METAL DEPLETION ASSESSMENT OF WASTEWATER TREATMENT SYSTEM BASED ON LIFE CYCLE ANALYSIS

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Abstract

Management of non-renewable resources, including metals, is a key issue in the circular economy and one of the priorities of the EU's environmental policy. Life Cycle Assessment (LCA) is a technique for assessing the environmental impact in a product or technology life cycle which allows the estimation of metal, minerals and fossil fuels consumption, including both direct demand for them in the technological processes as well as indirect demand for them in the production of raw materials, materials and energy used in these processes. The analysis results of cumulative metal consumption in wastewater treatment system based on life cycle analysis are presented in this paper. In addition to economic issues, the use of methods to assess environmental performance at the stage of construction, operation and decommissioning of water and wastewater infrastructure is becoming more important in the wastewater economy. In this context, a new approach to the assessment of environmental aspects is the use of a life cycle analysis concept that allows the assessment of cumulative resource demands throughout the whole life cycle of a wastewater treatment system. The Life Cycle Impact Assessment (LCIA) of wastewater treatment system proposed in this paper allows the identification and assessment of its potential environmental impacts from the perspective of metal consumption. It has been shown that the LCA technique is an appropriate tool for assessing the cumulative metal consumption.

Keywords: Metal depletion, natural resources management, wastewater treatment system, life cycle assessment

1. INTRODUCTION

In the countries of the European Union, effective use of metals and fossil fuels is an important policy direction promoting sustainable development. According to the European Commission, securing the availability of resources through economical use and rational extraction is the objective of the flagship initiative within the strategy 'Europe 2020' [1], Europe effectively using resources that covers all types of natural resources. Limiting the use of non-renewable natural resources, including metals, is considered to be a key activity in a circular economy. The first step in reducing resources should be consumption assessment, so methods should be developed which allow such assessments, especially in the context of sustainable development assessment. For this assessment, a life cycle analysis technique can be used which serves to identify potential environmental burdens and it can be used to support environmental management, taking into account new guidelines for ISO 14001:2015 [2]. So far natural resources management were presented in the papers [3-5] and life cycle assessment were shown in the paper [6]. According to the European Commission's recommendations, the life cycle assessment should be one of the horizontal environmental criteria, which is primarily intended to reinforce the EU policy aimed at practical and measurable consideration of sustainable development principles. In the long term, this approach is intended to reduce the pressure on the environment by promoting measures that minimize the impact on the environment, among which it is important to reduce the use of natural resources, including metals.

The main goal of the paper was presented potential of Life Cycle Assessment for assessing the cumulative metal consumption in the life cycle of a wastewater treatment system.

2. METHODS AND ASSUMPTIONS

According to the life cycle assessment, impact categories related to material consumption, including metals, include their cumulative consumption (both direct and indirect). The materials analysed include i.a..: aluminium, chromium, copper, gold, lead, manganese, molybdenum, iron, nickel, platinum, rhodium, tin, uranium, zinc, gal, gold, lead, magnesium, mercury, nickel, niobium, phosphorus, platinum, potassium, selenium, silicon, silver, sodium, sulphur, tantalum, uranium, vanadium. Consumption of natural resources according to the life cycle assessment methodology is understood as their depletion, which is connected with the reduction of their availability for future generations. SimaPro 8 software and ecoinvent 3 database were used to evaluate metal consumption of the life cycle of the system. The ReCiPe Midpoint method developed by RIVM (Rijksinstituut voor Volksgezondheid en Milieu), PRé Consultants and Radboud Universiteit Nijmegen and CML (Instititute of Environmental Sciences) was used for cumulative metal depletion analyses [7]. In the ReCiPe Midpoint method, metal consumption in the life cycle of a product or technology is expressed as kg Fe eq.

LCA analyses for the impact category of metal consumption were made for collection, transport and wastewater treatment system operating in a specific area, which consists of four components:

1) Septic holding tanks in which wastewater is collected in an area without sewerage system and transported by waste removal vehicles to collective wastewater treatment plants,
2) Individual wastewater treatment plants in which wastewater is treated in an area without sewerage system, and wastewater sludge generated there is transported by waste removal vehicles to the collective wastewater treatment plant [8].
3) Sewerage system together with pumping stations, transporting wastewater to the collective wastewater treatment plant.
4) Collective wastewater treatment plant treating wastewater flowing through the sewerage system and transported by waste removal vehicles from septic holding tanks, as well as wastewater sludge from individual wastewater treatment plants.

