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The Water-wastewater-sludge Sector and the Circular Economy

Abstract

The objective of this paper is a theoretical and empirical analysis and evaluation of the role, importance and opportunities of the water-sewage-sludge industry in the implementation of the circular economy. To realize this objective, a review of both the literature and the EU strategic documents concerning the subject of the study was conducted. The applied research method is a descriptive analysis based on available statistical data (Eurostat, EEA, EIO and the Polish Central Statistical Office) as well as on source materials. The theoretical part of the work presents the essence of the circular economy and the general characteristics of the analyzed sector, with a particular focus on the potential for the recovery of water from sewage and the reuse of wastewater, as well as the recovery of phosphorus from the wastewater treatment, processing and disposal of sewage sludge. The results of the study show that: (1) there are significant links between the development goals of the water-sewage-sludge sector and the circular economy. (2) it is necessary to seek and implement new solutions and technologies leading to the increased recovery of energy and biogens from sewage sludge. (3) there are still many barriers to the recycling of rainwater and graywater as well as to the reuse of wastewater. (4) the circular economy creates new opportunities for water-sewage and sludge management at the local and national level.

Keywords*: circular economy; water-sewage-sludge industry; reuse of wastewater; recovery of water; energy and phosphorus; sewage sludge*

JEL*: L950; O130; Q250; Q 530; Q550; Q560; Q420*

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1. Introduction

In many European countries, attempts have been made for many years to effectively utilize various types of waste or to optimize their recovery in line with the currently widely used linear production model (presented in short as make-take-dump). Today, however, it seems that a good solution in this area is to change the model of waste management into the circular economy model. This is a new idea that reaches to the roots of economic sciences.

The concepts of sustainable development, the green economy or the low-emission economy, widely known in the literature of the subject and implemented for many years on a global scale, have some common goals in terms of environmental protection, social needs and economic development, despite their specificity. The main element of the circular economy concept, supporting the implementation of the aforementioned concepts and interacting with them in terms of assumptions, is material efficiency. This is particularly important due to the constant shrinking of natural resources, including water resources and the growing negative impact of human interference in the environment.

The EU water policy is currently based mainly on protection against pollution, through tightening environmental standards. On the other hand, further development of cities is determined by the possibility of supplying clean water and the proper treatment of sewage and sewage sludge. Meanwhile, due to the constant increase in the costs of water protection and wastewater treatment, solutions are sought in many European countries that would enable the maximum protection of waters while minimizing social costs.

One of the solutions may be a change of approach to the role of the water and sewage disposal sector and especially the water and sewage plants in the national economy. Complying with environmental regulations, currently, these companies mainly deal with water supply, wastewater treatment and the treatment of sewage sludge. However, due to the expected economic, social and environmental benefits, they are also increasingly undertaking activities in the field of the recovery of energy and valuable raw materials, thus presenting a new "biogens-energy-water" paradigm in water-sewage-sludge management.[1] It mainly concerns the production of water recovered from wastewater, which can be used for various purposes after proper treatment. It also assumes the recovery of raw, energetic materials, biogens (nitrogen, phosphorus) and hydrogen or bioplastics from sewage and sewage sludge. The new approach shows a significant convergence with the idea of a circular economy. Both ideas are characterized by common goals: sustainable

[1] See: Stanowisko Komisji Środowiska Senatu Rzeczpospolitej Polskiej na temat innowacyjnego wykorzystania ścieków jako źródła energii i zasobów, dnia 17 marca 2016 r. [Position of the Environment Committee of the Senate of the Republic of Poland on the innovative use of sewage as a source of energy and resources], March 17th, 2016, BPS/KS/0330/12/16, Warszawa (in Polish).

development, acquiring resources, saving resources and energy, using renewable energy sources, as well as preventing climate change and progressive eutrophication of waters.

For a long time, water has been perceived as a key element in a waste-free economy. However, the issue of sewage sludge in the context of the circular economy has also been considered for a long time in Europe and the rest of the world. Although sludge is a technological waste, it is considered biomass and is perceived as a valuable source of energy and valuable substances, such as phosphorus. Over the last several decades, the use of phosphorus in agriculture has increased in Europe, while the profitable reserves of phosphates, mainly used in the fertilizer and feeding industries, have significantly decreased. Therefore, the recovery of biogens (phosphorus and nitrogen) from wastewater and sewage sludge is considered to be particularly important today from the point of view of many sectors of the economy.

