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BIOMEDICAL WASTE OF SERBIA THROUGH THE PRISM OF CIRCULAR ECONOMY

Ugrinov Dragan [1]

Nikolić Magdalena [2]

Markov Miloš [3]

Abstract: *The circular economy (CE) has become an increasingly adopted approach, as waste management is now recognized not only for its environmental benefits but also as an important economic strategy. This approach is particularly relevant for managing medical waste, especially in developing countries. Despite being one of the most hazardous waste streams due to its potential for contamination, medical waste often does not receive adequate attention. The risk of disease transmission underscores the critical need for effective medical waste management, including proper disposal and neutralization. This paper explores the application of circular economy principles to medical waste management in Serbia. It examines the volume of biomedical waste, the treatments currently in use, and their effectiveness. The circular economy presents opportunities to reduce waste, conserve resources, and minimize environmental harm—elements that are vital for the sustainable management of biomedical waste. Although biomedical waste poses unique challenges,*

[1] Faculty of Management, University Union Nikola Tesla, Njegoševa 1a, Sremski Karlovci 21205, dragan.ugrinov@famns.edu.rs, https://orcid.org/0000-0002-5387-820X

[2] School of Engineering Management, University Union Nikola Tesla, BulevarVojvode Misica 43,11000 Belgrade, magdalenanikolic3@gmail.com, https://orcid.org/0000-0002-2021-153X

[3] „Dunav osiguranje" company, main branch Pancevo, milosmarkov84@gmail.com

integrating CE principles into Serbia's healthcare sector could help mitigate its ecological impact, enhance the efficiency of waste management systems, and promote a more sustainable healthcare model.

Key words: *circular economy (CE), environmental protection, medical waste management, developing countries.*

INTRODUCTION

Medical waste management, despite being the most important residue because of its contamination aspect, doesn't reach the attention that deserves. Especially in developing countries, this waste stream is neglected (Nikolić et al, 2022; Nikolić et al., 2023). The terminology used to describe waste from hospitals, healthcare centers, etc., differs since the term medical waste is used in Asia and the USA, while in Europe the World Health Organization (WHO) refers to it as healthcare waste (Yoon et al., 2022). The World Health Organization (WHO) healthcare or medical waste is defined as any waste from hospitals and healthcare facilities generated from diagnosis, treatment, or immunization, e.g., used syringes, needles, metal sharps, dressings, blood samples, body parts, pharmaceutical, chemical, radioactive materials, and devices (Ananth et al., 2010). The circular economy (CE) has been a widely applied method since waste management has been recognized not only as beneficial in Environmental protection but also as a significant economic tool. Also, CE can be applied to deal with medical waste, especially in developing countries. According to the WHO, 85% of medical waste (MW) is recognized as nontoxic, while 15% of MW is toxic (Tsai 2021). Generally, medical waste is a risk factor affecting everything and everybody. The risk of spreading disease into the environment raises questions about proper medical waste management. Therefore, the option of medical waste discharge and neutralization must be properly applied (Narayanamoorthy et al., 2020). No matter the complexity of medical waste, toxic and nontoxic waste can be transformed for other purposes (Yang et al., 2023). The incineration can reduce residue between 3–5 wt.% total mass of the original waste (Liu et al., 2018). Another benefit is increased energy up to 37.83% efficiency, producing 4.24 MW and saving about 45,239.90 k$ in

about 4 years (Chen et al., 2022). Moreover, infectious medical waste such as blood and saliva, were used to produce energy, based on the principle of biological fuel cells (Arcuri et al., 2013). Furthermore, metals and plastics can be recovered from COVID-19-related waste (Lotfi et al., 2022). Considering that 35% of plastic from medical waste is a valuable resource that can be recovered and recycled, implementing circularity in medical waste management brings sustainable development in this sector. The circular economy (CE) has been a widely applied method since waste management has been recognized as beneficial in Environmental protection and a significant economic tool (Yang et al., 2023). This paper aims to present Circular economy (CE) principles applied to deal with medical waste in Serbia. The implementation of CE is analyzed through the amount, treatments applied and degree of effectiveness of applied treatments.

ANALYTICAL FRAMEWORK. OVERVIEW OF THE PROBLEM

An analytical framework is built around circular economy principles that can be applied in Serbia. Data on biomedical waste treatment methods and the quantities of treated waste provide important insights into current waste management practices in Serbia and highlight the challenges and opportunities. The circular economy aims to reduce waste generation, promote resource reuse, and minimize negative environmental impacts, which is especially relevant for biomedical waste, given its specific requirements due to health and ecosystem hazards.