Life Cycle Assessment covered four stages (ISO 14040:2006) [9]: defining the purpose and scope of the analysis, collecting and analysing input and output data sets, impact assessment according to specific categories and interpretation of results. The analysis of the consumption of the analysed metals was carried out within the limits of the system, which covered all stages of the life cycle, i.e. construction, operation and decommission of analysed components of the system. To this end, all system components were identified and input and output elements were determined for each of them. For comparative purposes, all analyses were referred to the same functional unit. Functional unit (FU) is a quantitative effect of a system used as a reference unit. The functional unit (FU) of the analysed system is the Equivalent Number of Residents (1 RLM), which, in accordance with the regulations in force in the EU [10] and in Poland [11] is defined as a load of organic biodegradable substances expressed as an indicator of five-day biochemical oxygen demand (BZT_5) of 60 g oxygen per day [11].

Data collection should cover the entire life cycle, i.e. from the acquisition of raw material through its processing, obtaining the final product to the disposal of waste. Based on the identified elements of the system, data inventory was carried out covering all stages of the life cycle of the waste collection, transportation and waste treatment system. Detailed inventory data have been presented in the work [12]. Full inventory of data based on the actual system operating in an area inhabited by about 60 000 inhabitants, allows the assessment of the direct and indirect components of the system on the environmental burden associated with the consumption of individual metals. The use of the ReCiPe 2008 method has allowed the calculation of cumulative metal consumption over the life cycle of the wastewater treatment system, so that the depletion of individual metals can be assessed taking into account the demand for particular technologies and products for raw materials and energy as well as resources for production processes.

3. RESULTS AND DISCUSSION

Based on the collected and estimated data for the individual components of the collection, transport and wastewater treatment system, a comparative analysis was carried out and life cycle assessment was performed taking into account cumulative consumption of all metals (see **Figure 1**). The highest metal consumption indicator was shown for the stage of construction of collective wastewater treatment plants and septic holding tanks.