The main objective of this paper is the theoretical and empirical analysis and evaluation of the role and importance, potential, challenges and opportunities of the water-sewage-sludge industry in the context of the circular economy challenges proposed by EU legal regulations. Particular attention is paid to selected areas of the water and sewage sector activity, which concern the possibility of recovery of water from sewage, the secondary use of sewage, the use of closed water cycles in industry, the recovery of phosphorus and energy from sewage treatment processes and the treatment of sewage sludge – as elements of the circular economy.

2. The Circular Economy – a theoretical approach

The circular economy is defined in various ways in the available literature. Most often, it is described as a new concept of economic development; a modern vision of creating value through the rational use of resources; the principle of closing the product lifecycle; an ideological alternative to a linear economy based on the "take, use, and throw away" principle; the idea of minimizing the negative impact on the environment; the model in which the preferred rule is to reduce, repair, reuse, and recycle; a new opportunity for development and business opportunities; a solution that is able to reconcile sustainable development and economic growth, or popularly, cyclically giving a second, more interesting life to used products.

The circular economy development model has been developed since the end of the 1970s, with a large impact of the industrial economy, the collaborative economy, cradle-to-cradle, upcycling design, resource efficiency strategies, the vision of the recycling society, or principles of sustainable production and consumption. For more than ten years, new economic models based on knowledge, sharing and co-creation have been developed, aimed at closing the loop. At present, the circular economy is a priority of the European Commission's economic policy for the coming years (EC 2014a, 2014b, 2015, 2016, 2017a, 2018) and it is one of the key stimulators of the implementation of the principles of responsible and sustainable business.

Eco-design, reuse, the recycling of waste and preventing waste creation are the basic elements which enable us to maintain raw materials and their value in circulation. They play a key role in the implementation of the circular economy. The waste created in the production process is not to be the last link in the production chain, but is to be further used through material or energy recovery. The basic circular economy concept, therefore, means a production and consumption system based on repair, regeneration, recycling, and reuse, as well as product sharing, changes in consumption patterns and new business models and systems. However, the entire product life cycle is important here, including energy issues and anti-emissive activities, not just waste.

The Ellen MacArthur Foundation (EMF 2015, p. 3) pointed to two priority actions releasing the circular economy potential. These include creating favorable conditions for the development of innovation and its effective catalyzing, as well as conducting effective education in the field of this concept for all social groups, mainly children and young people.

The EEA (2016) indicates a few key theses of the circular economy. Firstly, in this model – compared to the linear model – there is less input and at the same time more efficient use (at each stage) of natural resources, including energy and water. Secondly, the share of renewable and recyclable resources and energy is increased. On the other hand, emissions, as well as losses and material residues, are reduced. In addition, this model is conducive to maintaining the value of products, components and materials in the economy.

The circular economy assumptions can be implemented in many sectors and branches of the economy. Currently, the waste and recycling sector is of key importance, but other sectors should also be indicated, such as electricity, heating, communal, renewable energy, commercial and services sectors. It is also worth noting that the concept described can be introduced in manufacturing companies as well as in state and local government institutions.

Numerous available studies and analyses of the impact of the circular economy on the economy show that the transition from a linear economy towards a circular economy can bring economic, environmental and social benefits at the local and the EU level (Coats, Benton 2015; Bachorz 2017; Karwacka 2017). Thanks to changes at all stages of a product's life-cycle, enabling the reuse of used materials, the circular economy is conducive to minimizing the negative environmental impact of manufactured products, improving both many macroeconomic indicators and the climate. The many potential benefits that the EEA (2016) has indicated include: (1) savings for enterprises (estimated at EUR 600 billion); (2) a 2–4% reduction of CO_2 emissions; (3) the creation of many new and valuable jobs; a reduction in the use of valuable natural resources, thus increasing resource security; (4) a reduction in the amount of waste generated; (5) the creation of new business models; (6) support for social innovation; (7) an increase in the competitiveness of the European economy in the global market.

According to Wijkman and Skånberg (2015), the introduction of circular economy principles in Poland may, in addition to the environmental effects and an increase in the number of jobs, also accelerate the rate of economic growth. Additionally, it seems possible for Poland to achieve an increase in energy efficiency by 25%, material efficiency by 7%, and a reduction of CO_2 emissions by 35%. However, among the many stimulators of change in the economic model, the need for change in the Polish tax system is stressed.

