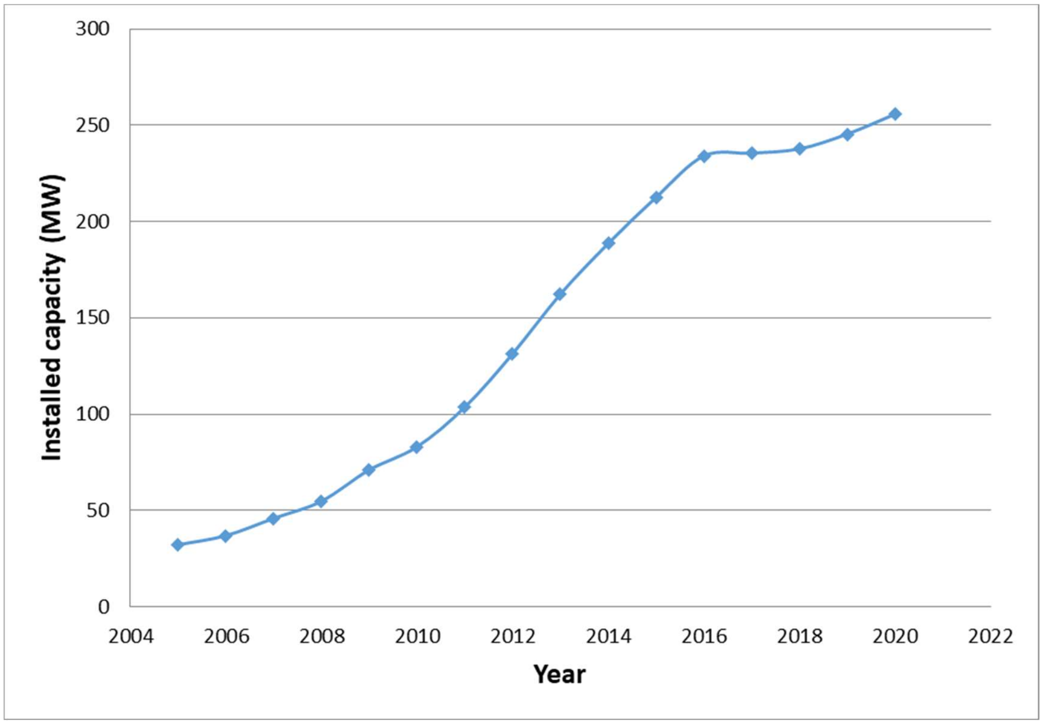

Figure 6. Changes in biogas plants installed capacity in Poland (URE, 2020)

One can see positive and promising forecasts regarding the development of the biogas economy in Poland. This is confirmed by the letter of intent for the development of the biogas and biomethane sector, signed in October 2020. Part of the development of the biogas market is also the planned sectoral agreement and cooperation between the signatories. Subsidy programs are also being created, such as "Agroenergia" (National Fund for Environmental Protection and Water Management) or a research and development project called "Innovative biogas plant" (NCBiR). A new support system is also in place and legislative improvements are planned for biomethane. These aspects are aimed at activating investors and developing the biogas market (Jacyszyn, 2021).

4.2. Technical state of the art

4.2.1. Carbon capture from industrial gases through microalgal photosynthesis

The development of civilization triggered the increase in energy consumption (especially fossil fuels), so does the output of greenhouse gases (GHG), by industries and other anthropogenic activities, responsible for global warming and climate change. Climate change

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threats include natural freshwater scarcity, increased soil erosion, disruption of food chains, and loss of biodiversity, among others.

Since the beginning of the industrial revolution (mid-18th century), to the early 21st century, carbon dioxide emissions increased 2700 times. Burning fossil fuels (oil, coal, peat, gas) for electricity, heat, transportation, and domestic uses is known to be the largest source of greenhouse gas emissions from human activities, although wastes (animal husbandry, agriculture) have been also important.

An exponentially growing world population, the depletion of resources, environmental pressures, and the impact of climate change require urgent measures to protect earth ecosystems as well as the mankind. Several attempts have been proposed to limit CO_2 (and other GHG) emissions and slow down global warming such as the Kyoto Protocol (1997), the Paris Agreement (2016) and the European Green Deal (2019), being the long-term outcome the climate change mitigation towards the European ambition to be the first climate-neutral continent by 2050. The European Green Deal is expected to transform the EU into a modern, resource-efficient, and competitive economy, ensuring economic growth decoupled from resource use, no citizen and no region left behind, the development of a circular economy, the protection of biodiversity and no net emissions of GHG by 2050. The topic of decarbonizing the energy sector has been placed in the top of EU priorities.

Carbon capture and storage (CCS) technologies have been expected to be a major tool for reducing atmospheric CO_2 concentration, being pivotal in climate change mitigation. Conventional CCS processes (geological, physical, and chemical) are known to be complex, highly power intensive, somewhat expensive, and environmentally doubtful (Singh & Dhar, 2019). Biological CCS technologies using microalgae have been proposed as environmentally-friendly promising alternatives offering a completely different approach— not only to trap CO_2 but also to immediately use it for circular energy production and generation of bio-based products, creating value as well (Singh & Dhar, 2019).

When the treatment of wastewaters is coupled with the use of flue gases, the energy production is enhanced and is a great opportunity for microalgae biotechnology. The atmospheric CO_2 concentration (around 0.04%) is limiting for microalgal mass culture and alternative rich sources are required, especially at zero or low cost. This is the case of the exhaust gases generated by industrial processes involving combustion which contain approximately 15% CO_2 on average.

As microalgae grow in aqueous medium, directly dissolving CO_2-rich gases through this environment is a very effective way of sequestering CO_2 to be further used as a biological carbon source through photosynthesis using solar energy. Due to their higher efficiency, higher CO_2 fixation rates and higher biomass productivities compared to conventional higher plants, microalgae production with flue gases can be used as a feedstock for biobased

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products and bioenergy, reducing carbon footprint and generating revenues. One ton of microalgae (dry weight basis) uptakes roughly two tons of CO_2, which means that an area of 1 ha (10000 m^2) can capture approximately 6.7 tons/day of CO_2. Research proved that microalgae have utilized successfully 90–99% CO_2 from natural gas processing industries as well as 13–15% of CO_2 in flue gas composition from thermal power plants. Moreover, microalgae also absorb excess nutrients and organic matter contained in wastewaters, playing a role in addressing water pollution.

If the challenges associated with algae-based carbon capture technology are solved successfully (for instance, the extent of accumulation of heavy metals in the biomass saturated with exhaust gases from thermal power plants, high production costs, scale-up difficulties), the proposed technology is expected to present a solution not only to the global warming problem, but also to decrease the fossil fuel consumption. Microalgae deal not only with the consequences of environmental pollution, but with which causes it. Microalgae can be fed with disreputable waste gases containing CO_2 and NO_x, SOx from flue gas, inorganic and organic C, N, P, and other pollutants from agricultural, industrial and sewage wastewater sources providing remarkable opportunities to convert them into bioenergy, high added value products and less harmful forms to the environment (Chisti, 2007).

According to several authors, a sequence of steps is required to have a complete C fixation from microalgae. The CO_2 should be transferred from the gas phase to the liquid phase, then a transfer from the resulting liquidized gas into the intracellular algal space; and finally, the growth, conversion, and consumption of CO_2 by the microalgal cells. The first and second stages are merely physical processes related to fluidics and mass transfer. The low solubility of CO_2 in water can be a limiting factor. The last step is totally a biochemical and transformational process. For instance, under phototrophic production mode, in open raceways, microalgal cultures can become carbon limited (de Godos et al., 2013), and as little as 5% of the C necessary by the culture is transferred directly from the atmosphere (Stepan et al., 2002).

To facilitate CO_2 mass transfer from gas to liquid phase several approaches have been presented such as increase the interfacial area between the phases with micro bubbling or membranes, such as hydrophobic contactors (Ferreira et al., 1998), or increasing the contact time in carbonation columns or carbonation sumps (de Godos et al., 2013). According to de Godos et al. (2013), a carbonation sump was operated in raceway ponds at different liquid/gas ratios, with the latter having the greatest influence on CO_2 recovery from the flue gas. A rate of mass transfer enough to meet up the needs of an actively growing microalgal culture was best achieved by maintaining pH at ~8. Full optimisation of the process required either pH control or selection of the best liquid/gas flow ratios. An algal productivity of 17 $g·m^{2}·day^{-1}$ was attained with only 4% direct loss of CO_2 in the sump with 66% of carbon

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incorporation into biomass, while 6% was lost by outgassing and the remainder as dissolved carbon in the liquid phase.

Chlorella is referred by Onyeaka et al. (2021) as the most promising species for carbon biofixation, being able to grow in an atmosphere containing up to 40% (v/v) CO_2 with high fixation CO_2 rates (up to 2.22 g/L/day). It has been reported that NO_x and SO_x generally existing in flue gases do not impact the performance of the production of microalgal biomass) (Cheah et al., 2015). Furthermore, NO_x and SO_x concentration reduction has been reported, likely due to its dissolution in water as acids, being beneficial to microalgae contributing to save nutrients during cultivation (Duarte et Fanka, 2016).

This CO_2 microalgae-based biosequestration as a blue bioeconomy application through the FRONTSH1P CSS3 is directed to solve specific problems as environmental services (decarbonization and wastewater treatment) together with the production of biobased products and bioenergy creating jobs and other benefits to either the community or neighbouring circular regions as well.

The development of the microalgae value chain is expected to bring circular solutions and resilience to the Łódzkie region (bio)economy, increasing self-sufficiency of bio-based products and limiting the need for imports.

Within the EU Algae Initiative by the EC, the Commission intends to boost the potential of the EU algae sector, supporting the development of upscaled regenerative microalgae cultivation and production, creating jobs for local communities, producing sustainable low-carbon products, regenerating ecosystems (e.g. fixing CO_2 from flue gases, nutrients from wastewaters and releasing oxygen), and providing environmental services. Most importantly the EU algae sector could become the success story that embodies the ambition of the European Green Deal to reinvent the EU economy with more sustainable, climate friendly and resilient industries and regions, fitting several FRONTSH1P CSS3 objectives.

The EU Green Deal, through the EU Algae initiative, targets priority areas where the algae production sector can provide a relevant contribution such as the dependence reduction on organic fertilizers, promoting a broader use of microalgae-based plant bio-stimulants, targeted products in CSS3 from flue gases and wastewaters. CSS3 is expected to play an important role for attaining this goal.

4.2.2. Microalgae-mediated wastewater treatment

The United Nations estimates that around 2,212 km^3 of wastewater (WW) are released annually, approximately 56% of all the freshwater used, of which around 80% is discharged

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without any prior treatment EEA (2017). On the other hand, even with a WW treatment (WWT), only a very small part of the treated water is reused. As it has been estimated that by 2030 the world will suffer a water deficit of 40%, it is urgent to search for sustainable processes enabling the reuse of wastewater WWAP (2012).

Conventional WWT systems consists of an activated sludge process use large amounts of energy (up to 0.6 kWh/m^3) to remove compounds from wastewater and release clean water into the environment at a cost of 0.3€/m^3 (Acien et al., 2016) (Figure 7).

The main pollutants from the WW side, namely carbon, nitrogen, and phosphorus, are the nutrients from the microalgae side. Therefore, microalgae cultivation from WW allows to recover these nutrients and to produce up to 1 kg of biomass per m^3 of wastewater at a lower energy consumption and cost (Acién et al. 2018). The robustness of algae and the great capacity to adapt to different climate conditions, such as light intensity and light/dark cycle, pH and temperature, carbon/nitrogen ratio, nitrogen/phosphorus ratio, CO_2 supplementation and cultivation modes can significantly affect the WWT efficiency of microalgae and, consequently, their productivity (Umamaheswari and Shanthakumar 2016). The efficient removal of pollutants/nutrients allows the water reuse with the benefit of using the produced biomass/compounds into different markets, such as biofuels, biofertilizers, biostimulants, high value chemicals, turned the microalgae an important skill of circular economy.

However, despite the benefits of microalgae-based technologies *vs* conventional systems, these processes imply large surface area involved.

Nevertheless, almost all water systems could be treated my using microalgal cultivation as a feasible alternative to the existing WW treatment processes, namely: i) urban WW (secondary and tertiary treatments thereof, including the removal of pharmaceuticals); ii) agriculture WW (e.g., wastes from farming – aquaculture, poultry, swine, cow, dairy, and food processing plants from which removal of antibiotics or pesticides is often needed) and iii) industrial wastes such as flue gas (either on their own or in combination with WW treatment). In addition to these nutrients, effluents may contain compounds such as pesticides, heavy metals and pharmaceuticals, and the ability of microalgae to metabolize these compounds makes their cultivation even more attractive (Acien et al., 2017).

Basically, in WWT the symbiosis of the consortium microalgae and bacteria could explain the success of the treatment: in the classical scheme, bacteria are responsible for chemical oxygen demand (COD) degradation to mineral components, consuming photosynthetic O_2 and releasing CO_2, whereas microalgae consume the CO_2 and mineral nutrients to produce microalgae biomass and the O_2 requested by bacteria (Figure 7). This process can replace the energetically expensive treatment steps in a Conventional WW treatment. In this treatment there are must higher GHG (greenhouse gas) emissions due the need of high energy to agitate the bacteria and from the process, the nutrients are not removed, and there is a production of a bacteria/chemical's sludge without any application.

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Contrarily, the WWT-based Microalgae there are no need of agitation due the symbiosis O_2/CO_2 between microalga-bacteria, and bacteria-microalga, respectively; the pollutants/nutrients are consumed by the microalga; and the produced valuable biomass can be used in several application (e.g., biofuels, bioplastics, biofertilizers/stimulant/pesticides, and feed). Bioremediation via microalgae has appeared as an eco-friendly and sustainable technique to curb the adverse effects of organic contaminants because microalgae can degrade complex organic compounds and convert them into simpler and non-toxic substances without the release of secondary pollutants. Even some of the organic pollutants can be exploited by microalgae as a source of carbon in mixotrophic cultivation.

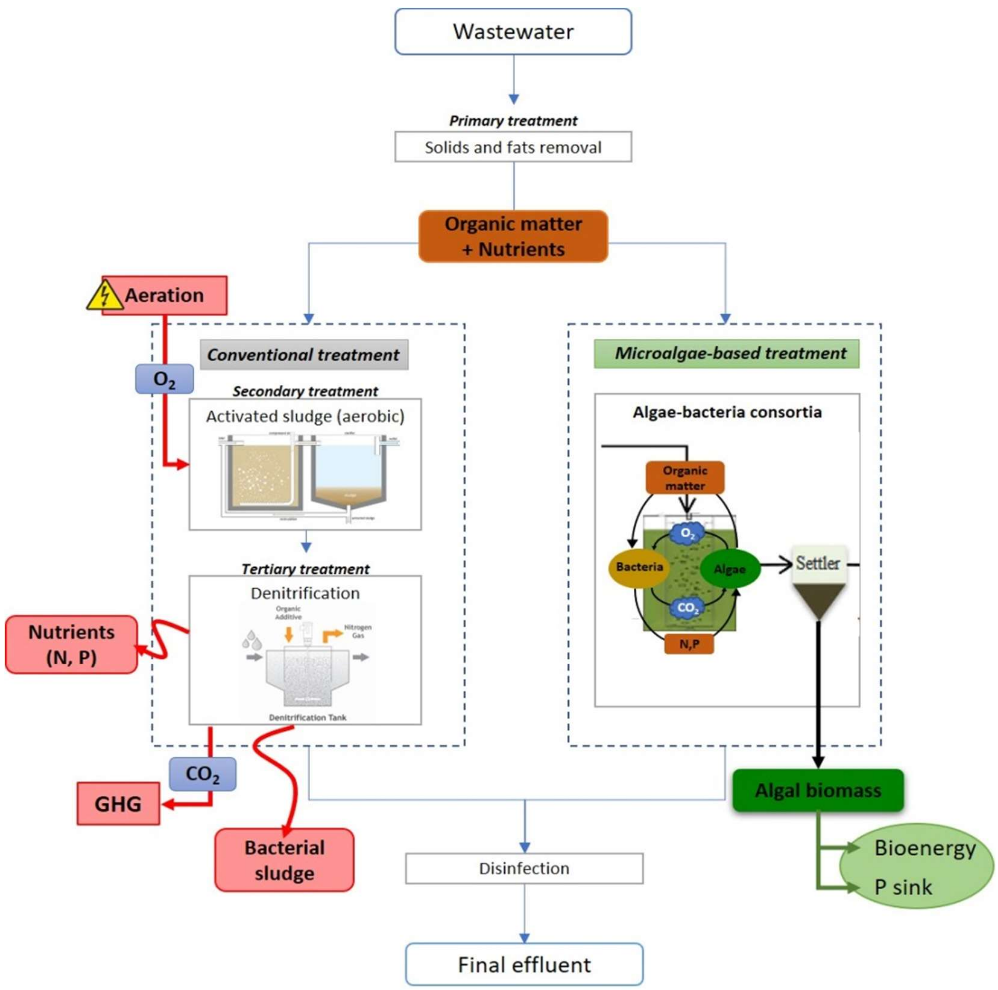

Figure 7A. Conventional wastewater treatment versus wastewater treatment-based microalgae. Source: Ferreira et al., 2019a.