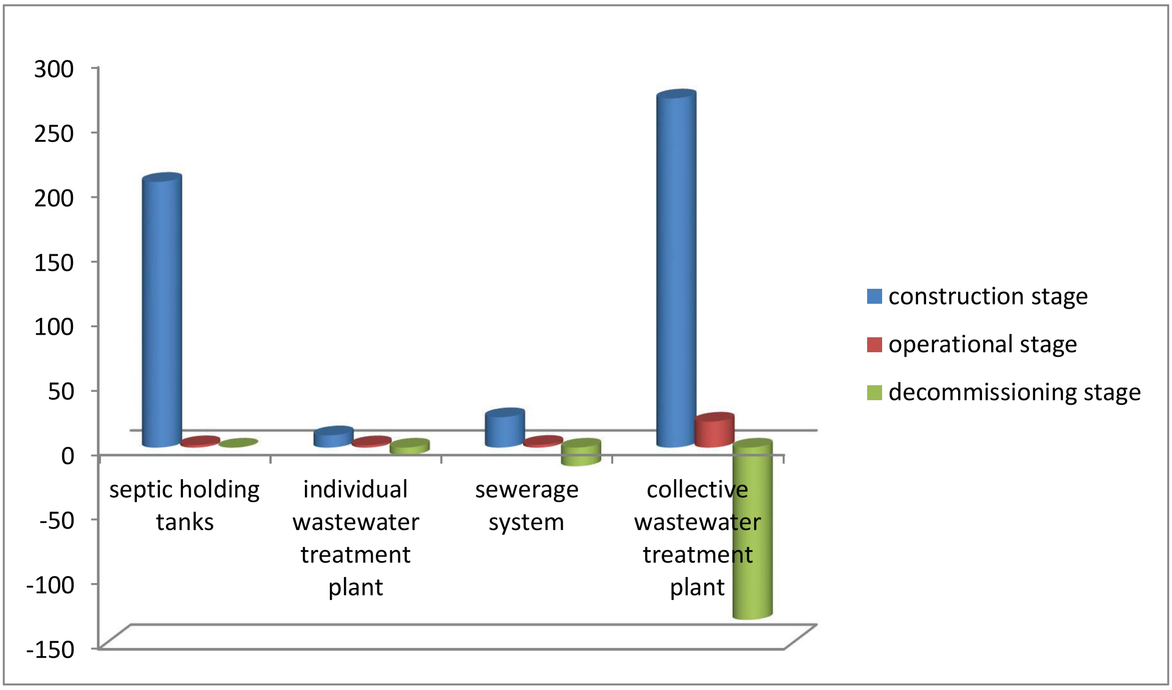

Figure 1 Cumulative metal consumption of wastewater treatment system

The analysis shows that 1 RLM within life cycle of the system consumes metals in the amount of 194.07 kg Fe 3q (for the users of septic holding tanks), or 168.34 kg Fe eq (for the users of both, sewerage system and collective wastewater systems), or 5.38 kg Fe eq (users of individual wastewater treatment plant) in the life cycle of the system. Metals consumed in the system life cycle (see **Figure 2**) are determined by the analysis of the types of metals consumed by the various components of the collection, transport and wastewater treatment system. In the case of septic holding tanks, the usage of metal in the life cycle of the system includes primarily four metals: manganese, iron, nickel and chromium. In the collective life cycle of the wastewater treatment plant, copper and chromium are consumed in the greatest amounts. On the other hand, in the life cycle of the sewerage system and individual wastewater treatment plants, the highest amounts of iron are used.

Septic holding tanks contribute the most to metal consumption, including 205.69 kg Fe eq/FU at the construction stage, 1.88 kg Fe eq/FU at the operational stage, while at the decommissioning stage metal consumption indicator is -13.50 Kg Fe eq/FU. The value of the metal consumption indicator at the construction stage is determined primarily by the amount of steel used to reinforce the tank structures (90 %). The assessment of life cycle of decommissioning stage of septic holding tanks has shown that environmental benefits are connected with this stage through recycling of metals (reinforcing steel, stainless steel, cast iron, copper and aluminum) in the amount of -128.8 kg Fe eq/FU, recycling of concrete and aggregates in the amount of -4.37 kg Fe eq/FU, significantly outweigh the amount of metal consumption or through earthworks and storage of bituminous materials and plastics.