3. Water and sewage sludge management as support for the circular economy

The European Union has been implementing a directive on urban wastewater treatment for over 25 years.[2] It is one of the key instruments of the EU legal acquis in the field of water resources and serves to protect the environment and human health while contributing to economic growth and job creation. This directive should also be seen as fundamental in the context of implementing the 6th sustainable development goal (SDG6)[3] and the transformation of the water-sewage-sludge sector towards the circular economy.

It should be noted that, currently, the level of implementation of this directive in all member states is relatively high, which contributes to a significant improvement in the quality of waters in Europe. However, there are still many challenges in the area of water and wastewater management in the EU. Those directly related to the concept of the circular economy include (EC 2017c, p. 19): (1) making further investments in the wastewater treatment sector; (2) improving the quality of sewage sludge and its recovery; (3) limiting the effects of stormwater overflows by promoting natural water retention systems or improving network management in connection with sewage treatment plants[4]; (4) increasing the degree of reuse of wastewater, mainly in water scarcity situations, while ensuring an adequate level of water quality; (5) optimizing energy consumption by sewage systems with the simultaneous production of renewable energy from biogas at the level of wastewater treatment plants.

[2] Council Directive 91/271/EC concerning urban waste-water treatment was adopted on 21 May 1991.

[3] SDG6 is related to “ensuring access to water and sanitation for all”: https://sustainabledevelopment.un.org/sdg6 and http://www.un.org/sustainabledevelopment/water-and-sanitation/

[4] Storm Water Overflows study: https://circabc.europa.eu/w/browse/e00a649a–7eb4–40b3–9b19-f5ace7a80e08 (accssed: 20.01.2018).

Many solutions are currently being applied to water protection, including those considered compatible with the concept of a circular economy, e.g., closing water cycles in production cycles, water recovery from wastewater, the use of waste-free technologies in industrial production, mine water disposal or re-injection of these waters into the rock mass. However, in order to reduce the volume flow of wastewater and the quantities of waste produced in production processes, the following are also commonly recommended: (1) to reuse water from one operation in another one; (2) to reuse water for another operation after it has been cleaned; (3) water renewal and its return to previous processes in the so-called closed circulation; and (4) reusing wastewater for economic purposes, including agriculture.

The increase in water scarcity and increased awareness related to the protection of water resources have the effect of recycling water in many EU countries, including Poland (Anderson 2003). It makes it possible, through the introduction of closed water cycles, to reuse water and simultaneously reduce the volume of wastewater generated in technological processes (Alcalde-Sanz, Gawlik 2014; Lazarova et al. 2013; Eslamian S. [ed.] 2016) Recycling water is an important proposition, especially for those industries that consume large amounts of water or which have highly contaminated streams of liquid and solid waste and pay high fees for their disposal.

In the context of effectively implementing circular economy objectives, particular importance should be attributed to sludge management, due to the possibility of recovering valuable raw materials from sewage sludge[5] and the use of its energy potential. However, it should be emphasized that due to ecological, technical and economic reasons, as well as sanitary safety issues, for many years there has been a serious problem of dealing with the growing amount of sludge on a global scale.

In 2017, European guidelines were presented on the management of sewage sludge and its use in agriculture, horticulture, forestry, green areas, as well as for energy production and in the recovery of phosphorus. Although the changing regulations oblige European Union member states to look for new solutions in this area, the sludge economy is still a topical issue, especially in the countries of Central and Eastern Europe. It can be noted, though, that there are significant investment needs in the maintenance and construction of new sludge disposal installations across the EU. Germany and the Benelux countries are the leaders in fast and effective adaptation to new requirements. The recommendations of the Helsinki Commission are also important for the sustainable management of sewage sludge in the Baltic Sea region.[6]

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[5] The term "sewage sludge" refers mainly to the biologically unprocessed liquid portion of wastewater, a by-product of wastewater treatment, constituting only 0.1% of wastewater as a whole, and considered to be hazardous waste. Sewage sludge is treated mainly by the water and sewage industry.

[6] See: Council Decision of 21 February 1994 on the accession of the Community to the Convention on the Protection of the Marine Environment of the Baltic Sea Area 1974 (Helsinki Convention), (94/156/EC).