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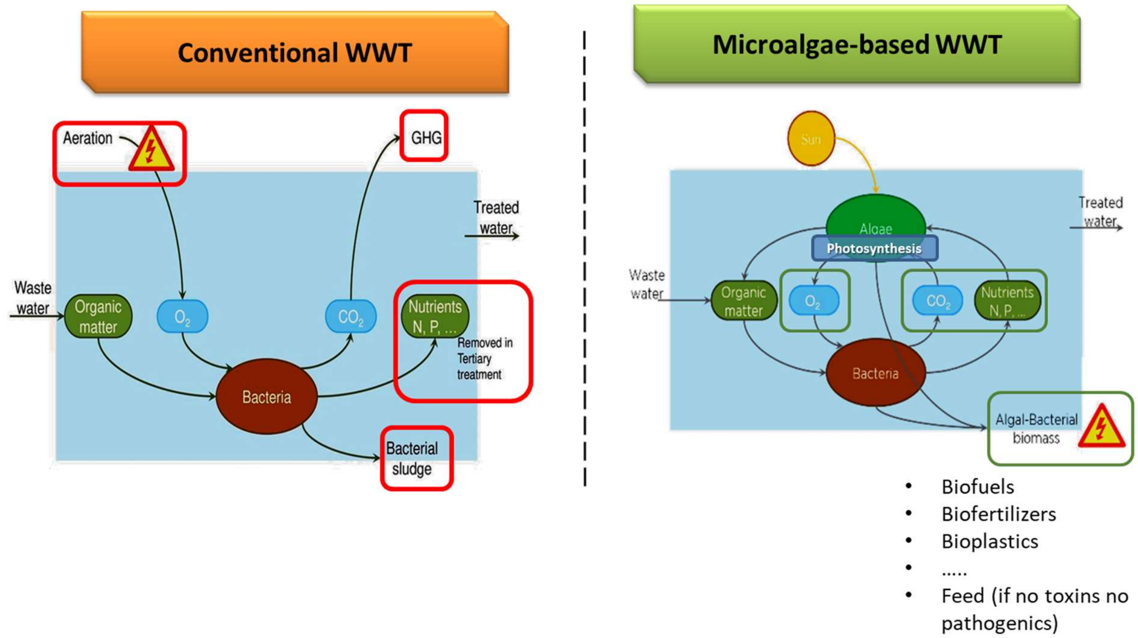

Figure 7B. Conventional wastewater treatment versus wastewater treatment-based microalgae.

The Raceways ponds are the used reactors to treat the WW and to produce the biomass at lowest price (Acién et al., 2018). The Table 11 shows the WWT performance achieved during outdoor real WWT.

Table 11. Wastewater treatment performance achieved during outdoor real treatment in High Rate Algae Ponds (HRAPs)

Wastewater	Volume (L)	HRT (days)	Removal efficiency (RE, %)	Productivity ($g\ m^{-2}\ day^{-1}$)	Reference
Domestic	570	3–10	TN≈57%–73%		García et al. (2000)
Domestic	500	4–8	COD≈66%–85%; NH_4^+≈99% (summer)		Matamoros et al. (2015)
Swine manure	464	10	COD≈76±11%; TKN≈88±6%; *P*≈10%	21–28	De Godos et al. (2009a)
Fish farm +primary domestic	180	7–20	COD≈77±9%; TKN≈83±1 0%; *P*≈94±6%	5	Posadas et al. (2015b)
Secondary domestic	530	10	TN≈60±1%	8.3±1.4	Arbid et al. (2013b)
Primary domestic	700–850	3–7	COD≈84±7%; TN≈79±14%; TP≈57±12%; *E. Coli*-RE≈93±7%	4±0–17±1	Posadas et al. (2015a)
Secondary domestic	533	8	TN≈92.1±1.4%; TP≈95.1±0.8%	19.8±0.4	Arbid et al. (2013a)
Swine manure	464	10	COD≈56±3%; NH_4^+≈98±1 %; TP≤15%		De Godos et al. (2010)
Primary domestic	4,375,000	5.5–9	N-NH_4^+≈79±13%; P_s≈49±22%		Sutherland et al. (2014)
Primary domestic	4,375,000	8–9	BOD_5≈50%; N-NH_4^+≈65%; P_s≈19%; *E. coli*≈2 log	8	Craggs et al. (2012)

Source: Posadas et al., 2017.

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Applications of the produced biomass

Microalgae/Cyanobacteria have been widely recognized by their massive applications as shown in Figure 8.

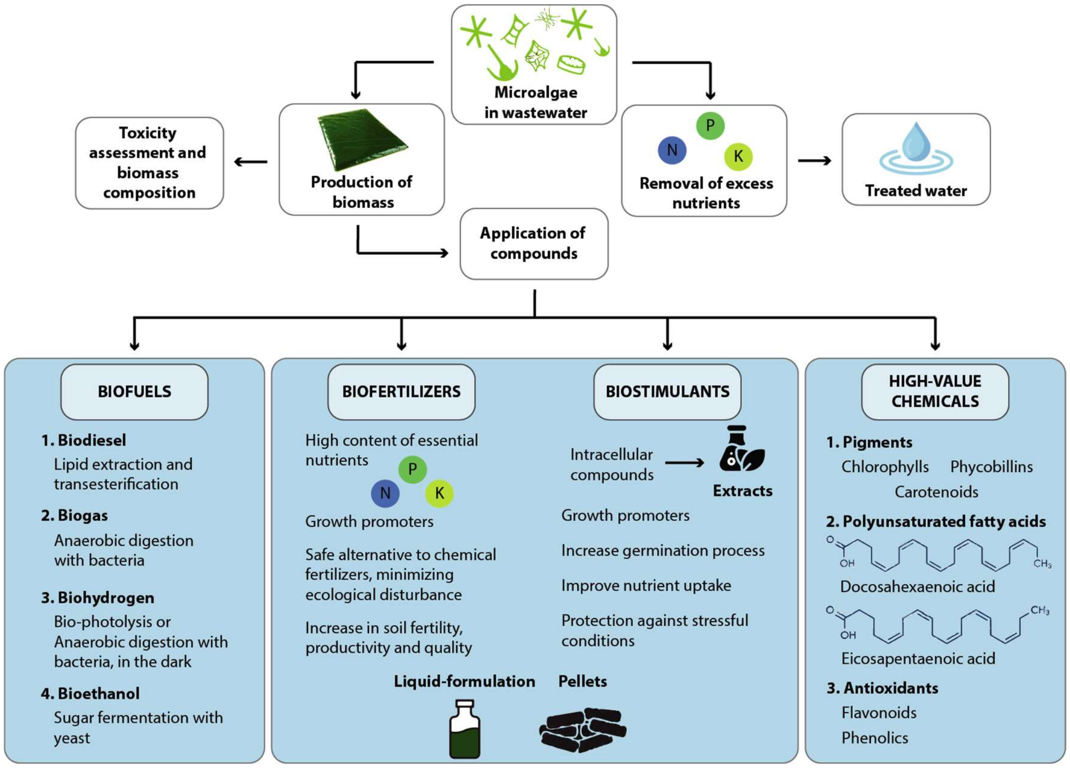

Figure 8. Bioproducts obtained from microalgal biomass produced in wastewater treatment. Source: Morais et al., 2021.

Biofertilizers/Biostimulants from microalgae cultivated in wastewater

Recently, the combination of wastewater treatment-based microalgae and the use of the obtained biomass in biofertilizers/stimulants/pesticides has been very highlighted with a massive interest in the agriculture field. Seems that by 2050 agriculture yields will decrease more than 10% due to the climate change; 33 % of the global soil is moderately to highly degraded due to erosion and pollution and between 50-80% of nitrogen load in freshwater bodies comes from the overuse of fertilizers (FAO, 2021). Besides, GreenDeal obliges to a reduction of 30% on fertilizers and 590% of pesticides. So, the agriculture sector needs to develop innovative products and technologies to feed the hunger people, to increase water reuse, to increase crop yield and quality while decreasing agricultural carbon footprint and increasing the economic benefits for farmers (Singh and Singh 2017).

Recently several authors highlighted the use of microalgae biomass produced in WWs for biofertilizer/biostimulant/biopesticides as the short-term top application (e.g., Ferreira et al., 2021, 2019b; Navarro-López et al., 2020a, 2020b; Viegas et al., 2021a, 2021b, 2021c, 2021d).

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Microalgae biomass contains higher amounts of nitrogen, whereas cyanobacteria biomass has a higher ability for nitrogen fixation. Other benefits include: i) growth promoters through the release of growth hormones, amino acids and polysaccharides for plants [10]; ii) biocontrol of agricultural pests and promotion of antagonism and biological control of phytopathogenic organisms [148]; iii) increased soil fertility [149]; iv) reduction of soil erosion through the regulation of water flow; v) reduction of energy consumption and contamination of soil and water bodies; vi) increased crop productivity per area; vii) nitrogen-fixation ability by cyanobacteria, which can be used by higher plants; and viii) renewable solution for chemical fertilizers.

Examples of WWT-based microalgae with biomass used as biofertilizers/biostimulants can accelerate seed germination.

Brewery WW was a culture medium of *Tetradesmus obliquus* (also known as *Scenedesmus obliquus*) with an increase by 40% the germination index of watercress seeds when using the biomass at 0.1 g L^{-1}, without any pre-treatment (Navarro-López et al. 2020b). Ferreira et al. (2019) also showed a good efficiency on brewery WWT by *Tetradesmus obliquus* as well as biostimulant effect on different seeds mainly on barley, which is the main raw material for beer production, being a great circular economy example.

Poultry WW bioremediation using three microalga strains, such as *Chlorella vulgaris*, *Chlorella protothecoides* and *Tetradesmus obliquus* revealed 100% removal for total nitrogen, more than 80% for total phosphorus and over 70% for COD. Average biomass productivities for 10 days of 94.9, 76.2 and 72.0 mg L^{-1} d^{-1} were obtained for *T. obliquus*, *C. vulgaris* and *C. protothecoides*, respectively. *C. vulgaris* microalga showed a 147% increase in wheat germination index (Viegas et al. 2021a).

Cattle WW was clean by using *Chlorella protothecoides* and *Tetradesmus obliquus* and the biomasses used as biostimulants for wheat and watercress seeds Increments in the germination index were 177% for wheat with *C. protothecoides* and 34% for watercress with *T. obliquus* (both for only 0.2 g/L biomass concentration) (Viegas et al. 2021b).

Aquaculture WW using *Chlorella vulgaris* (Cv) and *Tetradesmus obliquus* (To) for bioremediation had excellent rates for total nitrogen, total phosphorus, COD, and BOD_5 removals (100%, 96.5%, 96.2% and 99.7% for Cv and 100%, 98.6%, 97.7% and 99.7% for To, respectively) (Viegas et al. 2021c). The obtained biomass could be used as supplement for animal feed and showed very promising results as a biostimulant in the germination index with of wheat and watercress seeds (increments of 175% for Cv and 98% for To) (Viegas et al. 2021c).

Swine WW was treated by three microalgae (*Tetradesmus obliquus*, *Chlorella protothecoides*, and *Chlorella vulgaris*) and one cyanobacterium (*Synechocystis* sp.), achieving nutrient removals of 62-79% for COD, 84-92% for TKN (total Kjeldahl nitrogen), 79-92% for NH_4^+ and over 96% for PO_4^{3-} . The produced biomass was then tested as a biostimulant for seed germination and plant growth for various plants (tomato, watercress,

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cucumber, soybean, wheat, and barley). An overall increase on germination index of microalgae-treated seeds was observed, owing to the development of longer roots. The microalgae treatments achieved 75-138% increase of germination index of cucumber seeds (Ferreira et al. 2021).

Acutodesmus dimorphus, improved nutrient uptake in tomato plants (Garcia-Gonzalez and Sommerfeld 2016) while *Chlorella vulgaris* and *Tetradesmus quadricauda* upregulated the expression of genes related to nutrient acquisition in sugar beet (Barone et al. 2018).

Biofuels from microalgae cultivated in wastewater

Several studies apply the cultivated microalgae in WW to produce biofuels (Table 12).

Table 12**.** Examples of biofuels produced with microalgae biomass cultivated in different wastewaters.

Microalgae	Wastewater	Biofuel	Ref.
Microalgae consortium	Dairy	Biodiesel	[107]
Chlorella vulgaris	Textile	Biodiesel	[108]
Chlorella sp.	Urban	Biogas	[109]
Chlorella vulgaris, Tetradesmus obliquus and *Chlamydomonas reinhardtii*	Piggery	Biogas	[110]
Chlamydomonas reinhardtii UTEX 2243 and Chlorella sorokiniana UTEX 2714	Acetate rich wastewater	Biohydrogen	[111]
Chlorella vulgaris, Tetradesmus obliquus, Microalgae consortia	Urban	Biohydrogen	[112]
Wild yeast and microalgae consortium	Municipal	Bioethanol	[97]
Nannochloropsis oculata and *Tetraselmis suecica*	Municipal	Bioethanol	[95]
Tetradesmus obliquus	Brewery	Bio-oil, Biochar Biogas	[98]

Source: Morais et al., 2021.

Energy and Economics of Wastewater treatment plants (Conventional and Microalgae-based)

The company AQUALIA from Spain trough the ALL-GAS project took the results showed on the Figure 3 and Figure 4.

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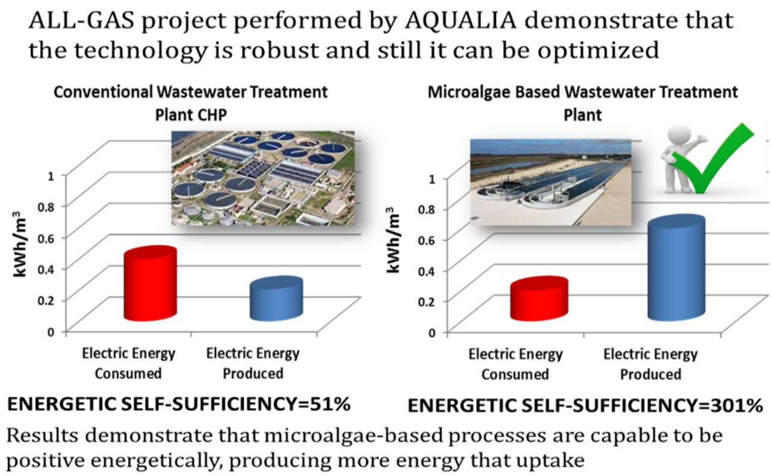
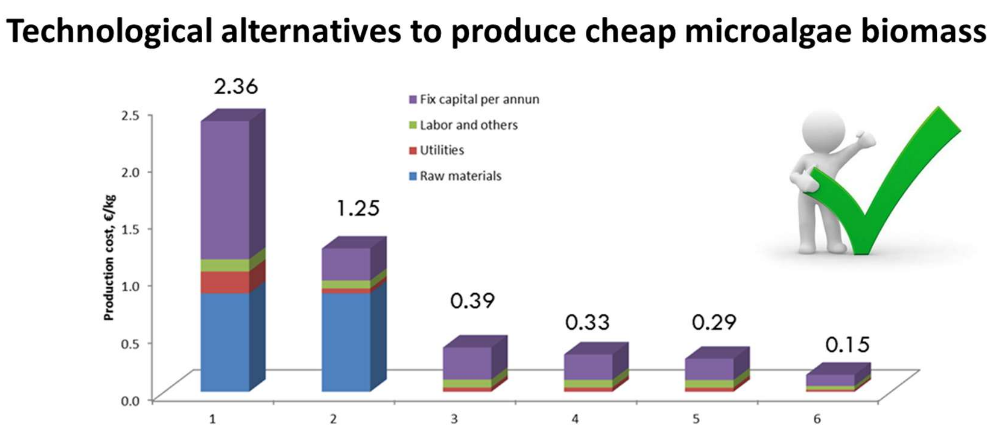


Figure 9. Electric energy consumed and produced by Conventional and Microalgae-based Wastewater Treatment Plants.



Scenario	Inputs	Reactor	Productivity	Harvesting
1	Water, CO2 and fertilizers	Raceway	Real	Centrifugation
2	Water, CO2 and fertilizers	Raceway	Real	Flocculation-Sedimentation+Centrifugation
3	Free flue gases and wastewater	Raceway	Real	Flocculation-Sedimentation+Centrifugation
4	Free flue gases and wastewater	Raceway	Real	Flocculation-LamellarSedimentation+Centrifugation
5	Free flue gases and wastewater	Raceway	Real	Flocculation-LamellarSedimentation+Filtration
6	Free flue gases and wastewater	Raceway	Theoretical	Flocculation-LamellarSedimentation+Filtration

Utilization of wastewater is the best option to reduce the production cost

Figure 10. Microalgae Production Costs using different inputs (water, CO_2 and fertilizers *vs* wastewater and free flue gases technologies) and harvesting technologies (centrifugation *vs* flocculation, filtration, and combination of different methodologies).

REAL Example of a Wastewater Treatment Plant

AQUALIA, a wastewater company based in Chiclana (Spain), is the largest demonstration facility and a real case of worldwide success, where WWT is based on the microalgae use,

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and from the obtained biomass they obtained biogas and biofertilizers (Arbib et al. 2014). From the ALL-GAS project case study, up to 80% and 90% of total N and P removal efficiencies were achieved, respectively, at an energy consumption of 0.2 kWh/m^3. The land required was less than 3 m^2/PE (person equivalent) at a hydraulic retention time of 2 days and average biomass production capacity of up to 90 t/ha year, close to the theoretical values for autotrophic growth (Arbib et al. 2014). The obtained clean water complies with national and European regulations and an annual production of biogas enough to run 325 000 km by 7 cars and a bus, as well as the production of 40-60 ton of biomass for biofertilizer (Figure 11). The same company are building three more Microalgae-based wastewater treatment plants in Spain.