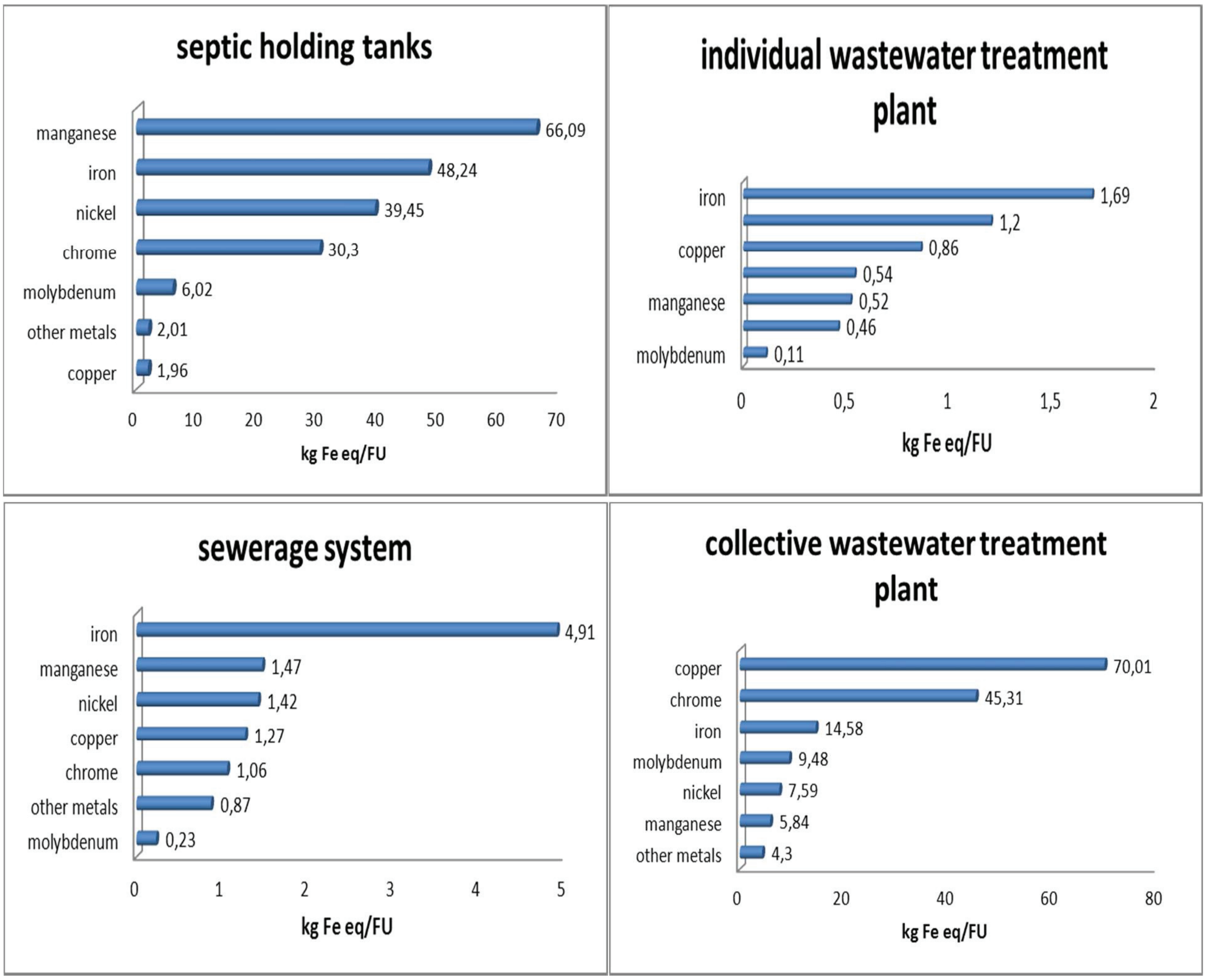

Figure 2 Comparison of metals used in system components throughout the whole life cycle

Based on the life cycle analysis of collective wastewater treatment plant, it has been shown that it contributes to the consumption of metals in the amount of 157.11 kg Fe eq/FU, including 270.14 kg Fe eq/FU at the construction stage, and 20.07 kg Fe eq/FU at the operational stage, while at the decommissioning stage the indicator of metal consumption associated with their recycling is -133.11 kg Fe eq/FU. The value of metal consumption indicator at the construction stage is determined mainly by the amount of used: reinforcing steel (47 %) used in construction of buildings, copper (27 %), stainless steel (22 %) used in plant equipment (e.g. pumps) as well as concrete (3 %).

The sewerage system contributes to the consumption of metals in the amount of 11.23 kg Fe eq/FU, including 23.49 kg Fe eq/FU at the stage of construction, 2.16 kg Fe eq/FU at the operational stage, while at the stage of decommissioning, metal consumption indicator is -14.42 kg Fe eq/FU. The value of metal consumption indicator at the construction stage is determined primarily by the amount of: cast iron (58 %), asphalt (18.00 %) and steel used for the needs of intermediate wastewater pumping stations. The other factors constitute 14 %. The environmental assessment of sewerage system operational stage has shown that the value of metal consumption indicator is determined by the size and frequency of reclamation of the sewerage system (69 %) and the amount and type of the electricity consumed (30 %). Relatively high share of energy in metal consumption as part of operational stage of sewerage system can be attributed to the large number of intermediate wastewater pumping stations in the system and covering 100 % of electricity demand from the power network. The life cycle assessment of the sewerage system showed that the decommissioning stage has environmental benefits in the amount of 14.42 kg Fe eq/FU resulting from the recycling of galvanized steel, copper, cast iron and stainless steel.

Individual wastewater treatment plants contribute to the consumption of metals in the amount of 5.38 kg Fe eq/FU, including 9.47 kg Fe eq/FU at the construction stage, 1.79 kg Fe eq/FU at the operational stage, while at the stage of decommissioning, metal consumption indicator is -5.88 kg Fe eq/FU. The value of the metal consumption indicator at the construction stage is determined primarily by the amount of used: stainless steel (about 27 %) and copper (14 %) in biological reactors and cast iron for manhole covers (22 %). It should be noted that the consumption of metals at the stage of construction of individual wastewater treatment plants is small.