The vast majority of sludge is processed and recycled through agricultural use, reclamation, composting and other uses. Some of the sludge generated in the EU is subjected to thermal utilization, with the excess heat from this process being used for the generation of heat and energy. The least preferred option, according to the hierarchy of waste management practices and the circular economy, is the accumulation of sludge in lagoons or landfills. Recycling sludge used for natural and agricultural purposes is the most sustainable solution, because it can reduce the need for fertilizers and improve soil structure. However, the applicability of recycling depends on local conditions and requirements regarding transport, consumption of energy and other resources.

It should be emphasized that the new solutions and technologies have been sought and implemented gradually for many years in sludge management, increasing the efficiency of the sludge treatment process. The main goal here is to increase the recovery of energy accumulated in the sludge until the full energetic self-sufficiency of the sewage treatment plants is reached, and thus to approach the assumptions of the circular economy in this industry.

EU and national legal regulations in the field of energy efficiency have a significant impact on the functioning of water and sewage companies[7], due to which the energy audit is increasingly used by these companies. It gives an opportunity to optimize energy efficiency and can bring real economic and environmental benefits, including the energy autonomy of sewage treatment plants. The main role in this field is played by the rational and effective management of sewage sludge, which after drying is a source of valuable raw materials with energy values. It is energy efficient, for example, to use the biogas produced from sludge in the methane fermentation process for the production of electricity and heat, or as a source of energy for drying sewage sludge.

It is also worth noting that the management of sewage sludge constitutes a significant part of the total costs of wastewater treatment and nowadays the problem for Polish enterprises is, apart from managing the generated sludge, also a significant disorder of the regulations on their use, as they are considered a hazardous waste. Good examples of many European countries, however, confirm that investing in processes and new methods of wastewater treatment contributes to the creation of a smaller quantity and a better quality of sludge, and the problem of their management is thus reduced.

It is well known that biogenic compounds (mainly nitrogen and phosphorus) that get into the aquatic environment uncontrolled cause eutrophication of water reservoirs. This phenomenon should be counteracted by the more effective elimination of nitrogen and phosphorus compounds from sewage in sewage treatment plants. However, in the face of shrinking phosphorus resources, attempts are being made to recover phosphorus from wastewater for reuse. According to Warężak

[7] In Poland, this is the Act of May 20, 2016 on energy efficiency (Dz.U. 2016, item 831), which introduced a number of changes, e.g. the mode of calculating the energy saving obligation.

(2017, p. 65), this approach may be conducive to the reduction of sewage sludge volume, the reduction of chemical compounds used in wastewater treatment plants, the protection of surface waters through the improvement of the wastewater treatment process, a reduction of the level of extraction and consumption of phosphate rock, as well as a reduction in mineral fertilizer used on farms.

4. Results and discussion

4.1. Circular Economy

There is no one synthetic indicator available which would enable the measurement of the degree of implementation of the circular economy model in a given country in the overall dimension. However, a number of specific indicators can be used to help measure the results achieved in those areas which particularly contribute to the development of the circular economy. There is also a monitoring framework implemented in the EU which consists of 10 indicators, divided into four thematic areas[8]: production and consumption, waste management, secondary raw materials, and competitiveness and innovation. Two specific indicators were selected for the purposes of this study – employment and revenue – which are analyzed below.

Analyzing eco-innovation and circular economy industries on a global scale, it can be stated that in terms of the volume of revenues earned in these industries Europe is a clear leader, ahead of such regions of the world as Asia & Oceania and North America. It is worth noting that in all the surveyed regions, a higher level of employment translates into a greater sum of revenues in these sectors (Table 1).

As reported by the EC[9] in 2014, among the 15 countries in the world with the largest number of employees in eco-innovation and circular economy activities, Brazil had the highest number of full-time employees (1.82 million ppl), ahead of Russia (1.01), France (0.82) and the United States (0.61). In the league table of the sum of eco revenues, France is ranked first (233.2 trillion USD), followed by Australia (202.1), Great Britain (200.8) and Japan (199).

It is worth mentioning that, currently, circular economy principles have already been implemented with great success in many EU member states. Finland has been recognised as the world leader of the circular economy due to its 'Road Map to a circular economy 2016–2025'. Sweden and Denmark also present outstanding performance in this respect.[10] Between 2017 and 2020, London will spend

[8] Eurostat: http://ec.europa.eu/eurostat/web/circular-economy/indicators

[9] European Commission, Environment: Eco-Innovation Action Plan: https://ec.europa.eu/ environment/ ecoap/indicators/socio-economic-outcomes_en (accssed: 20.01.2018).