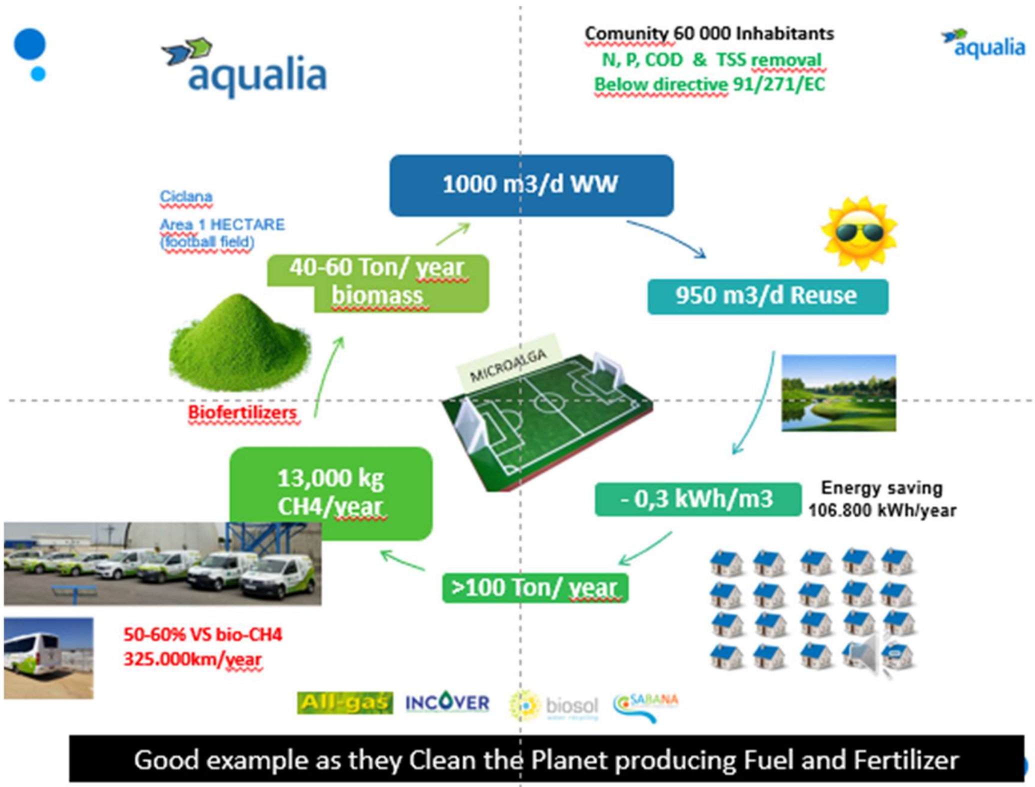

Figure 11. AQUALIA company in Chiclana, Spain.

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4.3. Identification, involvement, needs and expectations from regional stakeholders involved in CSS3

4.3.1. Legal framework

The water reuse related to possible applications of the reclaimed water: public sector, industry, agriculture, sport and recreation has at the momentum the highest priority in Poland. Significant progress has been made over the past 30 years; since 1990, total water abstraction has decreased by 19% as a consequence of advances in water efficiency and supply management. The EU Water Framework Directive, the EU Urban Wastewater Directive, and the EU Drinking Water Directive are primarily responsible for the observed improvement.

Polish law regulates municipal sludge and water management issues while also taking into account the criteria and guidelines established by European law. The fundamental legal procedures in this field include regulations, which allow to reduce the pressure on the environment and the use of valuable water resources. It is shows in the legal acts:

1. Act of 20 July 2017 Water law (JL 2017 pos. 1566 with subsequent changes). According to the idea of sustainable development, the Act governs water management, including the formation and protection of water resources, water usage, and management of water resources. The Act also establishes guidelines for the management of water and land that is submerged in water, as well as ownership of these elements in connection to State Treasury assets.
2. Act of 7 June 2001 on collective water supply and collective sewage disposal (JL 2001 No 72 pos. 747 with subsequent changes). The Act outlines the rules and guidelines for the collective provision of water for human consumption and the disposal of sewage, including the rules and guidelines for: a) the operation of water supply and sewage businesses; b) setting up circumstances to ensure the continuity of supply, acceptable water quality, and dependable collection and treatment of sewage; and c) protecting the interests of service receivers while taking into consideration environmental protection laws.

Reduced raw material use is one of the trends in contemporary law. However, the regulations' shortcomings are evident from the inadequate implementation of them, and other issues related to the CE. Particularly, the growth of the circular economy is not supported by the present waste management laws (Li and Yu, 2011; Govindan and Hasanagic, 2018). Legislative barriers can be identified in three areas (Takacs, Brunner, and Frankenberger, 2022):

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- hindering legislation,
- lack of institutionalized system and standardization,
- lack of clear vision from legislators on CE in public procurement.

Growing concerns about global warming, the phase-out of gasoline and diesel vehicles and transportation, and the scarcity of resources at landfills may prompt changes in many sector laws that might catalyse the transition to a circular economy (Upadhyay et al., 2021). The sectors like packaging, plastics, wastewater, agriculture, energy are covered by plenty of laws, ordinances, restrictions, and uncertainties. This leads to a disjointed and complicated legal system at the European, national, and municipal levels (Hina et al., 2022; Khajuria et al., 2022). It is worth mentioning the legal guidelines which aim for a linear model, where a product is treated as waste in its ultimate stages, most often after being recycled or "downcycled" into goods have less of an impact on the environment (Jaeger and Upadhyay, 2020). In this regard the company has not yet achieved all it can with implementing circular economy. The subject of people's involvement in the CE approach is also raised and should be imposed by law (Charef, Ganjian, and Emmitt, 2021). Governmental policies, laws, and regulations have a significant impact as it transitions from linear to CE as corporate environmental management, the participation of the government is crucial to advance CE procedures, (Kazancoglu et al., 2021). However, limitations that have been identified, such as a lack or ineffectively implemented of environmental rules and regulations, a lack of environmental management certifications and systems, and a lack of favourable tax policies to support circular models are at least influencing the transformation (Mangla et al., 2018; Ranta et al., 2018).

The confrontation of the role of local government units among individual project partners is especially important due to the importance that the European Commission attaches to eco-design. It seems that the development of eco-design, supported by the initiative of the Commission in the scope of relevant directives, may lead to the formation of many simple relations in the future between the owner of the waste (raw material), i.e., a citizen or entrepreneur, and another entrepreneur interested in its purchase.

The first important element of identifying the involvement, needs and expectations of regional CRC stakeholders was the verification of the perception of legal institutions in the CSS3 area. The diagnosis of formal errors and legal barriers is also information about the reasons for a specific state of involvement. It is also indirectly identifying the expectations of stakeholders towards the legal framework for the functioning of the CSS3 market. Two research methods were used to identify legal and formal barriers: online survey and participant observation.

Participating observation with moderation of the discussion during two seminars with the participation of experts related to waste management in local government units. During

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the seminar, the basic areas of formal failures were identified. During the observations of the participants, it was found that legal and formal barriers may be factual or apparent ones. In the first case, it concerns the occurrence of formal errors, contradictions in the law, loopholes in the law, imperfect definitions, inoperability of legal provisions, or difficulties in applying the law. In the second case, failures result primarily from the lack of awareness and knowledge about the legal institutions of the stakeholders, the inability, or the ability to interpret the law, and the existence of erroneous, outdated behavior patterns.

The survey addressed to selected local government units. The questionnaire was addressed to the municipalities that are part of the Inter-Communal Association of Bzura and neighbors in proximity - potential members of the developing CRC. A total of 15 responses were obtained. The study was conducted in the period from 01/03/2022 to 03/03/2022. The questionnaire was carried out online. The results show that among the main difficulties of effective involvement of the municipality in selective collected waste are:

1. Low level of circular market development and sector diversification,
2. The lack of appropriate skills among officers, citizens, scientists and entrepreneurs in building circular market,
3. Lack of cooperation between local government units in area of waste management - lack of gaining scale effect,
4. Limited access to databases with information about waste and raw materials collected on regional level,
5. Lack of databases with market information addressed to companies and society,
6. The unusability of waste management databases,
7. Lack of cooperation and integrated activities between companies, society, local non-government organisations and academy,
8. Lack of regional networks exchange of good practice in scope of waste management,
9. Limited access to sources financing CE for local government,
10. Limited knowledge of innovative technologies in field of implementing CE,
11. Few companies on regional market of waste management (oligopoly market)

To sum up, important issue is local law (i.e. act on order and cleanliness in the municipality) regulating waste management. Those acts are created separately in every municipality. The better solution will be preparing one act for many municipalities. It lets to build the legal framework for Circular Regional Cluster. Creating one act for group of municipalities is allowed by Polish law. In practise the interpretation of this law is different. National entities that control the activities of municipalities (provincial office) impose nationwide, standard, simplified solutions in this regard (separated local acts and limited flexibility of local governments).

The following detailed conclusions regarding the research carried out have been formulated:

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- Vaguely defined municipalities' responsibilities for waste management and the organization responsible for waste management.
- Low diversification of the municipality revenue sources in the municipal and industrial waste management system.
- Circular economy regulations are scattered in many legal acts.
- The environmental impact of products and services is not included in the sales price.
- The problem with the enforcement of penalties.

These conclusions are strongly connected with circular economy elements based on all materials: packaging, plastics, food, water, and nutrients analysed in FrontSh1p project.

4.3.2. Climatic and environmental conditions

The area of the Łódzkie Region in terms of climate belongs to the Central Poland region. A characteristic feature is the high variability of atmospheric pressure and the types of weather. Compared to other regions, this area is distinguished by a large number of days, an average of 38 a year, with very warm weather characterized by moderate cloudy skies and no rainfall, and quite frosty weather with heavy clouds and precipitation, 7 days a year on average. Throughout the year, there are an average of 35–40 clear days and about 140 cloudy days, and the predominant western (20% frequency among all winds) and south-western winds (10–12% frequency among all winds). Air flows quite often from the south-east and from the east (more than 10% of the time), most often in spring and autumn. There are also frequent winds from the northern sector in the spring months. Atmospheric precipitation shows a greater spatial differentiation on the scale of the voivodeship. Larger annual sums of precipitation, reaching 620 mm per year, occur in the southern and south-eastern parts of the area and decrease towards the north to 550–500 mm per year (Figure 12).

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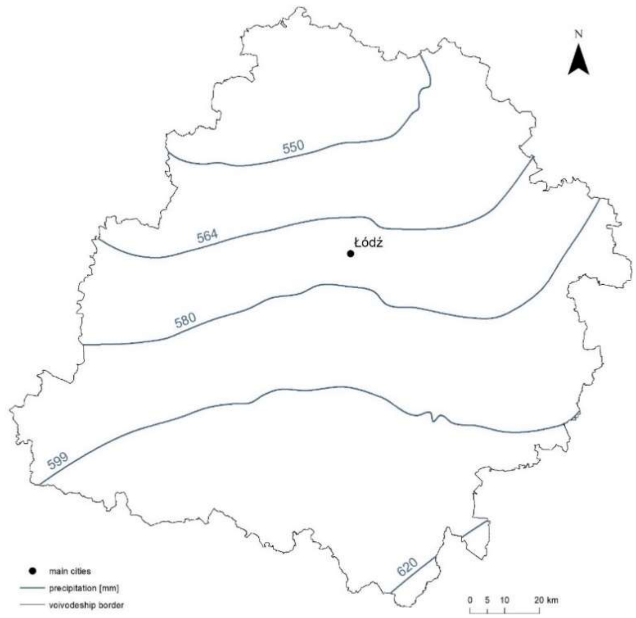

Figure 12. Spatial distribution in the Łódzkie Region mean yearly precipitation totals (in mm), in years 1961–2015. Source: own study based on Wibig, Radziun, 2019.

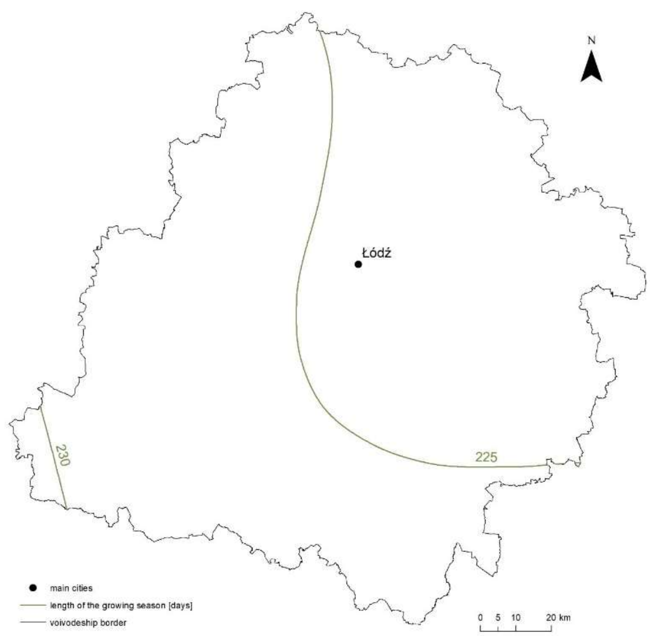

Figure 13. Mean length of the growing seasons in the Łódzkie Region (in days), in years 1971–2010. Source: own study based on Tomczyk, Szyga-Pluta, 2016.

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The average annual air temperature values, calculated based on long-term data, range from 7.6 ° C to 8 ° C. Temperature maximums are above 36 ° C are and minima -30 ° C recorded. Hot days with a temperature above 25 ° C are on average 34-37, and frosty days, when the temperature does not exceed 0 ° C throughout the day, about 40. The duration of the seasons for the year is similar, except for winter, which begins faster in and eastern the ends of the voivodship and ends fastest in the west. The average length of the growing season in the Łódzkie Region is 230 days in the south-west and changes to 225 days in its central and eastern parts (Figure 13). The earliest growing season begins in the western part of the voivodship on average March 22nd, a little later around March 25 in the central and eastern parts. There, the growing season ends earlier on average on November 5, and in the western part, on November 7 (Woś, 1996; Kłysik, 2001; Podstawczyńska, 2010; Wibig, Radziun, 2019, Tomczyk, Szyga-Pluta, 2016).

4.3.3. Identification of marginal areas in Łódzkie Region

The localisation of marginal land in the Łódzkie Region was analysed using the soil and agricultural map. The map is a part of the Łódzkie Region Geoportal. On the map is information about the land use connected with the ordinance of the Economic Development and Technology Minister on the register of land and buildings of 27 July 2021 with subsequent changes. The database was sourced from the Department of Geodesy, Cartography and Geology of Łódzkie Region. The agricultural wastelands are connected with devastated areas and marginal soils with low productivity. This land was excluded from agricultural use.

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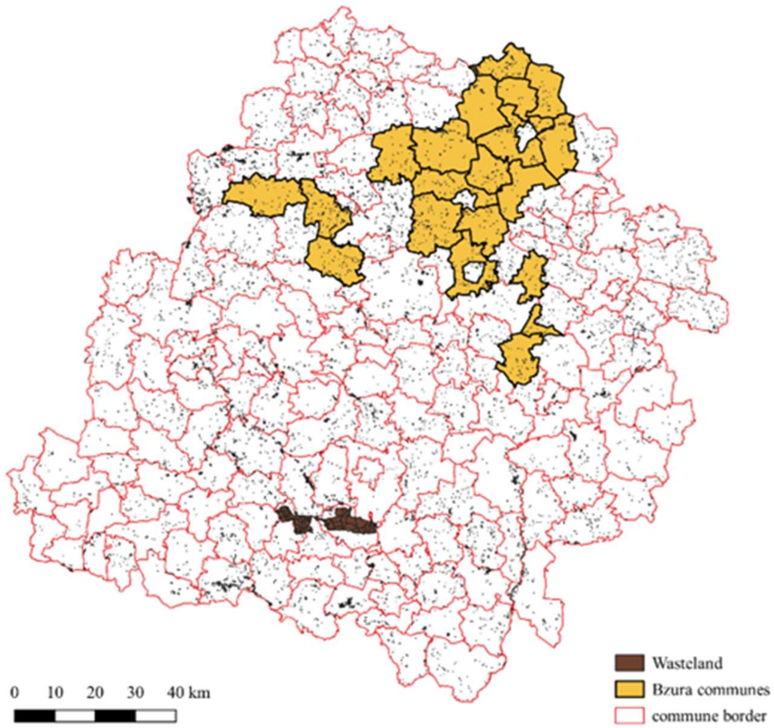

Figure 14. Localisation of wasteland in the Łódzkie Region

Source: Own work based on the soil and agricultural map Department of Geodesy, Cartography and Geology of Łódzkie Region.

The information allows presenting land use with the wasteland area (Figure 14). The analysis was connected with filtration of this type of land use and aggregation of data about each land area inside each Łódzkie Region commune. Statistical analysis used in this report is the primary step to show which commune in the Łódzkie Region is a leader in the field of wasteland share. The information about the wasteland shows that Łódzkie Region's communes are divided into two groups. The communes containing more than 5% of wasteland relate to the opencast mining. In the second group, there are communes with less than 5 per cent of wasteland area. In this group are all communes of Bzura (Figure 15).