Based on the carried out assessment of the life cycle of the system, it has been shown that the highest amount of metal is used for the construction of septic holding tanks and wastewater treatment plants for reinforcement structures, concrete and technological equipment of collective wastewater treatment plants. The smallest metal consumption is associated with individual wastewater treatment plants.

4. CONCLUSION

Based on the LCA analysis, the processes, raw materials and materials have been identified, which are characterized by the highest indicator of metal consumption in the life cycle of the wastewater management system. The highest consumption of metals (including manganese, iron, nickel and chromium) was found for the stage of construction of septic holding tanks. High metal consumption has also been demonstrated for the collective wastewater treatment plant. In the case of all the system components, it has been shown at the decommissioning stage that recycling is an environmental benefit for metal consumption, while earthworks are the factor of a negative impact.

In line with the principles of sustainable development and circular economy, efforts should be made to reduce the consumption of non-renewable resources, including the use of metals and fossil fuels. The first step in this direction is to assess the cumulative consumption of non-renewable natural resources. Based on the conducted analyses it has been proved that the LCA technique can aid decisions concerning the reduction of metal consumption in life cycle, which from a strategic point of view is an important approach to the problem of limited access to resources.

The paper presents a significant problem which is the depletion of metal resources as a result of their utilization, among others, in wastewater management systems. The identification of metals necessary in the system of collection, transportation and wastewater treatment as well as the assessment of these resources consumption is the basis for making decisions regarding the reduction of natural resources consumption in urban engineering. The use of life cycle assessment enables full identification and inventory of cumulative metal resources consumption. The paper points to the possibility of using the LCA as an appropriate tool for assessing metal consumption in wastewater management systems and shaping a resource-limited strategy taking into account the closed-loop paradigm.

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REFERENCES

[1] *EUROPA 2020 - A resource-efficient Europe - flagship initiative under the Europe 2020 Strategy*. European Commission, 2011.

[2] *ISO 14001:2015 Environmental management systems - Requirements with guidance for use*. International Organization for Standardization, 2015.

[3] SANIUK, S., SANIUK, A., LENORT, R., SAMOLEJOVÁ, A. Formation and planning of virtual production networks (VPN) in metallurgical clusters. *Metalurgija*, 2014, vol. 53, no. 4, pp. 725-727.

[4] PUSTĚJOVSKÁ, P., JURSOVÁ, S. Measure to Reduce CO_2 Emissions in Metallurgy. In *METAL 2011: 20th International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2011.

[5] BURCHART-KOROL, D. Sustainability and eco-efficiency assessment of biomass use in steelmaking. In *METAL 2013: 22nd International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2013.

[6] CZAPLICKA-KOLARZ, K., BURCHART-KOROL, D., KOROL, J. Application of life cycle assessment and exergy to environmental evaluation of selected polymers. *Polimery*, no. 7-8, pp. 605-609.

[7] GOEDKOOP, M., HEIJUNGS, R., HUIJBREGTS, M., DE SCHRYVER, A., STRUIJS, J., VAN ZELM, R. *ReCiPe 2008 A life cycle impact assessment method with comprises harmonised category indicators at the midpoint and the endpoint level*. Ruimte en Milieu, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, 2013.

[8] ZDEBIK, D., ZAWARTKA, P. Wpływ dowożonych osadów na prace oczyszczalni. In *VII Międzynarodowa Konferencja Naukowo-Techniczna, Przedsiębiorstwa wodociągowo-kanalizacyjne - wczoraj, dziś i jutro, Materiały konferencyjne*, 2015, pp. 307-320.

[9] *ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework*. International Organization for Standardization, 2006.

[10] *Dyrektywa Rady 91/271/EWG z dnia 21 maja 1991 r. dotycząca oczyszczania ścieków komunalnych*. EUR-Lex, 1991. Available from: http://eur-lex.europa.eu, Available at: 24-03-2017.

[11] *Ustawa Prawo wodne z dnia 18 lipca 2001, Tekst jednolity Dz.U. 2015 nr 0 poz. 469 z późn. zm.* Available from: http://isap.sejm.gov.pl, Available at: 24-03-2017.

[12] ZAWARTKA, P. *Determinants of the environmental life cycle assessment for the system of collection, transport and wastewater treatment.* PhD Thesis. Katowice: Central Mining Institute, 2017.