[10] See: Leading the cycle – Finnish road map to a circular economy 2016–2025, Sitra 2016. (accssed: 20.01.2018).

GBP 50 million to adjust and create circular economy instruments, and the Netherlands is the first country planning to become a circular economy state by 2050. Non-European countries such as Canada, Japan and Australia, are also taking actions in line with the EU's circular economy strategy.

Table 1. Eco-innovation and the circular economy in different regions of the World, 2014

Region	Number of Eco employees	Eco revenues, billion USD
Africa	177,578	57.9
Asia & Oceania	1,744,049	641.8
Europe	5,192,856	1286.1
Latin America	2,075,767	141.4
Middle East	20,789	17.1
North America	849,319	150.9

Source: EIO calculation based on the ORBIS database.[11]

The higher employment rate in eco-innovation and circular economy activities in individual EU countries in 2016, as in other regions of the world, was, to a large extent, correlated with higher revenues generated in these sectors (Table 2). In terms of the share of employed in the analyzed industries, the leaders are Central and Eastern European countries: the Czech Republic, Slovenia, Romania and Hungary, as well as France. In terms of revenues, the highest indicator among the EU countries was recorded in the Netherlands.

Table 2. Employment in eco-innovation and circular economy industries, EU28, 2016

Country	Employment in eco-industry as % of total employment	Eco-industry revenue as % of total revenue
Croatia	0.00	0.00
Luxembourg	0.00	0.00
Cyprus	0.12	0.03
Austria	1.72	0.73
Ireland	2.38	1.17
Denmark	1.38	1.35
Germany	1.27	1.41
Greece	1.88	1.63
Malta	0.00	1.63
U. Kingdom	1.82	1.86
Belgium	1.80	1.87
Italy	2.56	2.11
Sweden	2.36	2.13
Lithuania	2.80	2.14

[11] https://ec.europa.eu/environment/ecoap/indicators/socio-economic-outcomes_en (accessed: 18.01.2018).

Country	Employment in eco-industry as % of total employment	Eco-industry revenue as % of total revenue
Hungary	4.11	2.24
Slovakia	2.67	2.33
Poland	0.85	2.44
Portugal	2.99	2.56
Finland	3.61	2.56
Bulgaria	2.53	2.62
Estonia	3.32	2.63
Spain	3.45	2.77
France	4.59	2.85
Romania	4.26	2.99
Latvia	3.16	3.32
Slovenia	4.64	3.42
Czech Rep.	4.83	3.53
Netherlands	2.37	4.35
EU Average	**2.53**	**2.22**

Source: EIO calculation based on the ORBIS database.[12]

As indicated by the above data, the overall potential of the circular economy in the world is significant. Moreover, it is believed that the transformation towards this concept may increase the value of the global economy by as much as USD 4.5 billion (Lacy, Rutqvist 2015, p. 3).

4.2. The water and wastewater sectors in Europe

First, it should be emphasized that the entire wastewater treatment sector (including exports) has a significant contribution to the European economy.[13] The value of production of this sector is approximately EUR 96 billion per year, and the value added is approximately EUR 41 billion per year. It generates approximately 600,000 jobs expressed as full-time equivalents (EC 2017c, p. 18).

The EurEau report (2017) shows[14] that in the 29 analyzed European countries, the estimated population connected to the water supply network is 499 million (which is about 93% of all Europeans), to the sewage network – 450 million, and to sewage treatment plants – 435 million (without taking into account the number of people connected to individual sewage management systems). The highest share of population connected to the water supply network (around 100%) is recorded in Germany, Denmark, Switzerland, Malta and the Netherlands. In comparison with other countries, Poland is below the European average in terms of the share

[12] https://ec.europa.eu/environment/ecoap/indicators/socio-economic-outcomes_en

[13] See: http://ec.europa.eu/eurostat/web/environment/environmental-goods-and-services-sector/ database (accssed: 20.01.2018).