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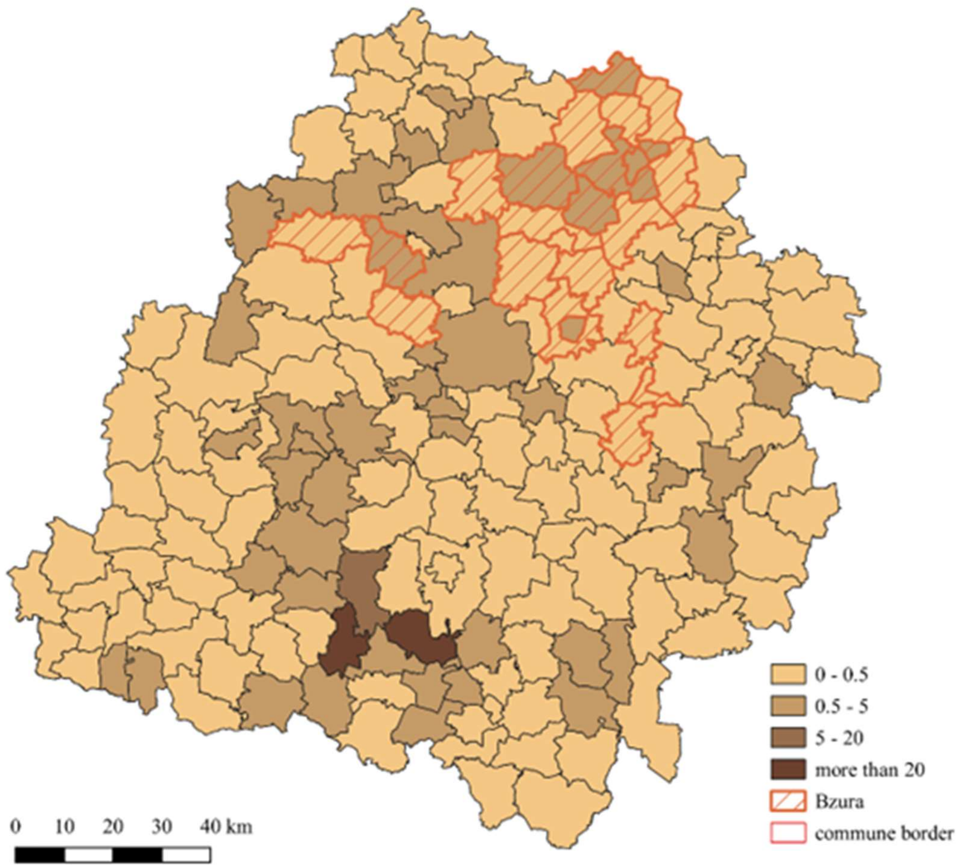

Figure 15. Share of wastelands in the commune area in [%]

Source: Own work based on the soil and agricultural map Department of Geodesy, Cartography and Geology of Łódzkie Region.

In the case of Poland, the owners of the lands may be identified if they belong to public entities. The five communes in the Bzura have got a share of the wasteland of more than 0.5%. There are Domaniewice (1.27%), Kiernozia (1.07%), Parzęczew (0.81%), Bielawy (0.67%) and Łowicz (0.65%). The other communes in Bzura have a share of wasteland from 0.05 to 0.31%.

The analysis contains information about the area in hectares in each commune in the Łódzkie Region. The median area of wasteland is 29.83 hectares. The analysis allows identifying the lowest value of this measure in the Czastary commune (1.09 ha) (Appendix 1).

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4.3.4. Awareness of the needs of stakeholders in the field of building CE

The Łódzkie Region has 2,426,806 inhabitants, of which 52.4% are women, and 47.6% are men. From 2002-2021, the number of inhabitants decreased by 6.9%. The average age of the inhabitants is 43.3 years, slightly higher than the average age of the entire Polish population. The projected number of inhabitants of Łódź in 2050 is 1,999,131, of which 1,031,519 are women, and 967,612 are men (GUS – Local Data Bank, 2022).

In the Łódzkie Region, a negative natural increase is recorded, amounting to -14 916. This situation corresponds to the natural decrease of -6.09 per 1000 inhabitants of Łódź. In 2020, 20,891 children were born, including 48.9% girls and 51.1% boys. The demographic dynamics index, i.e. the ratio of the number of live births to the number of deaths, is 0.58 and is much lower than the average for the entire country. In 2019, 36.3% of deaths in Łódź were caused by cardiovascular diseases, 25.1% of deaths in Łódź were caused by cancers, and respiratory diseases caused 7.9% of deaths. There are 14.62 deaths per 1000 inhabitants of Łódź. (GUS – Local Data Bank, 2022) It is much more than the average for Poland. In 2020, 19,670 registrations in internal traffic and 21,482 deregistrations were registered; as a result, the balance of internal migrations for the Łódzkie Region was -1,812. In the same year, 445 people checked in from abroad, and 305 deregistrations abroad were registered - this gives the balance of foreign migrations amounting to 140. The structure of people in Łódzkie Region is: 58.3% of the inhabitants of Łódź have a working age, 17.1% have pre-working age, and 24.7% of the inhabitants have post-working age (however, it is necessary to take into account the current changes caused by the war in Ukraine and the significant number of refugees who they also settle in the Łódzkie Region) (GUS – Local Data Bank, 2022).

Analyzes show that the search for potential in the production of waste related to the water and nutrients sector may be associated with the density of buildings and, thus, the density of address points. Readers should note that the density of address points and the density of the population depend on the administrative and legal status of the commune. This situation is connected with the clustering of people, regardless of the size of the city. Nevertheless, one should note that activities related to the water and nutrients sector are focused primarily on rural areas (Figure 16).

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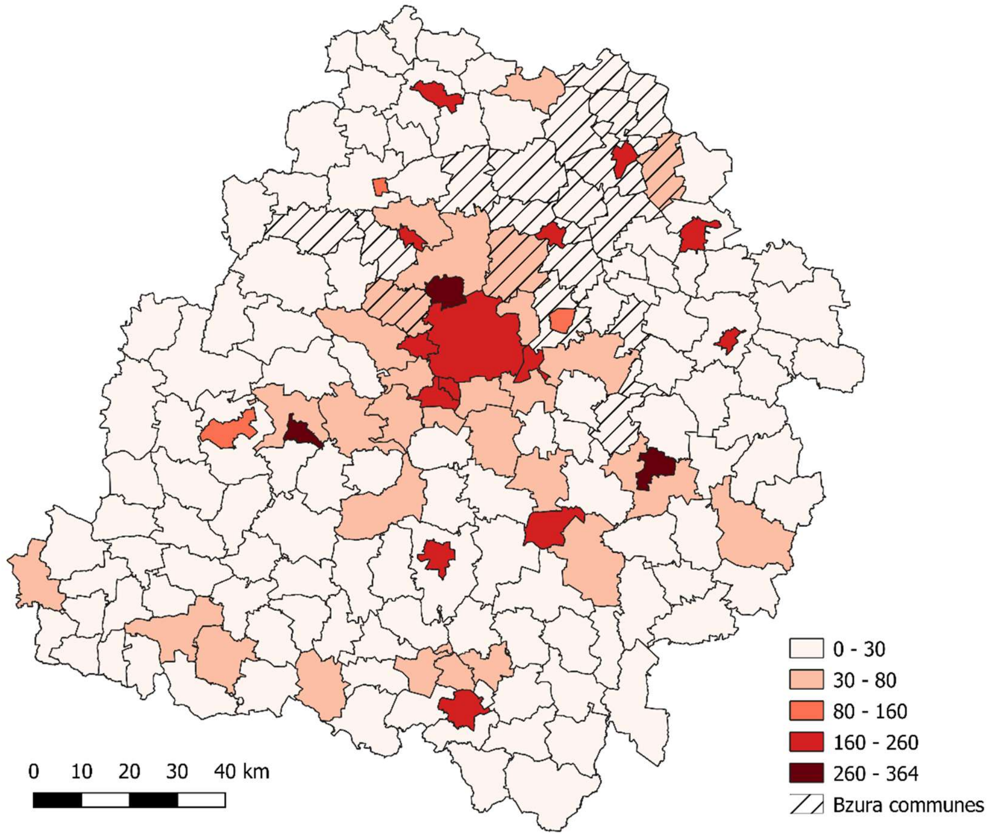

Figure 16. The density of address points on each square kilometre
Source: own work based on data from Head Office of Geodesy and Cartography (GUGiK).

The same situation is also observed when analyzing the density index of the number of address points in geodetic areas. In the case of areas outside cities, the higher density of address points per square kilometre is characterized by the precincts associated with the seats of municipalities and units that constitute suburbs (Figure 17). These units have increased potential for providing recyclable materials linked to priority areas of circular economy based on packaging, plastics, food, water and nutrients, both in the case of entrepreneurs and residents.

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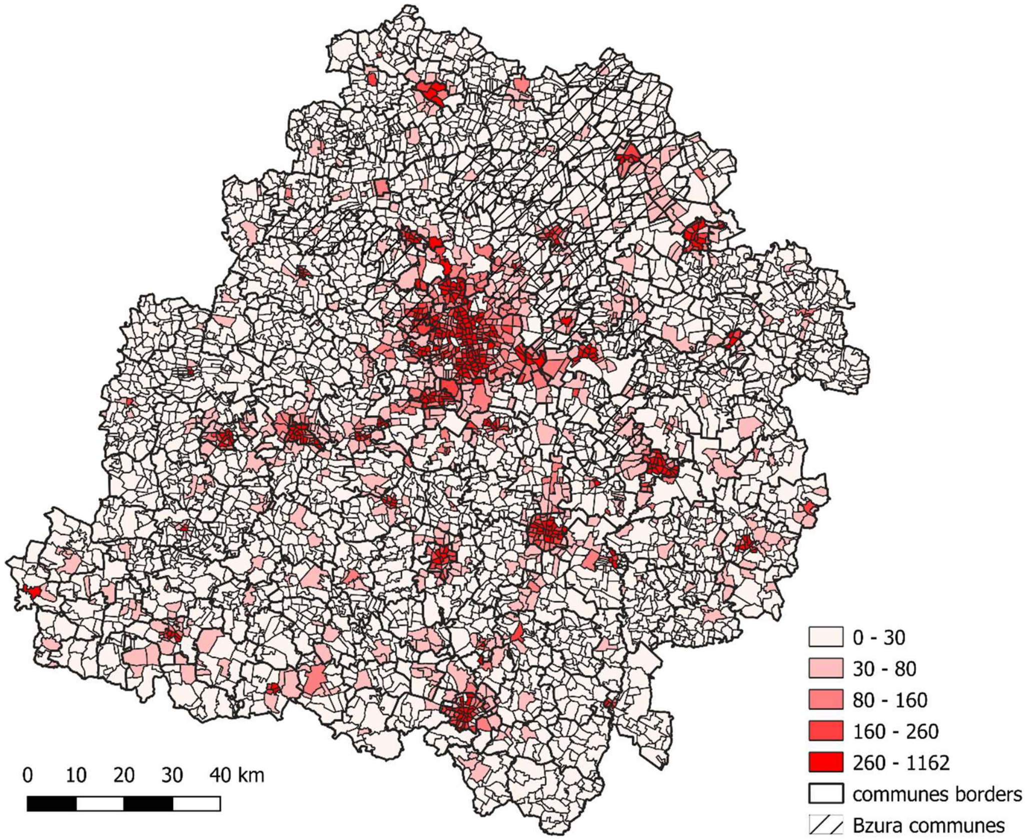

Figure 17. The density of address points on each square kilometre
Source: own work based on data from Head Office of Geodesy and Cartography (GUGiK).

There are approximately 5,800 different NGOs in the Łódzkie Region. Most of them are registered as associations (4,100), followed by foundations (0,8). Among the NGOs, the dominant ones focus their main activities on supporting and promoting the sport, recreation, tourism and hobbies. There is also a large group of NGOs whose activities focus on culture and the arts. Compared to the whole of Poland, in the Łódzkie Region, a relatively large proportion of NGOs operate in the area of supporting local and socio-economic development.

In the rural areas works the Local Action Groups (LAGs). They are responsible for allocating funds from the LEADER program to the area of operation of individual action groups (Figure 18). Each municipality can only belong to one LAGs. In the case of communes from the Bzura association, they belong to the following LAGs called: Mroga, Ziemia łowicka, Polcentrum, Prym and Gniazdo.

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Figure 18. Local Action Groups in Łódzkie Region
Source: KSOW of Łódzkie Region, http://Łódzkie.archiwum.ksow.pl/fileadmin/user_upload/Łódzkie/grafika/aktualnosci/LGD/MAPA_LEADER_ŁÓDZKIE_2018.JPG, (accessed 9.27.22).

Each market's development faces various constraints in the form of market failures appearing on it. The most common categories of market failures are public goods, externalities, imperfect competition, incompleteness of the market, and asymmetrical information (Randall, 1983, Stiglitz, 2004, Moreau, 2004, Jackson, Jabbie, 2019). Others also add incomplete property rights to this list (i.e., Perman et al., 2003; Acheson, 2006). A different approach was presented in the evolutionary economy, where the market is perceived as dynamic, chaotic, and constantly changing, rather than tending to a state of equilibrium (Nelson, Winter, 2002, Nelson, 2008, Schmidt, 2018). From this point of view, market failures typical for a neoclassic economy are not failures.

In this report, we looked at the market failure from the circular economy perspective. In a circular economy, it is more often to identify the barriers which derail or slow down the

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transition towards a CE (Kirchherr, 2017). The most common categories of barriers are technological, economic, institutional, and social. De Jesus and Mendonça (2018, p. 77) introduced an additional classification for the above barriers. They divided them into hard ones and soft ones. Hard barriers are related to techno-economic, and soft ones, have to do with regulatory and social issues.

The economy of Łódzkie Region is still in process of transition to CE. That is why, we decided to identify "classical" market failures, which are universal for all areas and entities operating within the circular economy. Our research aimed to identify market failure in the circular economy and to assess the level of their occurrence in Łódzkie Region. The research was conducted among four groups: business, government, academia and society, who we consider as main actors in the market. To achieve the aim, we conducted two-stage research:

1. Quantitative stage: Survey – online survey conducted among representatives of four mentioned groups. A separate survey sheet was prepared for each group.
2. Qualitative stage: Focus Group Interview (FGI), conducted among representatives of mentioned groups, with the same respondents. FGI research allowed verification of survey results and their interpretation.

The limited development opportunities in each territory of the circular economy and the creation of the circular cluster provided for in the project, using, among other things, water and nutrients, are affected by the occurrence of at least some market failures. First, we are dealing with a barrier to entry into the market, which is dominated by a natural public monopoly in the form of imperfect competition and public goods. Furthermore, entering this market generates very high costs, characteristic of this type of infrastructure, even in the case of the construction of on-site sewage treatment plants (incompleteness of the market). Moreover, in the case of companies interested in setting up on-site treatment plants, there is often a lack of sufficient knowledge about the appropriate methods of industrial wastewater treatment (information asymmetry). A significant mistake is also the limited scope of educational activities in the circular economy, including water and sewage, community concerns about the location of sewage treatment plants in their area, both large - municipal and more minor - in-house and (imperfect competition). In the case of poorly urbanized areas, primarily rural areas, the so-called free rider effect (externalities) occurs. It results from:

- the lack of awareness of the consequences of such activities (imperfect competition),
- social responsibility and consent (public goods),
- a limited monitoring and control system (incompleteness of the market)
- the desire to avoid costs related to the treatment of produced wastewater (externalities).

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4.3.5. Requirements and success criteria to satisfy the implementation of non-technological solutions required in CSS3

The requirements and success criteria to satisfy the implementation of the required non-technological solutions relate to various areas, including in particular:

– the scope and appropriateness of applying incentives,
– identification of areas requiring intensification of the integration processes of regional stakeholders' activities,

The research aimed to identify the operating incentives in the area of the circular economy. It was based on the use of the qualitative method. The advantages of which are widely emphasized in the literature on the subject: a more in-depth understanding of social phenomena, through active participation in the studied processes, the researcher has a chance to get to know the context and the process of development of phenomena (happening over time). The next ones are a holistic perspective, recognizing many nuances in attitudes, behaviours and conversations with the respondents; Most of the fieldwork, therefore, yields data that cannot be easily reduced to numbers and would be invisible, unforeseen, and immeasurable in those numbers. Qualitative research, thus, provides a new quality of knowledge and information. "(Babbie, 2004). There is a hidden belief in this approach that the function of research is not only to generate knowledge but also "a tool for education and awareness development and mobilization to act" (Gaventa, 1991).

It was also decided to use a triangulation approach, which consists in collecting data using various techniques and research tools. Then comparing and combining the results, it is possible to test the same hypothesis and reduce the error burden resulting from the limitations and disadvantages of individual research techniques (Denzin, 2006). The triangulation approach gives research a new dimension by introducing interpretative research attitudes based on social views and experience, which provides greater flexibility in research techniques and tools used.

As part of the qualitative method, it was decided to use three different research techniques:

1. Open participant observation[1].

[1] The first observation was carried out on April 6, 2022, at Municipal Waste Disposal Plant (Zakład Unieszkodliwiania Odpadów Komunalnych) "Orli Staw" premises in Prażuchy Nowe, visiting all facilities related to the site and getting acquainted with the technologies and the overall idea of the plant's operation. The authors collected photographic material, documents, and auxiliary materials during this time. Interviews were conducted with key and, at the moment - potential respondents, who were then invited to in-depth interviews. Ultimately, it is planned to have at least three such visits combined with participant observation.

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2. Individual (free) interviews with a standardized list of information sought (IDI - Individual In-Depth Interview), where scientific and research instructions were the research tool, i.e. the list of information sought by the researcher[2].
3. Analysis of qualitative data consists of the value of observations made thanks to the use of participant observation. Analysis of the content of the collected materials and conducted qualitative interviews, as well as the analysis of the literature on the subject (scientific articles, reports, EU studies)), made it possible to reveal the functioning system of incentives within the implementation of circular economy in the Łódzkie Region and beyond.

This study aimed to discover the regularity of the phenomenon through the following characteristics, typical for the analysis of qualitative data: frequency, intensity, structure, processes, causes, and consequences of the process (Lofland and Lofland, 1995).

The incentive system to support the implementation of CE can be considered for specific groups of waste: Plastics and Rubber, Water and Nutrients, Food and Feed, Wood Packaging.

Incentives can be dedicated and targeted directly to entrepreneurs and other entities operating in industries relevant to a particular waste group, as well as be universal and independent of waste type. Respondents surveyed indicated both types of incentives, saying, however, that very few of them are dedicated, and most are universal ones. An example of such a universal incentive is the NFOSiGW and WFOSiGW system of grants and loans for the implementation of environmental tasks including those aimed at implementing CE. Individuals, entrepreneurs, NGOs, local government and state budgetary units can apply for them, provided that a specific task is included in the priorities set for a given year in a resolution of the Fund's Board. However, considering the division into the four waste groups and their specificity, recommendations for each of them were established during the conducted procedures. The Water Law (Act of 20 July 2017) regulates the wastewater issue and is currently more "civilized" than the issue of plastic waste.