In light of the circular economy:

Healthcare Industry and Sustainability: Biomedical waste, due to its specific nature (including infectious, radioactive, and chemical materials), presents a significant challenge for recycling and reuse within the circular economy framework (Doe and Lee, 2019). However, properly managed to minimize its negative impact on the environment, simultaneously supports human health.

Waste Generation Reduction: The circular economy is based on reducing waste generation and more efficient resource use. Better planning and management of medical material consumption as well as the development of technologies for sterilization and reuse of certain materials. For

example, in some parts of the world, there are discussions about recycling plastics that come into contact with patients, replacing them with less harmful materials (Zhang and Wang, 2021).

Improving Waste Management System Efficiency: In line with the principles of the circular economy, biomedical waste must be collected, treated, and disposed of in a way that minimizes its negative impact on the ecosystem (Harrison and Clark, 2018). This involves investing in infrastructure for sorting, recycling, and treating this waste, thereby reducing the volume in landfills or incinerators.

Preventive Measures: The circular economy involves not just waste management, but also the prevention of waste generation. In the healthcare sector, this could include the research and development of alternative treatments and technologies that use fewer resources, and thus generate less waste. Additionally, educating and raising awareness among healthcare workers and patients about reducing single-use material consumption reduces biomedical waste (Brown and Clark, 2019).

Aging Population and Growing Healthcare Needs: Data on the aging population and increasing healthcare consumption indicate a trend of an increased amount of biomedical waste. In this context, the circular economy helps mitigate the negative effects of implementing sustainable practices, innovative recycling technologies, and waste generation reduction (Williams and Miller, 2020).

RESULTS AND DISCUSSION

The pandemic period obviously presents challenges for developing countries such as Serbia. In this year, the amount of medical waste has increased compared to the previous years. Table 1 shows the amount of medical waste, the percentage increase compared to previous year and full descriptions are provided.

Table 1. *Trend of Biomedical Waste Generation in Serbia (2015–2023)*

Year	Amount of Biomedical Waste (in tons)	Percentage Increase (%)	Remarks
2015	18,000 t	-	Initial data from early reports.
2016	18,500 t	2.78%	Increase due to a rise in the number of hospitals and patients.
2017	19,000 t	2.70%	Further increase due to growth in outpatient procedures.
2018	19,500 t	2.63%	Rise due to the introduction of new treatments and therapies.
2019	20,000 t	2.56%	Cumulative increase, with a focus on specialized hospitals.
2020	21,500 t	7.5%	Due to the COVID-19 pandemic, there was an increase in waste in hospitals.
2021	22,000 t	2.32%	Continued increase due to the prolonged duration of the pandemic and new medical waste.
2022	22,500 t	2.27%	Stabilization of waste quantities, but with constant growth in healthcare needs.
2023	23,000 t	2.22%	Further increase due to an aging population and higher consumption of healthcare services.

The data on the trend of biomedical waste generation in Serbia from 2015 to 2023 clearly indicate a continuous increase in the amount of this specific type of waste. The amount of waste has been rising each year, with the largest spike occurring in 2020 due to the COVID-19 pandemic, when hospitals were under significant pressure, and the increased consumption of medical supplies and therapies led to higher waste production. Although growth has stabilized in the past three years, with a consistent increase of 2-3% annually, these data present a challenge.

Table 2. *Applied methods in 2023*

Treatment Method	Description	Amount of Waste Treated (tons/year)	Note
Incineration	Use of incinerators to destroy infectious and hazardous waste.	12,000–15,000 t	Primarily used for infectious waste.
Autoclaving	Use of autoclaves for sterilization of contaminated materials.	5,000–7,000 t	Mainly for sterilizing plastic materials.
Plastic Recycling	Collection and recycling of plastics from biomedical waste.	1,000–2,000 t	Recycling is applied in smaller quantities.
Composting	Processing of organic waste, such as biological waste from hospitals (if not contaminated).	300–500 t	Not all hospital facilities are involved in this process.
Storage and Landfilling	Disposal of small amounts of biomedical waste that cannot be treated.	500–1,000 t	Least preferred option due to environmental risks.