[14] EurEau – a European federation bringing together national organizations representing tens of thousands of water and sewage companies (accessed: 10.05.2018).

of the population connected to the water supply (over 90%) and the sewage network and sewage treatment plants (approximately 70%). Romania is in last place (about 60% and below 50%) among the 29 surveyed countries belonging to the Union. The European industry invests approximately EUR 45 billion per year in water and sewage infrastructure, which means average annual investments totaling EUR 93.5 per capita. The funds come mainly from tariffs and also from the redistribution of taxes and fees, as well as from subsidies.

The entities providing water and sewage services employ 476,000 people (full-time), which represents 0.1% of the population of the European Union. The highest number of employees is recorded in France (over 100,000), in Great Britain and in Denmark. Poland takes fourth place in this ranking.

The total length of the water supply network in Europe is 4,225,527 km, and the total amount of water supplied in the EU is 44.7 billion m^3/year. The longest network is in France, at 900,000 km. Water for treatment is captured mainly from surface intakes (approximately 60%) as well as from deep water intakes (approx. 40%). Additionally, drinking water is also, to a small extent (about 1%), obtained in desalination processes, e.g., in Cyprus, Malta, Spain and Greece. The average daily consumption of water per capita in European households is 128 liters. The highest water consumption was recorded in Norway (around 200 liters), Portugal and Greece. Poles consume less than 100 liters of water per capita per day.

Available statistical data on access to drinking water or water stress show that in many European countries, including Poland, there is a high risk of permanent significant water deficit[15] which is why closing water cycles may become an important element of the circular economy in the future.[16] In Poland, as in many European countries, the recirculation of water in production plants is increasingly used, but unfortunately, this process is still under-utilized. In 2016, 36.5% of all plants in Poland were equipped with closed water cycles. However, the use of water for production purposes in closed cycles in Poland amounted to 3.4% of total water consumption for production purposes.[17]

The issue of wastewater treatment still requires urgent solutions in many European Union countries. There are currently 3 levels of sewage purification available. On average, about 70% of the pollutant load in sewage in the EU is subjected to the third level, which today, in the most effective way, allows the removal of biogens and the disinfection of treated wastewater (Figure 1). Countries such as Cyprus, the Netherlands and Slovakia use only the third level of treatment, while in Poland the corresponding ratio is 80%

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[15] http://ec.europa.eu/eurostat/statistics-explained/index.php/Water_statistics (accssed: 20.01.2018).

[16] The closed water cycle is a system in which water once used is not discharged to the receiver but returned to the direct water supply point to be reused and recirculated. Source: GUS (2017), *Enviroment 2017*, CSO, Regional and Environmental Surveys Department; Warsaw. (in Polish) (accssed: 20.01.2018).

[17] Central Statistical Office: www.stat.gov.pl (accessed: 9.12.2018).

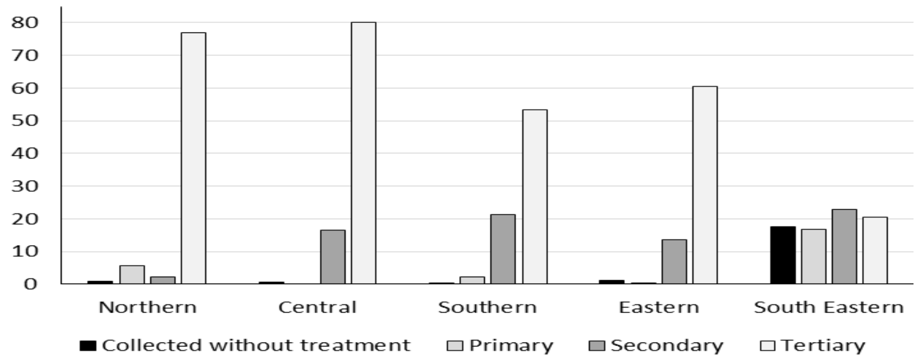

Figure 1. Urban wastewater treatment in Europe in 2015, percentage of population[18]

Source: author's own elaboration based on EEA data.[19]

4.3. Wastewater and sewage sludge production and reuse

Water scarcity in some parts of the EU has significantly worsened in recent years (EC 2017a). Therefore, the reuse of treated wastewater carried out in safe and cost-effective conditions today seems a valuable way to increase water supply and reduce the pressure on water resources. In 2016, the EC issued guidelines to better integrate water reuse in planning and managing water resources.[20] This issue has also become the main priority in the European Innovation Partnership (EIP) on water.[21]

Work is currently underway at EU level on a legislative initiative to promote the reuse of wastewater in the context of the Communication *"Closing the Loop – An EU Action Plan for the Circular Economy"* (EC 2015). The aim of this measure is to enable the cost-effective reuse of wastewater for irrigation in agriculture, while ensuring a high level of health and environmental protection. Although the data in this subject are not collected regularly and are not fully available, it is now known that wastewater in European Union countries is reused only to a limited extent (EC 2017c, p. 14). Only eight Member States regularly reuse part of the treated wastewater: Greece, the United Kingdom, France, Italy, Malta, Cyprus, Estonia and Belgium.