Depending on the origin, there are three types of sewage: domestic sewage - sewage from residential buildings, collective housing and public utility buildings, generated as a result of human metabolism or the functioning of households; municipal wastewater - i.e. domestic wastewater or a mixture of domestic wastewater with industrial wastewater or rainwater or

[2] As part of the research, four interviews were conducted with key people in the field of the circular economy. The responders were officials representing: the Director Department of Environmental Protection at the Marshal's Office, the Head of the Provincial Inspection for Environmental Protection, the director of the "Orli Staw" Municipal Waste Disposal Plant (ZUOK) and entrepreneur - founder of the Ekotechnologie company, which develops and implements new generation technologies. We are talking about an innovative and environmentally friendly method of producing the Biorol natural fertilizer, which was developed for implementation as part of the project: Support for innovation favouring resource-efficient and low-emission economy "SOKÓŁ Interdisciplinary - Implementation of innovative environmental technologies. The respondents played the role of experts in the topic under study and were selected on purpose.

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meltwater resulting from precipitation, discharged by sewage devices and industrial wastewater - created in connection with commercial, industrial, storage, transport or service activities.

In the case of industrial wastewater, it is impossible to reuse them due to the presence of hazardous substances (loads) in them, both chemical and biological. Therefore they are intended only for disposal. Industrial wastewater cannot reuse this type of waste. Domestic wastewater is also contaminated, and in smaller agglomeration units, the concentrations of hazardous compounds are lower; for example, those coming from Łódź are so high that due to their contamination, local actors cannot reuse them. An important remark is that the currently operating sewage treatment plants are not prepared to purify water from new types of compounds that appear in wastewater. In recent years, this problem has become more and more common.

Taking into account sewage sludge, a form of support for their reuse is the provision in the Waste Act (14 December 2012). sewage sludge can be used as fertilizer (to be used for agricultural purposes), as well as the Act on fertilization and fertilization (of 10 July 2007), which says about meeting the relevant standards so that the sludge can be reused.

Another issue is the composting of this sludge. It can also be seen as a support, as statutory provisions allow for such use. The only problem is the sewage septic tanks, which often do not meet tightness standards.

The process of encouraging (to implement the assumptions of circular economy), i.e. giving and receiving incentives, can be presented using and analogically to the communication model functioning in the literature (Griffin, 2000; Dobek, 2002; Drzazga, 2004). Sender (Source) and recipient (auditorium), and the message will be synonymous with a specific incentive. The conducted research reveals six types of models of encouraging (communication) processes:

1. one-way and two-way communication model: one sender - one incentive - one recipient;

2. mass communication model: one sender - one incentive - several recipients;

3. sectoral communication model: one sender - one incentive - sectoral recipients;

4. communication model of a multitude of senders: many senders - one incentive - one recipient;

5. model of communication of a multitude of senders and incentives: many senders – many incentive - one recipient;

6. communication model – multiple incentives: one senders – many incentive - one recipient.

The sender of the incentives will be mainly the Government, but also, in a few cases, other actors of the cluster: Society, Company and Academy. On the other hand, the incentive

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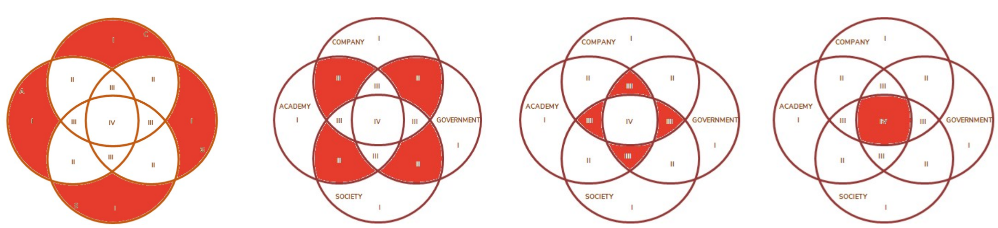
recipients are mainly the Company (understood as an entrepreneur), Society, and marginally Government and Academy. It should be noted that each incentive indicated in the table creates a single encouraging process, conforming to a specific model with individual conditions (context, understanding, channel, noise, feedback).

Referring to the identification of areas requiring the intensification of the **integration processes of regional stakeholders' activities**, attention should be paid to the specific type of network organization to be created. The implementation of the circular economy requires the involvement of all four groups of partners responsible for creating CRC: company, academy, society, and government. This involvement requires monitoring and coordination. Such coordination should be the domain of public authorities at both the local and regional levels. Integration of activities induces synergy processes and is therefore a function of the speed of change and the dynamics of regional development processes. This element is particularly important when talking about systemic changes - the evolution of a free-market economy operating under a linear production model into a circular economy. However, it should be highlighted that integration of activities on a regional scale (CRC) does not necessarily mean direct cooperation between partners. It is most important that the activities of individual partners affect the resolution of the challenges of the other partners to the greatest extent possible. In other words, partners do not have to be directly bound to each other by formal agreements - it is important that "the sailors in the boat row in the same direction and with solidarity commitment." Hence the importance of the study, which aims to identify the scope of impact of the projects implemented by individual CRC stakeholders on the realization of the challenges and objectives of the projects of the other regional partners.

The Leopold Matrix method was used to achieve this goal. The method makes it possible to assess the level of relations between regional partners as measured by the degree of the synergy of their projects. In Frontsh1p, this method was modified to identify the levels of integration between 4 sets of partners: company, academy, society, and government. The study analyzed: 187 projects.

The research allowed to identify four types of impacts: intra-sectoral interaction (specific impact), cross-sectoral interaction (between two sets of partners), cross-sectoral interaction (between three sets of partners) Integration (simultaneous integration between all collections of partners) (Figure 19).



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[I] intra-sectoral interaction (specific impact)	[II] cross-sectoral interaction (2.level)	[III] cross-sectoral interaction (3.level)	[IV] Integration

Figure 19. Types of interactions between projects and indicators

Source: own compilation.

Analysis of the synergy of aims and results of CRC stakeholder activities in the Łódzkie Region at the beginning allows concluding that projects have been identified in each group that strengthens CE building. However, the sum of such projects is small: 187 projects, implemented in the period 2014-2021 (Company and Academy) and 2019-2021 (Society, Governance). Thus, one can speak of a low level of project involvement of CRC stakeholders in Łódzkie Region in strengthening CE.

The number of projects that strengthen CE building varies due to the availability of information in the databases and the size of the projects. Nevertheless, it can be noted that in the Company (28) and Academy (28) groups, the selected projects directly relate to activities involving green technologies and are related to environmental protection in various aspects. On the other hand, in the Society (99) and Governance (32) groups, most projects involve activities indirectly related to strengthening CE. Most often, these are projects that strengthen the sense of responsibility, level of participation and social activation, sharing of things, services or reduction of consumption. Less often, these projects involve processes related to recycling and reusing things. The three times higher number of projects in the Society group is due to their fragmentation and small scale of activities. Nevertheless, projects of this type are characteristic of activities undertaken by residents and local community groups. To sum up, projects undertaken directly by local authorities (Governance) and the local community (Society) are rarely about empowerment or inclusion in the Circular Value Chain.

Analyzing the findings on the interactions between the regional partners' project activities, it is important to note the relatively large variation in the average ratings for each impact category (Figure 20).

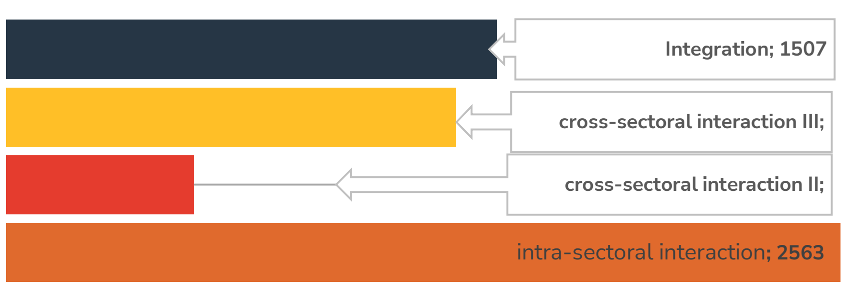

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Figure 20. Average ratings of synergistic interactions between stakeholder groups
Source: own compilation.

Most implemented projects by CRT stakeholders are sectoral (2563). These projects do not affect the achievement of results by other partners. They are important from the point of view of strengthening the sector's internal competitiveness, but their synergistic effects on the local and regional environment are marginal. Optimally, the quantities identifying the different levels of impact should be high and balanced. The lack of this level of sustainability is especially underscored by the fact that the assessment of interaction impacts is five times lower (577.25), concerning partnership relations between two groups of stakeholders.

It is difficult to speak of a sustainable level, nevertheless, it is worth noting that there were cross-sectoral projects in the region that effectively achieved their goals and contributed to the achievement of results in three groups (1,381) or all stakeholder groups (1,507).

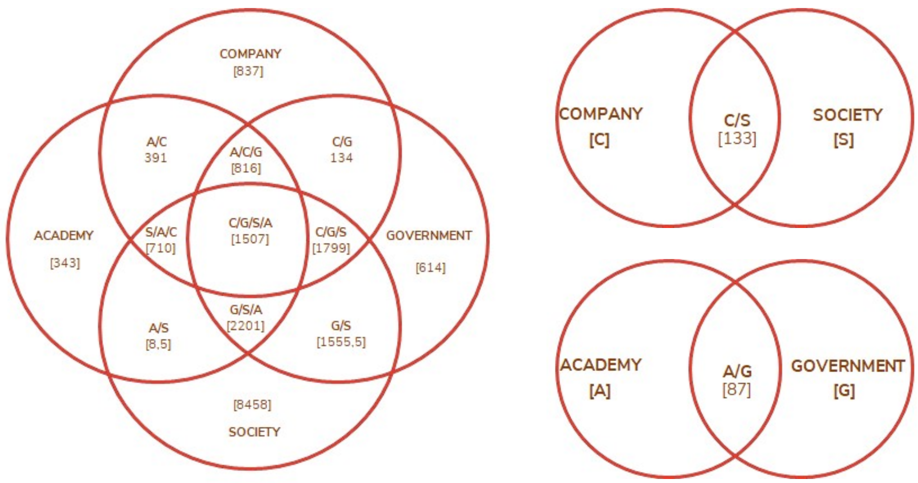

Figure 21. Scope and levels of synergistic effects among CRC stakeholders in Łódzkie Region

Source: own compilation.

The most important image illustrating the scope and needs for coordination of integration activities is given by the analysis at the detailed level (Figure 21). This diagnosis indicates the weaknesses and strengths of partnerships between regional stakeholders. It is also important to remember that it is not the existence of formal partnerships. Often, in this case, the strength of synergistic effects depends on the level of awareness and tacit knowledge in the CRC.

In intra-sectoral interaction, the highest level of self-management of development processes within the sector is observed in the Society group (8458). On the one hand, this is good information. On the other hand, the height of this indicator can be interpreted as a

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closure of the sector to interactions with other sectors. This conclusion is supported by the values of second-level interactions between Society and Company (133) and Society and Academy (8.5), which are practically non-existent. The convergence of the Society sector's internal goals is mainly because of copying the ideas of neighbours and the specificity and monoculture of non-governmental institutions at the local level. In the Government and Company sectors, the ratios are significantly lower, respectively: 614, 837. Nevertheless, it can be considered that these values are at the average level. In this case, the interaction between the objectives of the projects was determined primarily by the availability of project funding sources. It is about the orientation of the subject matter of the projects by the terms of the grants. The lowest value of the intra-sectoral interaction index is identified in the Academy sector (343). This is related, on the one hand, to the low budget 0for R&D in Poland, sectoral closure and individualism determined by the low degree of territorialization of academic sector entities in the Łódzkie Region. Sectoral closure usually means the implementation of partnership projects but based on industry similarity of partners, rarely spatial proximity.

The situation at the second level interaction is also a challenge. There is a lack of cross-sectoral sustainability. On the one hand, four areas of neglect can be identified: Academy/Society (8.5), Academy/Government (87), Company/Society (133) and Company/Government (134). The processes of synergistic effects between these areas hardly occur. On the other hand, one can see a positive picture of project relations between the Academy/Company sectors (391). This is not an indicator of a particularly high value, but nevertheless, this scope of cooperation is particularly desirable and difficult in Polish conditions, so it is worth highlighting. On the other hand, the value of the indicator of relations between sectors is high: Government/Society (1555.5). This means that local authorities influence the behaviour of residents to a large extent and can carry out coordination activities with great effectiveness.

Particular attention should be paid to the Third level of interaction and integrated impacts. In projects implemented in a group of Government or realizing its goals, the interaction has a balanced and relatively high level (from 1507 to 2201). In another case, for example, in the sets: Society/Academy/Company (710) the value is less than half. We can conclude that the goals of projects that coincide with local or regional development policies have a significantly higher potential for synergistic effects. This also means that an extremely important role must be played by local and regional Government in the transformation of the traditional economy to a circular economy in the Łódzkie Region.

In Łódzkie Region in the CRC, care should be taken to strengthen the synergies obtained through public, private, and social investments. Projects undertaken by all regional partners, above all, should be implemented far more often in scopes related to the formation of CE. This effect can be achieved not only by increasing investment budgets but, above all,

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by targeting resources more precisely to the goals of CE implementation. In this regard, it is also worth emphasizing the importance of Green Public Procurement, which is used to a minimal extent. In contrast, the potential of targeted public spending is high.

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5. Citizen engagement plan to CSS3

5.1. Road map of citizen engagement and definitions

Road map of citizen engagement:

1. Characteristics of social involvement in circular economy and its indicators in EU literature and documents: the study is based on the literature.

   Title: "Indicators of social commitment to the circular economy".

   Implementation methods: descriptive analysis of desk research literature.

   Schedule: December 2021 – March 2022

2. Definition of citizens engagement in a circular economy (CE): the study made based on literature. Will be interactively modified during implementation of the activities provided for in this plan.

   Methods of implementation: descriptive analysis of desk research type literature and expert discussion.

   Schedule: implemented in March – April 2022 (version 1);

   June – September 2022 (version 2).

   In the course of further work, the wording of the definition might be updated (according to the identified problems, regarding the forms of citizen involvement and the possibility of supporting them).

3. Comments on the social acceptance of the circular economy: the study is based on the literature.

   Implementation methods: descriptive analysis of desk research literature and expert discussion.

   Schedule: March 2022.

4. Identification of the expected citizen (household) involvement for a given CSS

   Methods of implementation Table 13: surveys with the participation of leaders of individual CSS and WP activities and descriptive analysis of the survey as well as expert discussion.

   Schedule: November 2022 – January 2023.

   Methods of implementation Table 13A: Descriptive analysis of the survey, comparative analysis, and expert discussion.

   Schedule: February – April 2023.

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5. Identification of the determinants of social involvement of citizens (households) and the possibility of undertaking practices for activities in each CSS

   Methods of implementation Table 14: Matrix analysis of conditions based on information / data received from local government partners (local communities & authorities, union of municipalities) participating in the project. Expert discussion using the Delphi method.

   Schedule: the months of May – June 2023.

6. Analysis/ assessment of the importance of the various identified determinants of citizens engagement of households in undertaking practices for activities in a given CSS

   Methods of implementation: Expert discussion. Descriptive analysis of the study.

   Schedule: May – June 2023.

7. Identification of instruments (tools) to support household practices in their commitment to activities within framework of CSS 3 "water & nutrients".

   Methods of implementation Table 15: Matrix analysis based on the literature review and previous work provided for in this plan. Expert discussion using the Delphi method.

   Schedule: June – August 2023.

8. Description of recommended instruments (tools) to support household practices in their commitment to activities within the framework of CSS 3

   Methods of implementation: Expert discussion. Descriptive analysis based on literature review and previously performed work provided for in this plan.

   Schedule: months of August – September 2023.

9. WP-specific activities implemented under the framework of CSS 3

   Methods of implementation: focus research in the local community on the needs for the use of water and nutrients, technological analysis, expert discussion

   Schedule: months November 2022 – October 2025.

Citizens engagement in the circular economy refers to the involvement of the public (households and communities) in activities (processes) for the implementation of the solutions that make up the circular economy system (CES), otherwise known as the circular economy (CE) or closed-loop economy (CLE). This concept means, first of all, involvement in real processes related to management (processes from the real sphere), that is, undertaking specific practices, i.e. those that bring material effects consisting in increasing the degree of circulation of natural resources in the socio-economic system, and, consequently, in reducing the anthropogenic impact on the natural environment, first of all, from generation and accumulation in it of various types of waste, mainly the post-consumption waste, i.e. the

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waste accompanying consumption (therefore, this refers mainly to the so-called municipal waste).

The practices of households in the field of CE may be initiated and supported by various types of activities (instruments) undertaken (applied) by public entities, non-governmental organizations, etc. These supporting activities should also be analyzed as part of research on social involvement in CE.

Social involvement in a closed loop economy, in a broader sense, may also refer to regulatory processes related to management (processes from the regulatory sphere), i.e. those that are related to designing of organisational solutions aimed at increasing the degree of natural resources circulation in the socio-economic system, and thus reducing the anthropogenic impact on the natural environment, mainly from generation and accumulation of various types of waste, mainly post-consumption waste, i.e. waste that accompanies consumption (thus mainly municipal waste).