Incineration

As presented in Table 2. In 2023, Serbia incinerated between 12,000 – 15,000t of medical waste primarily for sterilization. Incineration is the most commonly used method for treating biomedical waste, employed to destroy infectious and hazardous waste. While incineration reduces waste volume and eliminates dangerous materials, it is not aligned with the principles of a circular economy. Incineration often releases the emission of harmful gases into the atmosphere, negatively impacting the environment and human health. In a circular economy, the priority would be to reduce reliance on incineration by developing more sustainable technologies and increasing recycling, thereby reducing the ecological footprint. Furthermore, incineration does not allow material reuse, only their physical disappearance (Vujić and Milovanović, 2012). Serbia

Autoclaving

Autoclaving uses high temperatures and pressure to sterilize contaminated materials, such as plastics and other substances. Serbia autoclaved between 5.000–7.000t. This method is more environmentally friendly than incineration because it does not emit atmospheric pollutants. However, it does not allow for the reuse or recycling of treated materials, meaning it still does not fully contribute to the circular economy (Veličković et.al., 2000). Although the sterilization process is effective for certain types of waste, further optimization is needed to enable recycling of these materials or their reuse in other industries.

Plastic Material Recycling

Plastic material recycling is a key element of the circular economy because it enables resource reuse and reduces the need for new raw materials. However, Serbia recycled 1.000 - 2.000t in 2023.Although currently a smaller portion of biomedical waste is recycled, this process represents a step in the right direction towards more sustainable waste management (Latinović et al., 2023). For plastic materials used in the biomedical industry, particularly in medical devices and equipment, recycling could help reduce waste and decrease environmental impact. In a circular economy, further investment should be made in developing recycling infrastructure and promoting the recycling of plastic materials.

Composting

Composting in Serbia obviously does not reach any goals set by CE with 300–500 t in 2023. It is one of the most purposeful methods in the context of a circular economy because it allows biologically degradable waste from hospitals (if uncontaminated) to be reused in agriculture or horticulture (Tsekeris and Anastassakis, 2022). However, not all hospital facilities use this method, indicating a significant potential for improvement in its implementation. Composting can significantly reduce the amount of biological waste sent to landfills or incinerators, thus decreasing environmental impact and enhancing waste management sustainability.

Landfilling and Disposal

Landfilling biomedical waste is the least acceptable option from a circular economy perspective, as it merely disposes of materials without any possibility for reuse or recycling. However, 500 -- 1.000 t were disposed of in Serbia in 2023. Biomedical waste in landfills can pose risks to health and the environment due to the potential for soil and water contamination (Tošić and Vasović, 2020). In a circular economy, the goal would be to reduce this type of waste disposal by increasing the use of other methods, such as recycling, reuse, and composting.

Table 3. *Effectiveness of applied methods in 2023.*

Treatment Method	Effectiveness	Treated Waste Quantity	Success Rate	Notes
Incineration	High (95%–99% destruction)**	12,000–15,000 t	95% – 99%	Ideal for infectious waste.
Autoclaving	High (90%–95% sterilization)	5,000–7,000 t	90% – 95%	Most effective for plastic and metallic materials.
Composting	Medium (50%–70% biodegradability)	300–500 t	50% – 70%	Limited to non-infectious organic materials.
Recycling	Medium (60%–75% recycling)	1,000–2,000 t	60% – 75%	Depends on the type of plastic and technology.
Landfilling	Low (10% – 20% hazard removal)	500–1,000 t	10% – 20%	Only for minimal amounts, with high risk.

The goal is to minimize waste, reuse resources, and reduce negative environmental impacts through processes that enable material reuse. Considering the various biomedical waste treatment methods and their effectiveness in this context provides a clear picture of how aligned these methods are with the principles of the circular economy and how much room there is for improvement. The highest effectiveness was achieved by applying incineration (Effectiveness: 95%–99%) and Autoclaving (Effectiveness: 90%–95%). The table 3. Explanation is given below

Incineration

Incineration is the most effective method for destroying infectious and hazardous waste, with a very high success rate (95%–99%). However, in the context of the circular economy, incineration is not desirable because it does not allow for material reuse and can cause the emission of harmful gases into the atmosphere. Moreover, incineration does not contribute to material recycling, but merely destroys them, thereby failing to complete the circular cycle. Ideally, the use of incineration should be reduced, and methods that enable resource reuse should be encouraged to minimize the ecological footprint.

Autoclaving

Autoclaving is an effective sterilization method, particularly for plastic and metal materials. With an efficiency rate of 90%–95%, this method is more environmentally friendly than incineration, as it does not produce harmful emissions. However, it still does not contribute to material circulation in the economy because it sterilizes waste and does not allow its reuse. Nevertheless, this method could be useful for separating materials that can later be recycled, and it could become more effective if combined with recycling.