[18] Northern Europe: Norway, Sweden, Finland and Iceland; Central Europe: Austria, Belgium, Denmark, Netherlands, Germany, Switzerland, Luxembourg and the United Kingdom; Eastern Europe: the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland and Slovenia; South-eastern Europe: Bulgaria, Romania and Turkey.

[19] https://www.eea.europa.eu/data-and-maps/indicators/urban-waste-water-treatment/urban-waste-water -treatment-assessment–4 (accssed: 20.01.2018).

[20] See: http://ec.europa.eu/environment/water/pdf/Guidelines_on_water_reuse.pdf

[21] EIP: http://ec.europa.eu/environment/water/innovationpartnership/ (accssed: 20.01.2018).

The percentage of treated wastewater that is reused ranges from 0.08% in the UK to 97% in Cyprus, and the EU average is 2%. The reuse takes place mainly in agriculture and occasionally in industry, and to supply water to the aquifer. Croatia, Hungary, Slovakia and Romania declare their intention to reuse sewage in the future. However, Latvia and Austria do not see such a necessity due to the high availability of fresh water in their countries. Other Member States also do not intend to reuse sewage in the near future (EC 2017c, p. 14). Currently, more than 40,000 million m^3 of wastewater is treated each year in the EU, but only 964 million m^3 of treated water is reused.

The analysis of the data on sewage sludge management shows that 8.7 million tonnes of sludge was produced in the EU in the form of a dry solid mass in 2014, which is about 17 kg per inhabitant. The values for Belgium, Cyprus, Italy, Portugal and Romania were less than 10 kg per capita (EC 2017c, p. 13). It is important that 58% of the sludge generated in the EU was reused, mainly in agriculture.[22] The agricultural use of sewage sludge is not allowed in some countries, e.g., in the Netherlands, Denmark and Austria.

Along with the new EU regulations, new methods of using sludge will be available. 27% of the sludge, mainly generated in cities, is incinerated. This technology is used on a wide scale in countries such as Austria, Denmark and the Netherlands. At the same time, there is a constant development of fermentation technologies, which contribute to both the reduction of sludge and to the production of energy from biogas produced in the process of methane fermentation, i.e., renewable energy.

According to data from the Central Statistical Office (2017), the volume of municipal sewage sludge in Poland doubled from 2000 to 2016. It has to be managed in a secure, modern and economically acceptable way. The recycling or disposal of sewage sludge in a sustainable manner is a serious challenge for the whole water and sewage sector, especially after January 1, 2016, when the EU ban on depositing waste with a gross calorific value of over 6 MJ/kg of dry matter came into force. At the same time, despite the numerous installations of thermal processing of sludge, drying and incineration (including eleven mono-incineration plants) operating in Poland, there is still a shortage of new installations for its treatment, including those using advanced biological methods. Unfortunately, some of the technologies currently used in Poland may turn out to be outdated in a few years. Traditional methods usually include thetreatment of sludge or its use in nature, which has been adopted for years. Thanks to further treatment, sewage sludge can be transformed into fertilizer and biogas, and after making the necessary capital investments (e.g., in innovative mechanical compaction and drainage) they can also have energy application, generating renewable energy from biogas. The sewage sludge incineration plants operating in Poland, obtaining sludge from munici-

[22] According to Directive 86/278/EEC of 12 June 1986 – on the protection of the environment.

pal sewage treatment plants, manage about 18% of the total sludge. What is more, sludge is mainly used in agriculture (20.4%).[23] The possibility of the wider management of sludge in biogas installations or other innovative waste treatment installations in Poland is also worth considering.