We define the activities of citizens (households) for the circular economy as real (and not only declarative) involvement in the following practices and processes:

- refusing (e.g., not necessary consumption of goods; elimination of unnecessary / harmful consumption),
- reducing (consumption of goods to lower the physical flow of matter in economic processes),
- reusing (the multiplication of the use of material goods for their current purpose),
- refurbishing (renewal of material goods to restore the original functionality and extend the lifetime),
- repairing (fixing of broken or damage material goods),
- repurposing (finding new applications and functionalities for material objects already used up for their original purpose),
- recycling (processing material goods into new, secondary raw material),

as well as activities not directly related to CE, but supporting such practices:

- sharing (using one item / material good together with other households in order to increase the intensity and efficiency of use),
- leasing (rental systems of material goods).
- and segregation and selective collection in the local waste management system.

Analyzing (researching) activities supporting the involvement of citizens (households) in the above-mentioned practices for the benefit of circular economy will consist in assessing the

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effects of initiatives undertaken by public institutions, non-governmental organizations, or other entities, such as:

a) activities increasing awareness and knowledge of issues related to the circular economy (soft activities),

b) action modifying the behaviour of citizens (households) in the sphere of managing material resources, in an institutionalized manner, i.e. as a result of the application of legal and administrative coercion, as well as through a system of incentives and / or negative incentives – respectively: forcing, stimulating or discouraging to specific activities (practices) (hard actions of a command-control nature, regulations and economic instruments);

c) activities involving citizens in the process of creating system and regulatory solutions in the field of circular economy (activities such as: regulations by reaching an agreement and co-creating policies and participation in decision-making processes);

d) activities encouraging citizens (households) to behave and practice consistent with the concept of circular economy, introduced by private entities on the basis of self-regulation (voluntary regulation).

Ad. (a) awareness-raising and awareness-raising activities are targeted at citizens as audiences and include, inter alia:

a) information activities,

b) educational activities,

c) promotional activities (e.g., targeting the creation of new social trends in the field of CE),

d) advisory activities.

Awareness and knowledge-raising activities can be carried out by very different entities, i.e.:

a) national (central), regional and local authorities,

b) non-governmental / social organizations, social partners,

c) private and public enterprises,

d) educational and educational institutions.

Ad. b) actions modifying the behaviour of citizens (households) in the field of managing material resources, in an institutionalized way, they include legal regulations and economic / financial solutions that can be introduced by local, regional and central authorities to persuade, force, encourage or punish a citizen for application or non-compliance with specific practices in the field of circular economy, and which are of interest to public policy (public interest sphere). These activities include, for example:

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a) introducing an obligation to segregate and separate waste collection,

b) introducing a system of fees (e.g., for products, recycling) and penalties, as well as subsidies by national / local government authorities,

c) introducing an obligatory deposit system when using specific packaging by producers,

d) other.

Ad. c) activities involving the process of creating systemic solutions, including in particular regulatory ones, in accordance with the principle of co-management (governance by co-governance) – they include the involvement of citizens as participants and stakeholders in the processes related to the organization of the material resource management system itself (in particular waste management) on levels: strategic, operational and related to the creation of draft legislative solutions to support circular economy. These activities can be implemented on various scales: local / regional / national and may include, for example:

a) participation of citizens in consultation processes and co-creation of various types of public documents (concepts, policies, strategies, plans, programs) describing the directions of activities relating directly or indirectly to the issues of circular economy,

b) participation of citizens in legislative initiatives (e.g., legislative initiative),

c) participation of citizens in advocacy and lobbying activities (including, for example, petitions to the authorities),

d) activities undertaken by citizens within the so-called non-statutory planning,

e) other.

Ad. d) activities encouraging citizens (households) to behave and practice consistent with the concept of circular economy, introduced by private entities (e.g. commercial establishments, service entities) on the basis of self-regulation (voluntary regulation). This includes activities such as:

a) voluntary introduction of deposit systems, e.g., for the return of certain types of packaging,

b) introducing free collection services for used tangible goods when purchasing a new one,

c) others.

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5.2. Scope and areas of citizens (households) engagement under CSS 3 “water & nutrients”

5.2.1. Identification of the expected citizen (household) involvement for CSS3

As part of this section, an assessment will be made of the feasibility of applying circular economy activities at the household level, which, because of the previous analysis, included the following practices:

- refusing,
- reducing,
- reusing,
- refurbishing (renewal),
- repairing (fixing),
- repurposing,
- recycling (processing),

as well as activities not directly related to CE, but supporting such practices:

- sharing,
- leasing (rental).

and segregation and selective collection in the local waste management system. The analysis will consider CSS “water&nutrients” specific practices, including in particular refusing, reducing, repurposing and others beyond the analysed scheme, e.g.

The starting point for performing such an assessment is a technical report. The assessment is to demonstrate to what extent an action (practice) from the group is necessary for the introduction in the local/regional circular economy system of the designed technical solutions for CSS 3 “water & nutrients”.

Table 13. Analysis and assessment chart of the feasibility of household practices for

implementing solutions in CSS3

Practice name (practice categories)	CSS 3 “water & nutrients”
refusing	
reducing	
reusing	

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refurbishing (renewal)	
repairing (fixing)	
repurposing	
recycling (processing)	
segregation and selective collection in the local waste management system	
sharing	
leasing (rental)	
other practices specific to CSS	

NOTE: the table is used to initially identify the link between a given practice type and the activities anticipated under a given CSS type, using the following designations:

- **practices needed** to implement CSS (PN),
- **practices to support** CSS implementation (PS),
- **general practices** - i.e., directly unrelated to the implementation of CSS (to increase citizens engagement in circular economy solutions in general (GP),
- **lack of practices** adequate for the activities envisioned in a given CSS (LP).

Source: own study.

5.2.2. Characteristics of the specifics of the expected household practices identified for CSS 3

For each category of practice identified for a given CSS, a subject (essential) description will then be made of the activities that households are expected to undertake. This description will provide a characterization of the expected households engagement in activities in each CSS.

In the summary of the description, a breakdown of the activities can be made:

- indispensable – i.e., conditioning the ability to implement the technological activities envisaged in the project.
- supportive – i.e., enhancing the effectiveness of the implementation of technological activities envisaged in the project, but not necessary for its implementation.

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- general – i.e., raising the general level of public awareness of the need to act for the circular economy on the issues addressed in a given CSS.

Conducting the analysis indicated in Table 13 and then performing the above description will further allow us to determine whether there are any areas of common practice for each CSS, which can then be standardized at the regional/local implementation level (Table 13A).

Table 13A. Assessment of the feasibility of direct household practices for implementing solutions in each CSS – summary table

Practice name (practice categories)	**CSS type / name**			
	CSS 1	**CSS 2**	**CSS 3**	**CSS 4**
refusing				
reducing				
reusing				
refurbishing (renewal)				
repairing (fixing)				
repurposing				
recycling (processing)				
segregation and selective collection in the local waste management system				
sharing				
leasing (rental)				
other practices specific to CSS				

NOTE: the table is used to initially identify the link between the type of practice and the activities envisaged under the type of CSS, using the following designations:

- **practices needed** to implement CSS (PN),
- **practices to support** CSS implementation (PS),
- **general practices** – i.e., directly unrelated to the implementation of CSS (to increase citizens engagement in circular economy solutions in general (GP),
- **lack of practices** adequate for the activities envisioned in a given CSS (LP).

Source: own study.

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5.3. Types of activities dedicated to supporting social involvement/ engagement in CSS3 (analysis of conditions and selection of instruments)

5.3.1. Identification of the determinants of social involvement of citizens (households) and the possibility of undertaking practices for activities in CSS3.

The activity will identify the determinants that influence households to undertake the practices identified in 6.2.1 and 6.2.2 for CSS. The logic diagram for such identification is presented in Table 14. This analysis will be carried out separately for each CSS.

Table 14. Diagram for identifying / analyzing / assessing the determinants of the application of household practices for the implementation of solutions in the framework of CSS3 "water & nutrients"

Determinants of social commitment / citizens (households) engagement in CE (CSS)	**Name of practice (practice categories)**										
	refusing	**reducing**	**reusing**	**refurbishing (renewal)**	**repairing (fixing)**	**repurposing**	**recycling (processing)**	**segregation and selective collection in the local waste management**	**sharing**	**leasing (rental)**	**other practices specific to CSS**
Technology (increasing accessibility)											
Awareness and knowledge (improvement through education)											
Coercionv(creation of legal and administrative solutions with an enforcement mechanism)											
Stimulus: stimulant / destimulant (creation of economic and financial solutions)											
Best practice (dissemination, popularization)											
Cultural pattern (creation and dissemination)											

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NOTE: the table is used to identify the determinants of social engagement of households in undertaking practices for the implementation of activities/solutions envisioned in a given CSS. Identification using scale:

- very important / key condition (conditioning the effectiveness of CSS activities - essential),
- essential condition (supporting the effectiveness of CSS activities),
- conditionality generally supportive of public commitment to CE,
- no relationship or marginal importance of a given determinant for undertaking practices in a particular area (no or insignificant impact on the implementation of activities under a given CSS).

Source: own study.

5.3.2. Analysis/ assessment of the importance of the various identified determinants of citizens engagement of households in undertaking practices for activities in each CSS.

In this activity, a descriptive analysis (assessment) of the relevance of the various identified determinants that affect households' uptake of the practices identified in Section 6.2.1 and 6.2.2 for CSS3 will be made. The analysis will be used to develop a summary that identifies key determinants of the effectiveness of households' undertaking practices relevant to the implementation of CSS3 activities. Recognition of these conditions, and determinants will be necessary for the identification and, finally, programming (on a local / regional scale) of activities supporting households in their involvement in CSS 3 and the selection of instruments for this purpose (Section 6.3.3).

5.3.3. Identification of instruments (tools) to support household practices in their commitment to activities within framework of CSS 3 “water & nutrients”.

The activity will include the initial identification, review and mapping of instruments that can potentially influence households to undertake the practices for implementation of CSS 3 identified in Section 6.2.1 and 6.2.2. The starting point for the selection of instruments is the analysis performed in Section 6.2.2. The logic diagram for such identification is presented in Table 15. This analysis will be performed separately for each CSS.

Table 15. Flowchart for identifying / analyzing / evaluating instruments to support household practices for implementing solutions for each CSS (separately)

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Instruments / tools to promote social engagement	Name of practice (practice categories)										
	refusing	reducing	reusing	refurbishing (renewal)	repairing (fixing)	repurposing	recycling (processing)	segregation and selective collection in the local waste management system	sharing	leasing (rental)	other practices specific to CSS
Promotional activities/ initiatives											
Educational activities/ initiatives											
Information and consultancy activities/ initiatives											
Financial incentives (positive and negative)											
Legal and administrative regulations											
Co-creating solutions (consultations, workshops, forums, referenda)											
Self-regulation (voluntary regulation)											
Other (?)											

NOTE: the table is used to identify instruments to promote social engagement of households in undertaking practices for implementation of activities/solutions envisioned in a given CSS. Identification using scale:

- very important / key instruments (conditioning the effectiveness of CSS activities - essential),
- essential instruments (to support the effectiveness of CSS activities),
- Instruments generally supporting social commitment to CE,
- no relationship or marginal importance of a given instrument for undertaking practices in a particular area (no or insignificant impact on the implementation of activities under a given CSS).

Source: own study.

5.3.4. Description of recommended instruments (tools) to support household practices in their commitment to activities within the framework of CSS3.

The activity will carry out a descriptive conceptualization of the instruments that should be used at the level of the local/regional territorial system for supporting household practices (identified in Section 6.2.1 and 6.2.2), the undertaking of which will contribute to the

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implementation of the activities envisaged under the given CSS and increase community engagement in the CE in general. The starting point for the detailed characterization of the instruments is their preliminary overview made in Section 6.3.3. The description of the instruments should include their assignment to following subjects:

- municipal / community local governments,
- county local governments,
- regional local governments,
- non-governmental organizations (NGO's),
- scientific and research entities, academic institutions,
- private entrepreneurs,
- public entrepreneurs,
- households,
- others (?).

5.3.5. WP-specific activities implemented under the framework of CSS3.

Within the framework of WP 5 T.5.4 activity, activities related to the conduct and dissemination of CSS 3 technology in local communities covered by project activities are envisaged. The activities described in sections 6.3.2 and 6.3.3 will include informational and educational activities on the use of microalgae for treating wastewaters and flue gases.

Under Measure 6.3.5, the following will be conducted:

a) analysis of the possibility of household engagement in the needs of cleaning wastewaters and gases,
b) analyze the technological feasibility of using waste to create items useful to households,
c) analyze the possibility to create social enterprises in CSS area.

5.4. Schedule of activities for citizens engagement in the implementation of activities within the framework of CSS3 "water & nutrients"

Table 16 is an overview of planned CSS3 activities related to citizens engagement in the form of a goal – implementation matrix.

Table 16. Activities planned for citizens engagement in the implementation of CSS 3 "water & nutrients"

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Objective of activities	Planned activities	Lead time	Contractor/leader	Place of implementation
Identification of needs regarding the scope of social involvement of citizens (households) within a given CSS (3)	[5.2.1] Identification of the expected citizen (household) involvement for a given CSS	November 2022 – January 2023	OPUS	All technical partners under CSS 3
	[5.2.2] Characteristics of the specifics of the expected household practices identified for CSS 4	February – April 2023	OPUS	All technical partners under CSS 3
Identification and analysis of conditions and selection of instruments to support the social involvement of citizens within the CSS 3	[5.3.1] Identification of the determinants of social involvement of citizens (households) and the possibility of undertaking practices for activities in a given CSS	May – June 2023	OPUS	Activities planned for use in the region of Łódź and the municipality of Parzeczew and on the territory of the Bzura Intercommunal Union
	[5.3.2] Analysis/ assessment of the importance of the various identified determinants of citizens engagement of households in undertaking practices for activities in a given CSS	May – June 2023	OPUS	
	[5.3.3] Identification of instruments (tools) to support household practices in their commitment to activities within framework of CSS3	June – August 2023	OPUS	
	[5.3.4] Description of recommended instruments (tools) to support household practices in their commitment to activities within the framework of CSS 3	August – September 2023	OPUS	

Source: own compilation.

The action plan for CSS 3 is linked to activities under WP 7 where individual activities will be implemented in the form of community testing.
The complementary catalogue of activities which are going to be launched under WP 7 framework are presented in Table 17.

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Table 17. Catalog of complementary activities to be launched under WP 7 framework

Objective of activities	Planned activities	Lead time	Contractor/ Leader	Implementation sites
Increase the knowledge of the region's residents concerning activities within the framework of CSS 3	Outreach activities: a) information campaigns on CSS 3, e.g., through traditional information channels (local media, social media); b) preparation of informational materials for residents in print and electronic form on CSS3 solutions (e.g. posters, podcasts, educational videos); c) creation/ establishing of a dedicated fanpage on the local community social media platform regarding all CSS; d) participation in local cultural events that will present the assumptions of the circular economy.	December 2022 -March 2025	Veltha	Activities planned for use in the region of Łódź and the municipality of Parzeczew and on the territory of the Bzura Intercommunal Union
	Educational activities a) hybrid thematic seminars (online and onsite) on the use of, for example b) training on the implementation of circular economy goals and design objectives - applicable to all CSS, c) educational activities for kindergartens, schools, including competitions for children in the area of CSS3	December 2022 -March 2025	Veltha	Activities planned for use in the region of Łódź and the municipality of Parzęczew and on the territory of the Bzura Intercommunal Union
Increase engagement of residents in the activities within the framework of CSS 3	a) local micro-grant programs for residents to promote closed-loop economy solutions including those dedicated to CSS 3		OPUS /municipality of Parzeczew/ ZMB	Activities planned for use in the region of Łódź and the municipality of Parzęczew and on the territory of the Bzura Intercommunal Union

Source: own compilation.

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6. IMPLEMENTATION PLAN

T5.1 **Systemic solution 3 Baseline & development of implementation plan** – Lead: LNEG (M06-M12) - Participants:(KFLEX, OPUS, UNILODZ, BZURA, PARZECZEW, STAM, LNEG, INL, VELTHA, RIC)

An exhaustive framework for CSS3 will be drafted by LNEG with support from the other CSS3 consortium partners towards the implementation of the technological and non-technological solutions required and to be executed in CSS3; Needs, involvement, and expectations for the stakeholders participating in CSS3 will be identified. The executive implementation plan of CSS3 will be launched by LNEG with the input of all CSS3 partners. When possible, requirements will be quantified to extract useful KPIs to be used during the evaluation phase of the CSS3 implementation as measurable metrics to assess the achievement of pre-defined targets. RIC will be involved in the data management to enable the CSS3 implementation at the regional level of Łódź area. Thus, it will provide the framework for data collection through the solution development. The data collection and management will include aspects such as type of waste/raw materials and feedstocks, minimum scale required for starting the technology implementation, allocation of waste volume for the companies involved, collection and delivery timing and patterns, as well as cooperation schemes at the regional level. The territorial deployment will start after CSS3 Baseline and the development of the implementation plan and in compliance with the regional CEAP for the Łódzkie area. The plan for CSS3 implementation and logistics is expected to be elaborated in the first months of this activity. The piloting/demonstration of CSS3 foresees the following stages: 1) Microalgal-mediated wastewater treatment plant setup; 2) Demonstration for microalgal-mediated CO_2 capture and conversion; 3) Demonstration for AD digestate utilization & conversion by microalgae; 4) Demonstration for biogas upgrading by microalgae; 5) Piloting/Demonstration of CSS3 & final demonstrative setup at K-FLEX and/or GMINY PARZECZEW (PL).