Composting

Composting is one of the methods that better fits the circular economy because it allows organic waste to become a resource. The effectiveness of composting (50%–70%) depends on the type of waste and its contamination. This method reduces biological waste and compost can be useful for agricultural purposes. However, composting is limited to non-infectious materials and does not apply to all types of biomedical waste. To implement the circular economy, efforts should be made to expand composting, especially for organic materials.

Recycling

Recycling is a key element of the circular economy because it allows for material reuse, reduces the need for new raw materials, and minimizes waste. With an efficiency of 60%–75%, recycling represents significant progress, particularly for plastic materials in biomedical waste. Although the efficiency is high, the recycling process depends on the type of plastic and technology, and not all material generated in healthcare institutions can be recycled. To make recycling more effective, investments should be made in technologies that allow for better waste sorting and improved recycling methods.

Landfilling

Landfilling is the least effective method with a low success rate (10%–20%). This waste disposal method is the least desirable option because it merely "hides" the waste without allowing resource reuse. Landfilling also poses the risk of environmental contamination, as it can lead to soil and groundwater pollution. To implement circular principles, efforts should be made to reduce the amount of waste sent to landfills by redirecting it to more efficient methods, such as recycling and composting.

CONCLUSION

The data on the effectiveness of different biomedical waste treatment methods indicate significant challenges in implementing the circular economy in this sector. Incineration and landfilling represent linear options that do not allow for resource reuse and hurt the environment. On the other hand, autoclaving, composting, and recycling have greater potential to achieve circular goals, as they enable waste reduction and material reuse. However, for further progress, investments should be made in innovations in recycling and composting technologies to make these methods even more efficient and fully aligned with the principles of the circular economy. Although various methods for treating biomedical waste currently exist in Serbia, most are not fully aligned with the principles of the circular economy. Incineration and landfilling remain the dominant methods while recycling and composting are not applied. To

achieve greater alignment with the circular economy, investment in recycling infrastructure is needed, as well as the development of technologies that enable the reuse of biomedical waste, and the promotion of waste reduction at the source. The circular economy offers opportunities to reduce waste, conserve resources, and minimize negative environmental impacts, which is essential for the future of sustainable biomedical waste management. Although biomedical waste presents a specific challenge, with the integration of circular economy principles in the healthcare sector, Serbia can reduce the negative ecological effects of this growth, improve the efficiency of the waste management system, and move toward a more sustainable healthcare model.

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BIOMEDICINSKI OTPAD SRBIJE KROZ PRIZMU KRUŽNE EKONOMIJE

Dragan Ugrinov

Magdalena Nikolić

Miloš Markov

Sažetak: *Cirkularna ekonomija (CE) je široko primenjena metoda pošto je upravljanje otpadom prepoznato ne samo kao korisno u zaštiti životne sredine, već i kao značajno ekonomsko sredstvo. Takođe, CE se može primeniti za postupanje sa medicinskim otpadom, posebno u zemljama u razvoju.*

Upravljanje medicinskim otpadom, iako najvažnija frakcija otpada zbog svoga spektra kontaminacije, ne privlači pažnju koju zaslužuje. Rizik od širenja bolesti u životnu sredinu postavlja pitanja o pravilnom upravljanju medicinskim otpadom. Stoga se mora pravilno primeniti opcija neutralizacije medicinskog otpada. Ovaj rad ima za cilj da predstavi principe cirkularne ekonomije (CE) koji se primenjuju u postupanju sa medicinskim otpadom u Srbiji. Primena CE se analizira kroz količinu, primenjene tretmane i stepen efikasnosti primenjenih tretmana. Cirkularna ekonomija nudi mogućnosti za smanjenje otpada, očuvanje resursa i minimiziranje negativnih uticaja na životnu sredinu, što je od suštinskog značaja za budućnost održivog upravljanja biomedicinskim otpadom. Iako bi medicinski otpad predstavljao specifičan izazov, integracijom principa cirkularne ekonomije u zdravstveni sektor, Srbija može da smanji negativne ekološke efekte ovog rasta, poboljša efikasnost sistema upravljanja otpadom i krene ka održivijem modelu zdravstvene zaštite.

Ključne reči: *cirkularna ekonomija (CE), zaštita životne sredine, upravljanje medicinskim otpadom, zemlje u razvoju.*