Regarding the recovery of phosphorus, the potential contribution of the European water and sewage sludge sector to the circular economy is significant. Already in 2014, more than half of the phosphorus removed from wastewater in sewage treatment plants was reused or recycled (EC 2017c, p. 13). Currently, the process of phosphorus recovery at various stages of the processing of sludge is developing dynamically in many European countries and it can be expected that the significance of this process will increase in the future.

5. Conclusions

The conducted analysis allows us to make several general conclusions. Many countries in the world have taken a development initiative in recent years, based on sustainable economic growth, that counteracts the waste of natural resources and is in line with the circular economy assumptions. The level of implementation of this model is very diverse, and the world's leaders, in terms of the number of employees and revenues, are in Europe, in particular, the countries of Central and Eastern Europe.

The circular economy creates new opportunities for the development of many sectors of the economy, including the water and sewage sludge sector. There are important links between the development goals of this sector and the circular economy concept, and they mainly concern sustainable development, acquiring resources, saving resources and energy, using renewable energy sources, as well as preventing climate change and the progressive eutrophication of waters. Therefore, it seems reasonable for water and sewage companies to undertake activities to verify existing business models in order to carry out their activities in a wider and wider scope in accordance with the circular model.

The circular economy offers many opportunities for the development of the water-sewage-sludge industry, for example, introducing innovative organizational and technological solutions that bring economic, environmental and social benefits (on a macro and microeconomic scale), mainly in the field of water renewal and the use of sewage and sewage sludge as a source of energy, and the sourcing of raw materials. The closed cycle in sewage treatment plants may lead to, among others, a reduction of costs, the recycling of biogens (mainly phosphorus), an im-

[23] Central Statistical Office: http://stat.gov.pl/obszary-tematyczne/srodowisko-energia/srodowisko/ ochrona-srodowiska–2016,1,17.html (accessed: 21.01.2018).

provement in energy efficiency, and even the achievement of energy self-sufficiency of wastewater treatment plants. However, there are still many barriers to the recycling of graywater and the secondary use of wastewater for economic purposes. It also seems necessary to seek and implement on a wider scale new solutions and technologies which would lead to an increase in energy and phosphorus recovery from sewage sludge, thus supporting the circular economy.

It can be expected that in the next several years resource management will be oriented on a closed cycle, consistent with the principles of sustainable development, beneficial to business, society and the environment. However, a wider approach to the circular economy shows that economic development should be based on a the sustainable and effective use of water resources, broader than before, and an improvement of the state of the environment in relation to one of the key areas of the economy today which is water, sewage and sewage sludge management.

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Streszczenie

BRANŻA WODNO-ŚCIEKOWO-OSADOWA A GOSPODARKA CYRKULARNA

Celem artykułu jest teoretyczna i empiryczna analiza oraz ocena roli i znaczenia branży wodno-ściekowo-osadowej w realizacji założeń koncepcji gospodarki o obiegu zamkniętym. Dla realizacji postawionego celu dokonano przeglądu literatury oraz unijnych dokumentów strategicznych z zakresu tematu opracowania. Zastosowana metoda badawcza to analiza opisowa na podstawie dostępnych materiałów źródłowych i danych statystycznych (Eurostat, EEA, EIO i GUS). W części teoretycznej pracy przedstawiono istotę gospodarki cyrkularnej oraz ogólną charakterystykę badanego sektora, zwracając szczególną uwagę na możliwości odnowy wody ze ścieków i wtórnego wykorzystania ścieków, a także odzysku energii i surowców (głównie fosforu) z procesów oczyszczania ścieków oraz przeróbki i unieszkodliwiania osadów ściekowych. Wyniki badań wskazują na: (1) istotne związki między celami rozwoju branży wodno-ściekowo-osadową a koncepcją gospodarki o obiegu zamkniętym. (2) konieczne wydaje się poszukiwanie i wdrażanie nowych rozwiązań i technologii prowadzących do wzrostu odzysku energii i fosforu z osadów ściekowych. (3) występuje wciąż wiele barier w zakresie wdrażania procesów recyklingu wody szarej, a także wtórnego wykorzystania ścieków. (4) gospodarka obiegowa stwarza nowe szanse dla rozwoju sektora wodno-ściekowo-osadowego na poziomie lokalnym i regionalnym.

Słowa kluczowe*: gospodarka cyrkularna; branża wodno-ściekowo-osadowa; powtórne wykorzystanie ścieków; odzysk wody, energii i fosforu; osady ściekowe*