T5.2 **Wastewaters, nutrients, and CO_2-rich gases route to become Circular streams** – Lead: STAM (M09-M018) Participants: (KFLEX, UNILODZ, BZURA, PARZECZEW, STAM, LNEG)

This activity can be divided on the following sub-activities: 1) Data collection and characterization of available wastewaters and CO_2-rich gases in Łódzkie region: identification and availability of wastewaters (from the digestate of anaerobic digesters but also others regionally available from agro-industrial processes within the FRONTSH1P consortium) and CO_2-rich gases will be performed; these sources will be evaluated as feedstocks with potential to be treated by microalgae with especial emphasis on the direct utilization by partners within the consortium (K-FLEX and GMINY PARZECZEW). The preferred wastewaters should be secondary (after a biological treatment step) collected at the

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Wastewater Treatment Plants (WWTP), ideally without a previous N or P removal. These WW are best suited for microalgal-mediated WW Treatment. The location of WWTPs in Poland can be accessed in https://water.europa.eu/freshwater/countries/uwwt/poland.An inventory of known physical and (bio)chemical data will be compiled. The exploitable wastewaters will be identified other than on the base of chemical-physical characteristics also on the base of availability, periodicity, environmental critical issue, geo-localization, and all relevant information about the released and discarded waters. Currently used conventional treatment processes and cost related with it will be used as base scenario to compare with microalgae-based treatment processes used into the project. Major parameters to be considered include COD, N and P content, among others for liquid effluents, whereas for gaseous effluents the CO_2, NO_x and SO_x content will be mandatory; 2) Physical and (bio)chemical characterization of selected wastewaters and CO_2-rich gases. All wastewaters (mainly digestate from anaerobic digesters and others from agro-industrial origin) and CO2-rich gases to be used as feedstocks for microalgae-based treatment by partners within the FRONTSH1P CSS3 consortium will be physically and (bio) chemically characterized. Samples from these wastes will be analysed to perform a complete characterization and to identify the most adequate strategies to use it to produce microalgae biomass. For wastewaters the major parameters to be determined must include turbidity to ensure enough light availability into the cultures, TSS- total suspended solids, COD to know the potential of bacterial contamination, and N and P concentrations to evaluate the potential of microalgae biomass production. Nitrogen species and concentrations, as ammonium or nitrate, must be determined as high levels can inhibit microalgae growth. Regarding gases, the CO_2 molar fraction in addition to NO_x and SO_x content will be determined. The presence of heavy metals and particles in the flue gases will be defined as criteria to reject the utilization of highly polluted flue gases to produce microalgae. Sampling on the places where wastewaters are discharged will be performed by GMINY PARZECZEW and K-FLEX to be further sent to LNEG which will carry out identification of the occurrence of naturally growing microalgae strains, better adapted to Łódzkie Voivodship prevailing conditions. These microalgae will be isolated to get pure strains and screened for their ability to withstand and treat successfully polish wastewaters. Moreover, microalgae strains maintained by LNEG with a successful previous track of different wastewater treatments (*Chlorella vulgaris*, *Desmodesmus obliquus*, *Parachlorella kessleri*, *Chlorella protothecoides*) will be used for selecting the best performing strain. The robustness and adaptation of the microalgae strains to the wastewaters and the operational conditions will be assessed throughout cell viability (cell membrane integrity, membrane potential, metabolic activity) monitoring, using the at-line technique Flow Cytometry (FC), which allows analysis of a high number of strains and cultivation conditions, at the same time. The best performing strain will be sent to STAM for further use for the subsequent trials at pilot-scale. Equipment available in each research centre will be used, according to standard methods; 3) Physical and (bio)chemical

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characterization of final disposed water, final released gases, biomass, and derived bio-based products: The produced biomass, the final disposed process water, and bio-based derived fractions/products from biomass (with emphasis on bio-fertilizers and bio-stimulants) will be characterized by partners within the FRONTSH1P consortium. The biomass will be analysed in terms of VSS, TSS and elemental composition. Treated wastewater will be analysed to verify that it accomplishes EU directives for final release to the environment, thus COD, N and P concentration below 100, 10 and 2 mg/L being requested, respectively.

***T5.3* Enhancement of a low cost and low energy consuming process for microalgae-based wastewater treatment and CO2 bio-fixation to bio-stimulants and other bio-based products –** Lead: STAM (M09-M36) - Participants: (BZURA, PARZECZEW, STAM, LNEG, INL)

A low cost and low energy consuming culture process for microalgae-based wastewater treatment (regardless the source and origin) and CO_2 bio-fixation will be enhanced starting from previous technology developed by LNEG and STAM starting at TRL 5. All culture systems will start to operate in a batch mode, then semi-continuously and finally continuously. Optimal C/N/P ratios will be adjusted to enhance wastewater treatment rates thus biomass production rates and carbon dioxide uptake rates. The mean hydraulic retention times (or dilution rates) will be studied to achieve adequate wastewater treatment (EU regulations compliance) at the shortest mean hydraulic retention times, ideally lower than 5 days. The C/N/P ratios will be imposed by using different proportions of wastewater with addition of extra N and P sources, as compensation. The strict pH control will be carried out by carbonation from the CO_2-rich gases. The inoculum will be produced in the laboratory and transferred to the production unit to amplify the initial inoculum produced in the lab. Although coupling the production of microalgae with wastewater, the requirements of CO_2 for microalgae growth are partially compensated by CO_2 released by bacteria from heterotrophic growth, the supply of CO_2 on these systems is mandatory. To ensure efficient CO_2 supply is mandatory, it meaning to be capable to supply the requested inorganic carbon with the minimum power consumption and ensuring no release or reemission of CO_2 to the atmosphere. Low pressure drop bubbling systems usually used in wastewater treatment plants will be evaluated and compared with conventional diffuser. A model of the system considering the requirement of CO_2 of the biological system and the transfer capacity of the CO_2 supply system will be developed.

This model will be used to develop a model predictive controller that will be finally evaluated in the pilot reactor MOONSHINE.

The MOONSHINE is a containerized plant developed using closed tubular Photo Bioreactors (PBRs) technology (phototrophic production) for the treatment of slurry and wastewater is at TRL6. The first section represents a compressed active sludge system for the BOD and COD

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reduction. The second part of the system is composed by a recirculation tank and tubular PBR, where the algae grow, and are exposed to artificial lightning. The system is equipped with sensors for the growing parameters monitoring (pH, Ox, Turbidity, Temperature, and suspended solids) and designed to overcome the problems associated with open pond cultivation systems. A typical PBR consists of a four-phase system: solid phase (microalgal cells), liquid phase (growth medium), gaseous phase (CO_2 and O_2) and superimposed light-radiation field. Horizontal tubular PBRs are the most popular closed systems due to advanced features with respect to the surface to volume ratio, the amount of gas in dispersion, the gas–liquid mass transfer characteristics, the nature of the fluid movement and the internal irradiance levels. The whole plant can contain and treat more than $5m^3$ of wastewaters operating in continuum. The system is designed to be suitable for cultivation various microalgal species and prevent fouling of the reactor such as *Chlorella*, *Spirulina* and *Desmodesmus* cultivations.

The performance of the microalgae based-wastewater treatment will be monitored integrating a spectroscopic portable sensor, which will designed, developed, and tested by INL during the project. FRONTSH1P CSS3 proposes to develop integrated surface-enhanced Raman scattering (SERS) sensing system involving (a) a microfluidic sampling interface taking advantage of SERS ultra-trace monitoring of CO_2, and (b) a multi-spectroscopic fibre optic probe. This configuration will offer a device sufficiently compact, portable, and robust to be fitted to MOONSHINE PBR. Prototype system development will be augmented by the introduction of appropriate multivariate calibration and data evaluation/mining strategies using advanced machine learning algorithms for correlating the obtained SERS spectral datasets, which will be integrated in the controller unit. For the sensor design and development, threshold values should be adjusted to make decisions on the reactor performance, such as the range of microalgae concentration for adequate or optimal wastewater treatment or to stop the treatment. It is also very important to tune the sensitivity, robustness, and selectivity of the system. Key parameters are the distance between “sampling points” (inflow and outflow), the available space for installing the probe, due to fluidics, and the range of wastewater quality parameters (pH, dissolved oxygen, conductivity, alkalinity, nitrates, turbidity, suspended solids, among others).

Finally, useful data for mass (water, nutrients) balances, energy balances, for cost estimations, for further LCI, LCA, S-LCA will be acquired and provided as well as operational data for the design and operation of a further pilot-scale plant. The produced biomass will be evaluated towards the production of bio-stimulants, bio-fertilizers, and other bio-based products with special emphasis on wet biomass (slurry) with and without physical disruption, to reduce either energy expenditure or water footprint. The process development will be implemented in the pilot.

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T5.4: Ecodesign of the Systemic solution 3 – Lead: NTUA (M012-M42) - Participants: (KFLEX, OPUS, BZURA, STAM, NTUA, LNEG, INL)

Aiming to promote the ecoefficiency of the microalgae production system, the ecodesign approach, based on the definition of the value chain, from reception of effluents to the final destination of the resulting material, the identification of inputs and outputs of materials and energy at all stages, as well as the equipment used, will optimize the system by applying the following ecodesign strategies (adapted from KATCH_e, CIRCO):

- Increase the durability of products/equipment.
- Increase repairability, preventive maintenance and upgrade of products/equipment.
- Contracting the purchase of services instead of products e.g. lighting, reagent leasing, equipment leasing.
- Increase the recyclability of products/equipment.
- Promote the remanufacturing of products/equipment.
- Increase the sustainability of the materials used in the system.
- Promoting the reduction, reuse and recycling of packaging used in the system.
- Increase energy efficiency and promote the use of renewable energies.

For each strategy, it will be possible to define criteria and performance indicators.

The efficiency of the system can also be enabled by use digitization/industry 4.0 to monitor and optimize the use of equipment and processes.

The decision making of choosing one approach (producing agricultural bio stimulants) or another (using biomass to obtain biogas (biomethane) and hence energy) could be addressed by the environmental Life Cycle Analysis (LCA) and social LCA (S-LCA) and Life Cycle Cost (LCC) will be conducted, and the assessment of the indicators previously mentioned.

LNEG will develop a framework for the ecodesign activities through 1) exploring the potential of the KATCH_e, CIRCO circular design strategies to identify the most promising strategies to promote the potential application of biobased products; 2) identifying improvement opportunities and measures for the strategies illustrated with examples and case studies if possible. As the core tool for eco-design, NTUA will investigate the environmental impact of the developed microalgae technology through LCA and S-LCA. The study will focus on the specific footprint of the bio-based products of CSS3 in terms of GHG emissions and a series of other indicators regarding human health, climate impact and ecosystem quality. A sensitivity analysis for a series of process parameters will enable to provide feedback on the major bottlenecks that need to be addressed during the eco-design procedure. The analysis will be carried out in stages; firstly, to provide feedback as part of the process eco-design and

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in a next step to demonstrate the benefits of the finalised demo process. The LCA will be performed according to ISO 14040/44, 21930 and other applicable standards in Sphera LCA FE (GaBi) software. The sources of the inventory will include standardised and/or readily available data as well as data produced during the WP course. Particularly, data contained in software databases will be necessary for comparing circular economy processes to linear production processes comprising the state-of-the art. Therefore, inventory data (LCI) will be derived from: 1) integrated databases in Sphera LCA FE (GaBi) for raw materials, wastes, products and processes (Ecoinvent, ELCD of EC-Joint Research Centre and others); 2) real stream analyses by chemical characterisation in T5.2; 3) modelling results for the biological system in T5.3; 4) actual demo plant performance (power consumption, mass, and energy balances, etc.) in T5.3. The life cycle thinking approach of eco-design will be extended to the cost of the developed processes for wastewater treatment through LCC. Process results will be used for the LCC, while equipment, operation, and maintenance costs will be derived during the demo plant construction. Other assumptions needed for calculating the cost of waste disposal, replacements, system decommissioning, etc. will be based on LNEG experience from the long-term operation of microalgae-based facilities. The study will be accompanied by a scale-up costing assessment for variable facility capacity considering process optimisation through sensitivity analysis.

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T5.4. Implementation plan

The purpose of this analysis is to investigate and evaluate the potential impacts of microalgae technology developed in the frame of CSS3.

To set the framework of the LCA/LCC/S-LCA the product system and its boundaries will be defined. The identification and definition of the boundaries of the system evaluated are part of the scope definition phase and they are essential for the analyses implementation as combined with the goal of the analysis set the frame for the Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA). The selected system boundaries are chosen to effectively serve the study goal and approach thoroughly the products' life. The definition of functional unit (FU) is of paramount importance as it is the unit to which the environmental, societal, and economic impact are attributed.

The implementation of the analyses will be following ISO 14040 and 14044:2006 and the International Life Cycle Data (ILCD) Handbook. In respect to the standards followed, several cut-off criteria will be applied to consider the inputs that will be used to enable the system simplification and LCA/S-LCA and LCC implementation, thus ensuring the results quality. As the treated system is multifunctional, in case there is necessary for the Allocation LCI procedure to be applied, it will be in line with ISO 14044:2006 guidelines.

The goal and scope definition follows the definition of impact categories under consideration, such as Global Warming Potential (GWP 100 years) and the LCI. In the LCI phase data will be gathered to perform the modeling in Sphera LCA FE software and to perform the impact assessment. Example of data required in

Table 18. Indicative data required for data inventory

Inputs	Outputs
Major materials	Products
Auxiliary materials	Intermediate products
Water	By- products
Energy (electricity, thermal energy, fossil fuels, non-fossil fuels)	Environmental releases and their type (e.g., air emissions, water wastes, solid wastes, hazardous solid wastes)
General data	
Information for the Plant	
Process description, production stages, their function, and interconnections in the frame of system boundaries.	
Source of major and auxiliary materials	
Wastes treatment mechanisms (e.g., treated, non-treated, recycled, landfilled, etc.)	
Transportation of information in the system boundaries (e.g., transportation mean, distances, energy type, consumption, etc.)	

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For ensuring the construction of a reliable and technologically representative database corresponding to the CSS3 technology and processes, LCI data will be collected from the CSSs cases. To achieve this, NTUA will formulate detailed questionnaires that will be distributed to the project partners involved in the CSS3. In parallel, literature review and other sources investigation take place for covering any information gaps that may arise.

The data from the site will be supplemented with data coming from the integrated databases in Sphera LCA FE for the raw materials, wastes, products, and processes (e.g., Ecoinvent, ELCD of EC-Joint Research Center, etc.). Datasets provided by Sphera LCA FE are considered technologically representative and updated, as the data are primarily gathered by industrial measurements. This data will be evaluated and used accordingly considering their coherence and applicability in the case of CSS3.

The system will be developed and modelled using the Sphera LCA FE software. The modelling results and demo plant performance results' will be mainly based on the data acquired from the partners via the questionnaires. To ensure the data collection and accuracy, NTUA will arrange remote interviews and meetings with the partners.

The information collected during this process will be reviewed and evaluated to ensure the data quality and will be related to the CSS3 assessment analyses. The data collected will be used for the system modelling. The LCI and system modelling follow LCIA. The results for the defined impact categories assessed will be calculated, evaluated, and interpreted. The results interpretation gives the chance to detect the hotspots that require taking action and any significant issues of the system and suggest solutions to improve the system performance.

The results derived from LCA/S-LCA and LCC analysis will contribute to the generation and proposal of a circular economy business model, in accordance with the expectations and needs of the included partners. The environmental, societal, and economic impact will be taken into consideration.

In the frame of assessment analyses' implementation, at least two meetings with WP partners will be realised, regarding both the preparatory actions and the final decisions on the implementation of LCA/S-LCA and LCC assessment. Finally, NTUA will conduct an internal report that will be updated every six months, considering the analyses' approach and the methodology followed. The report will enable the overview of the actions and progress of the task.

This Task is linked to D5.4 & D5.5

DELIVERABLES

D5.1 Implementation plan of CSS3 and citizen engagement Plan - SOCIAL + TECH (PU)

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Definition of an implementation framework for CSS3. This deliverable will cover the following aspects: 1) Technical and non-technical state of the art, requirements, and success criteria to satisfy the implementation of the technological and non-technological solutions required in CSS3; 2) Identification, involvement, needs and expectations from regional stakeholders involved in CSS3; 3) Executive implementation plan of CSS3; 4) citizen engagement Plan.

This Deliverable is linked to Task 5.1

D5.2 Inventory & characterization of available wastewaters & definition of suitable analytical protocols for product characterization for bio-Fertilizers and bio-stimulants – TECH (CO)

Firstly, a data collection and characterization of available wastewaters and CO_2-rich gases: identification and availability of wastewaters in Łódzkie region (from the digestate of anaerobic digesters but also others regionally available from agro-industrial processes within the FRONTSH1P consortium) and CO_2-rich gases will be performed.

Secondly will be performed a physical and (bio)chemical characterization of selected wastewaters and CO_2-rich gases. Samples from these wastes will be analysed to perform a complete characterization and to identify the most adequate strategies to use it to produce microalgae biomass.

Thirdly a Test on a lab scale to produce microalgal biomass with the selected waste stream will be developed. Lastly a Physical and (bio)chemical characterization of final disposed water, final released gases, biomass, and derived biobased products.

This Deliverable is linked to Task 5.2

D5.3 Low cost and low-energy systems for wastewater treatment and Optimized operation procedures - DEM

Development of the low cost and low energy consuming culture process for microalgae-based wastewater treatment and CO2 bio-fixation will. The systems will operate in a continuous mode. Optimal C/N/P ratios will be adjusted to enhance wastewater treatment rates thus biomass production rates and carbon dioxide uptake rates. The performance of microalgae based-wastewater treatment will be monitored integrating a spectroscopic portable sensor. An integrated surface-enhanced Raman scattering (SERS) sensing system involving (a) a microfluidic sampling interface taking advantage of SERS ultra-trace monitoring of CO_2, and a multi-spectroscopic fibre optic probe will be developed and tested. All data gathered will be provided as well as operational data for the design and operation of a further pilot-scale plant. The produced biomass will be evaluated towards the production of biostimulants, bio-fertilizers, and other bio-based products with special emphasis on wet biomass (slurry) with and without physical disruption, to reduce either energy expenditure or water footprint. The process development will be implemented in the pilot.

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Low cost and low-energy systems for wastewater treatment

Enhancement of the low cost and low energy consuming culture process for microalgae-based wastewater treatment and CO_2 bio-fixation will be enhanced starting from previous technology developed by partners at TRL 7. Specific objectives will aim to:

• achieve adequate wastewater treatment (EU regulations compliance) at the shortest mean hydraulic retention times.

• Control the C/N/P ratios using different proportions of primary treated wastewater and sludge

• Develop a model of the system considering the requirement of CO_2 of the biological system and the transfer capacity of the CO_2 supply system will be developed. This model will be used to develop a model predictive controller that will be finally evaluated in the pilot reactor.

This Deliverable is linked to Task 5.3.

D5.4 LCA, S-LCA and LCC & main outcomes from CSS3

LCA, LCC and S-LCA study of the CSS3 following ISO 14040/44, 21930 and other applicable standards, forming case studies. The main goal is to estimate the carbon footprint reduction potential of each scenario. The study will be conducted in SimaPro™ commercial software. The sources of the inventory will include standardised and/or readily available data as well as data produced during the WP course. Particularly, data contained in software databases will be necessary for comparing circular economy processes to linear production processes comprising the state-of-the-art. This Deliverable is linked to Task 5.4.

D5.5 Ecodesign case studies CSS3

Develop a framework for the eco-design activities in CSS3 by: • providing guidelines for LCA and S-LCA, integrating a circular design perspective and needs; • exploring the potential of the KATCH_e CE designer tool in the identification of the circular design strategies with more potential to the identified products; identifying improvement opportunities and measures for the strategies - illustrated with examples and case studies if possible; 4)structuring of the information, data, methodologies, and guidelines to support the development of the tool within WP7 This Deliverable is linked to Task 5.4.

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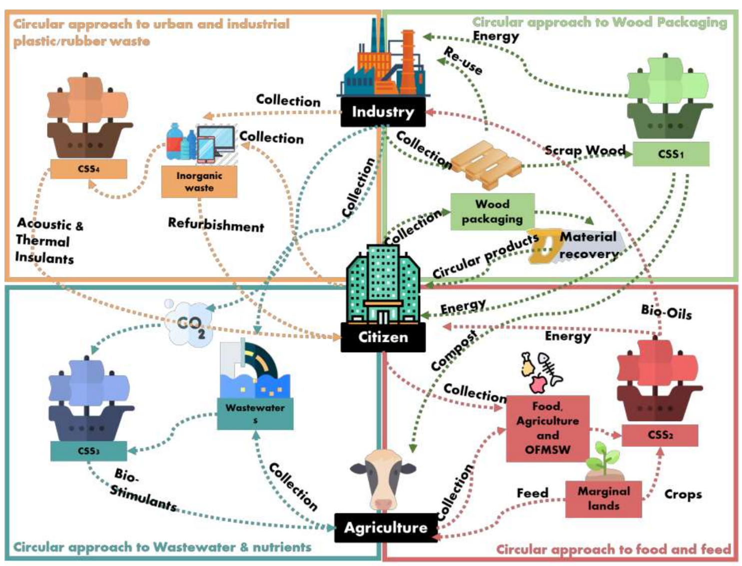
7. CSS3 – Water and Nutrients - Interactions with other FRONTSH1P CSSs (WPs)

FRONTSH1P project contains 4 major circular systemic solutions (CSSs) strongly linked between each other. All CSSs create a circular value chain within each CSSs as well as in the cross-cutting approach, i.e., on higher level of the entire project. More specifically, each CSSs is built on a well-developed network of information, data, and material exchange, which depends on each other to close the loop foreseen by the application of a circular approach.

CSS3 entitled Water and nutrients aims to further develop to higher TRL a compact wastewater management unit for nutrients (P, N, K) extraction from agricultural wastewaters and a bigger plant for municipal wastewater both using microalgae; to produce circular bio-stimulants from wastewaters; and to close the water loop and recycle clean water. All these will be embedded into a sustainable-oriented improvement of products through Life cycle thinking and Ecodesign fitted into technological, economic, social, and environmental dimensions considered in the FRONSTH1P project.



FRONTSH1P has the ambition to be a frontline project in Bioenergy Carbon Capture and Utilisation initiatives by demonstrating the carbon capture advantages in a territorial circular economy cluster. For this purpose, a compact post-combustion capture (PCC) unit from CSS1 operating with appropriate solvents for CO_2 capture will be designed, built, and tested at the NTUA facilities. In-house experimental and literature results will be exploited for validating thermodynamic models that describe the absorption of CO_2, with the purpose of developing a specific tool for the design of the entire syngas combustion and PCC processes in industrial settings. The tool will enable mapping the operations, selecting key parameters and plant configurations for both demo scale and industrial scale technology deployment based on a

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process optimization approach. The concept investigated foresees that the biomass gasifier will be connected to an existing industrial-scale natural gas boiler. First, standalone syngas combustion characteristics will be evaluated for possible boiler modifications functional to achieving satisfactory operating windows. Combustion tests will then be performed with methane/syngas mixtures that will replicate biogas/syngas co-firing. Finally, a validation of the CSS1 thermodynamic model with demo plant data will be performed.

The application of the circular approach for the valorization of wood packaging waste allows for the transition from fossil fuels to renewable syngas for heating purposes. When combined with post-combustion capture of CO_2, the proposed CCS1 solution supports the effective decarbonisation of the heating sector in both centralised and decentralised contexts, and significantly reduces GHG emissions and decreases forest depletion, possibly even allowing for a negative emission balance. Further utilization of CO_2 within industrial processes (e.g., to replace foaming agents in the plastic industry) will assist the decarbonization of the built environment while symbiotically replacing substances with higher toxicity currently employed in industry.

To close the loop within the boundaries of the FRONTSH1P project, the valorisation of wastewater and CO_2 from anthropogenic origin should occur in the same fields of application of the other CSSs. For this purpose, biofertilizers utilisation will be investigated in connection with CSS2 – a circular approach to food and feed, while CO_2 valorisation will be analysed in the context of CSS1 and 4. In CSS2, biostimulants will be tested as an additive for compost to enhance the fertility of marginal lands ensuring further reduction of synthetic fertiliser input and providing organic carbon to soil.

Not only valuable products, but also data will be exchanged among the different WPs. The data collection methodology is being defined in close cooperation with WP2 – regional systemic circular economic approach and other CSSs to analyse the policy framework and the market analysis considering the Łódzkie region as benchmark. The common approach adopted by all CSSs will not only ensure coordination among partners, but also ease the replication phase of all CSSs in other territories. Instead, the data collected during the implementation of WP5 will be transferred to WP7 – impact generation and assessment to help populating the digital platform that will be developed during the project and to WP8 – replication strategies to foster the replication of CSS3 in the region of Europe.

The interrelated structure of the FRONTSH1P project mirrors the natural need for the multidisciplinary exchange that nurtures a long-term sustainable industrial symbiosis network. In fact, in FRONTSH1P, we are going to see a reflection of the same expert knowledge transfer, information exchange, stakeholder engagement and material flows that will form the backbone of value creation in a full-scale circular system.

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To conclude, the successful implementation of CSS3, together with other CSSs will have a long-term leverage effect by a creation of a new agricultural business model around bio-fertilizers. Furthermore, engagement of public and private stakeholders in upscaling and replicating/adapting CSS and key enabling technologies (compact and modular wastewater treatment plants) will contribute to impacts achievement for the Circular Economy Action Plan 2030.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037031

Appendix 1 Area of wasteland in hectares in communes

TERYT Number	Area of wasteland in [ha]	TERYT Number	Area of wasteland in [ha]	TERYT Number	Area of wasteland in [ha]	TERYT Number	Area of wasteland in [ha]	TERYT Number	Area of wasteland in [ha]
1001042	4774.46	**1010072**	58.52	**1002011**	35.72	**1012142**	23.97	**1007032**	14.41
1009052	1767.43	**1013032**	58.20	**1016072**	35.68	**1002022**	23.93	**1012011**	14.20
1001072	1149.56	**1008072**	57.06	**1009062**	35.65	**1016082**	23.55	**1015052**	13.69
1009082	247.92	**1001052**	56.87	**1010062**	35.41	**1021022**	23.39	**1005092**	13.65
1061011	234.44	**1014082**	56.33	**1005102**	34.48	**1017062**	23.37	**1016022**	13.63
1004072	232.70	**1010082**	56.14	**1011012**	33.39	**1011052**	22.99	**1019011**	13.54
1009013	210.94	**1001032**	56.08	**1002043**	32.99	**1012032**	22.68	**1016062**	12.71
1003042	194.19	**1020062**	55.31	**1004082**	32.91	**1017093**	22.21	**1019023**	12.48
1011043	187.16	**1001062**	52.13	**1010042**	32.50	**1010032**	21.95	**1015092**	11.79
1004052	142.70	**1009032**	49.93	**1007012**	32.27	**1006073**	21.63	**1010022**	11.52
1012092	140.66	**1014011**	49.33	**1016011**	31.98	**1005011**	21.56	**1014032**	11.38
1007072	137.33	**1012053**	48.66	**1016092**	31.94	**1021011**	21.38	**1063011**	11.17
1020092	121.77	**1020083**	48.38	**1014052**	31.90	**1007062**	20.86	**1005062**	10.95
1014093	110.73	**1016042**	47.76	**1010012**	31.88	**1017022**	20.54	**1004011**	9.62
1005042	109.44	**1011033**	47.71	**1002082**	31.37	**1018052**	20.35	**1007043**	9.58
1005022	108.94	**1017032**	45.85	**1013042**	31.21	**1006103**	20.21	**1020011**	7.95
1009043	103.99	**1004042**	45.85	**1012132**	30.48	**1016102**	20.07	**1002072**	7.39
1010052	102.18	**1013023**	45.25	**1015082**	29.83	**1015062**	19.42	**1006022**	7.13
1011022	91.66	**1010102**	44.82	**1015032**	29.66	**1018062**	19.32	**1002092**	6.32
1010093	87.54	**1019032**	44.36	**1016112**	28.75	**1007052**	19.06	**1021042**	6.25
1005072	86.59	**1012072**	44.28	**1017072**	28.47	**1021032**	18.92	**1005082**	5.90
1003023	83.98	**1006032**	43.52	**1018043**	28.39	**1017052**	18.86	**1018012**	5.73
1020072	83.89	**1002062**	43.28	**1015042**	28.30	**1014113**	17.88	**1016032**	5.56
1003032	82.98	**1011062**	43.18	**1014062**	28.15	**1012042**	17.74	**1014072**	5.48
1005052	81.76	**1017042**	42.26	**1004022**	27.52	**1018032**	17.42	**1062011**	5.27
1019042	76.40	**1014023**	40.45	**1015013**	27.43	**1020052**	17.25	**1020021**	4.98
1016052	75.09	**1015022**	40.34	**1014102**	27.09	**1008011**	16.75	**1008052**	4.18
1001083	69.99	**1013062**	38.98	**1012062**	26.63	**1003052**	16.74	**1005032**	3.64
1002052	68.28	**1014042**	38.85	**1020043**	26.42	**1004032**	15.72	**1002032**	3.39
1012113	67.64	**1008032**	38.12	**1008021**	26.16	**1021052**	15.67	**1017012**	2.55
1007082	66.68	**1012122**	37.03	**1006113**	25.07	**1004063**	15.42	**1001011**	2.37
1001022	65.59	**1008042**	36.70	**1018073**	25.04	**1020031**	15.12	**1013052**	2.25
1012102	62.80	**1010113**	36.65	**1002113**	24.81	**1007023**	15.08	**1013011**	2.18
1012082	62.13	**1008063**	36.22	**1015072**	24.20	**1009022**	15.05	**1018022**	1.09
1012022	60.22	**1017082**	35.87	**1009072**	24.16	**1017102**	14.72		
		1002102	35.81	**1003012**	24.00	**1006082**	14.69		

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Appendix 2 Glossary

Ammoniacal Nitrogen ($N-NH_4$ OU $N-NH_3$)- A chemical parameter evaluating the concentration in ammoniacal nitrogen in its aqueous form ($N-NH_4$) or its gaseous form ($N-NH_3$).

Anaerobic digestion- Process of biological degradation (treatment) of organic matter in the absence of oxygen which occurs in digesters. Output: digestate (a more or less liquid fraction) and biogas.

Biochemical Methane Potential (BMP) -Maximal potential production of biogas by a specific substrate (usually expressed in m^3 biogas/tons of VS).

Biogas- Gas produced by the biological degradation (fermentation) of organic matter in the absence of oxygen. Crude (raw) biogas indicates to the gaseous effluent discharged from an anaerobic digester. Typical biogas composition: 60 to 80% methane (CH_4), 30 to 40% carbon dioxide (CO_2) and other minor gases (hydrogen sulphide (H_2S), ammonia (NH_3), and hydrogen (H_2)).

Biological Oxygen Demand (BOD)- Biological oxygen demand (BOD) generally represents how much oxygen is needed to break down organic matter in (waste)water under aerobic (oxygen is present) conditions at a specified temperature.

Biomethane- Gas resulting after the purification step (or upgrading) of biogas that can be adequate to be further injected into a gas network or utilized as a replacement for natural gas.

Biostimulants- Plant biostimulants are substances, mixtures, and micro-organisms which, differently from straight fertilisers, are not as such inputs of nutrients, but nevertheless stimulate plants' natural nutrition processes. They act in addition to fertilisers, with the aim of optimising the efficiency of those fertilisers and reducing the nutrient application rates and are by nature more like fertilising products than to most categories of plant protection products. Such products are therefore eligible for CE marking under Reg 1009/2019 and excluded from the scope of Reg (EC) No 1107/2009 on Plant protection products (e.g., pesticides).

Blue bioeconomy- Any economic activity or businesses related with the application of renewable aquatic biological resources to make products such as novel foods and food additives, nutraceuticals, pharmaceuticals, cosmetics, materials (e.g., clothes and construction materials) and energy.

C/N ratio- Carbon portion of the organic material on the total nitrogen portion.

COD (Chemical Oxygen Demand)- Is the amount of oxygen required to break down the organic material via chemical oxidation, also an indicator of the concentration of organics.

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Detention Time, Retention Time, Residence Time, HRT Hydraulic Residence Time- The average length of time the liquid influent remains in the digester or reactor for treatment.

Digestate- Liquid, pasty or solid residue resulting from the biomethanization of organic matter as feedstock. The raw digestate denotes the effluent at the exit of the biomethanizers. The dehydrated digestate is the solid fraction produced at the dehydration step (solid-liquid separation of the raw digestate). The dried digestate refers to the digestate which has undergone the dehydration and drying processes.

Digester, or anaerobic digester, or Biomethanizer- A sealed tank or container where the biological anaerobic digestion of animal manure or organic matter occurs, and from which results the production of biogas.

Digestion- The breaking down of sludge and other waste biologically by microorganisms, mainly bacteria. Results in byproducts such as methane gas, carbon dioxide, sludge solids and water. Aerobic digestion requires oxygen, anaerobic digestion the absence of oxygen.

Greenhouse Gas (GHG)- An atmospheric gas, which is transparent to incoming solar radiation but absorbs the infrared radiation emitted by the Earth's surface. The main greenhouse gases are carbon dioxide, methane, and CFCs.

Hydrolysis- Macromolecules (proteins, lipids, carbohydrates) conversion (break-down) to monomers.

Microalgae-Microscopic eukaryotic organisms composed of single differentiated cells able to obtain energy using chromophores. Generally single-celled but can occur as filamentous or colonial (Definitions taken from EN 17399:2020 - Algae and algae products - Terms and definitions.)

Nutrients-Organic or non-organic chemical compounds essential for plant growth.

Primary Wastewater Treatment-The first process usually associated with municipal wastewater treatment to remove the large inorganic solids and settle out sand and grit.

Reclaimed Water- Reusable wastewater from wastewater treatment such as tertiary treatment of wastewater in biological and other systems.

Secondary Wastewater Treatment- Second biological process of digestion with bacteria.

Sludge- The solid waste material which settles out in the wastewater treatment process, sometimes biosolids. Can be dewatered and reused or disposed.

TDS (Total Dissolved Solids)- the combined total of all dissolved solids in wastewater, both organic and inorganic and very fine, such as colloidal minerals. Generally, particles must be smaller than two micrometers to be considered a dissolved solid. For example, salt dissolved in water is a dissolved solid. Therefore, TDS will "survive" screening or other coarse filtration.

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Tertiary Wastewater Treatment- Wastewater Biological and/or Chemical polishing to eliminate organics, solids, and nutrients.

Total Suspended Solids (TSS)- Particles that are suspended (as opposed to dissolved) in the wastewater which are largely removable by filtration, flocculation, digestion and so on for removal in the treatment of wastewater. Although not necessarily pollutants TSS can be a measure of pollutants in water.

Toxic- A poisonous substance to a living organism.

Toxicity- The relative degree of being poisonous or toxic. This condition may exist in wastes and wastewaters that could eventually inhibit or destroy the growth or function of certain organisms.

Turbidity- A measure of how cloudy or muddy appearance the wastewater has.

Valorization- Further use of a product in a value-added application.

Volatile solids (%VS)- Physico-chemical parameter expressing the amount of volatile solids in a liquid sample.

Wastewater- The water leftover (used water) after its use in anthropogenic activities namely domestic, municipal, industrial, agricultural, mining, etc.

Adapted from

https://www.biogasworld.com/biogas-glossary/

http://www.mgsdistrict.org/wp-content/uploads/2011/11/Glossary-of-Wastewater-Terms.pdf

https://treeo.ufl.edu/media/treeoufledu/waterwastewater/student-resources/Glossary-of-Common-WW-Terms.pdf

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