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Opportunities for sustainable waste management in the pharmaceutical industry

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Abstract

The pharmaceutical industry significantly impacts the environment through its activities, primarily by generating pharmaceutical waste. Pharmaceutical products can be released into aquatic environments at every stage of their life cycle: from production, through use, to disposal. The majority of pharmaceutical products discharged into the environment, particularly into wastewater, originates from patient excretions. This paper, after defining and classifying waste, outlines the legal regulations as well as the possibilities for sustainable management of pharmaceutical waste.

The modern concept of pharmaceutical waste management aims to ensure that the pharmaceutical industry remains successful while becoming sustainable. Sustainable development and waste management are directly linked to the circular economy. Sustainable pharmaceutical waste management encompasses reduction, reuse, recycling, energy recovery, and disposal. These activities should be carried out by manufacturers, prescribers, distributors, pharmacists, and consumers. The waste management hierarchy represents a widely accepted and recommended order of priority actions, with waste prevention (reducing waste generation) being the most desirable option, followed by reuse, recycling, recovery, and finally disposal, which is the least desirable activity in waste management.

Positive changes in the sustainability of the pharmaceutical industry cannot be achieved without active collaboration involving pharmaceutical companies, academia, and policymakers.

The scientific community should intensively explore possibilities for sustainable pharmaceutical waste management. Harmonizing regulations across different countries is essential, and pharmacists in community pharmacies should work to raise public awareness about pharmaceutical waste.

Key words: pharmaceutical waste, sustainability, waste management hierarchy, hazardous waste

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Introduction

The pharmaceutical industry positively impacts people's lives daily, contributing to the improvement of health and quality of life for individuals. It is responsible for the research, development, production, and marketing of pharmaceutical products used in the prevention, diagnosis, and treatment of diseases, vaccines, and treatments for common and rare diseases.

There has been an increased demand for pharmaceutical products, which is expected to continue growing due to the aging global population, increasing life expectancy, and advances in healthcare delivery (1).

Due to the growing need for pharmaceutical products, pharmaceutical companies introduce new drugs to the market each year, in addition to a large number of existing pharmaceutical products (2).

Alongside numerous positive effects on human health, the pharmaceutical industry also significantly impacts the environment through its activities, primarily the creation of pharmaceutical waste (3).

Pharmaceutical products enter the environment through production, improper disposal, as well as patient use and excretion. It is estimated that the largest portion of pharmaceutical products released into the environment, particularly into wastewater, comes through patient excretion (4).

Besides sewage, pharmaceutical waste can enter the environment through wastewater discharge and leakage from landfills. Veterinary medicines, which enter the environment in various, mostly uncontrolled ways, should also be mentioned here. Through food, used veterinary therapeutics and supplements enter the soil or surface waters without prior treatment, as their excretions usually do not enter sewage systems with purification mechanisms (5).

Pharmaceutical products can be emitted into the aquatic environment at every stage of their life cycle: from production, through use, to disposal. Previously, it was believed that pollution from pharmaceutical production was insignificant. The pharmaceutical industry also claimed that significant release of active pharmaceutical ingredients (APIs) was unlikely for purely economic reasons, due to the high cost of drugs, which proved to be incorrect. The concentrations of pharmaceutical products excreted by humans are limited, as only a portion of the population uses defined doses. Unused drugs that become waste present an even bigger problem, as their concentration is not reduced by metabolism (6).

Residues of APIs, their metabolites, and transformation products (TP) resulting from incomplete degradation during usual wastewater treatment processes and after their release into the environment (based on review 2) represent one of the main causes of water contamination due to their continuous input into the aquatic ecosystem, including sewage flows, surface and groundwater, and their persistent presence, even in low concentrations. Although present in low concentrations, many of these molecules pose a significant hazard (based on review 2), especially as they are present as complex mixtures (7).

The presence of APIs in the aquatic environment is increasingly considered one of the main challenges for sustainable water resource management worldwide due to costly and insufficiently effective wastewater treatment measures.

The most commonly applied pharmaceutical waste management model involves proper collection, sorting, disposal, and destruction, usually by incineration. Additionally, primary consideration has been given to improving water treatment processes before they flow into sewage streams. It turned out that these processes have specific limitations and drawbacks (8).

The incineration process, which is the most recommended and used method for destroying pharmaceutical waste, is not sufficiently efficient, as it carries the risk of creating toxic compounds (9).

The newer concept of pharmaceutical waste management aims for the industry, one of the most important branches of the global economy, to remain successful, but also to become sustainable. Sustainable development is conceived as a harmonious relationship between ecology and the economy. In the process of protecting and preserving the environment today, besides specific environmental sectors, the burden and responsibility are equally shared by all social entities, such as central (republic) administrations, local governments (provinces, regions), industries, and citizens themselves (3).

Our regulation deals with pharmaceutical waste from collection to disposal, while sustainable waste management, in general, involves a series of measures and activities aimed at minimizing waste disposal or treatment by incineration (10).

Pharmaceutical waste management is a set of measures that include collection, sorting, packaging, labeling, storage, transportation, and treatment of waste to ensure its safe disposal for human, animal, and environmental health (11).

There is significant room for reducing waste generation, which would include the rationalization of production, prescribing, and use. The World Health Organization (WHO) estimates that more than half of drugs are used irrationally: at the levels of prescribing, dispensing, or sale and use. Over half of all drugs are prescribed, sold, or dispensed inappropriately, and nearly half of all patients worldwide do not take their medications correctly. All these practices are the leading cause of wastage (12).

The aim of the work was to present the European and national regulations in the management of pharmaceutical waste, as well as some of the possibilities for sustainable treatment of pharmaceutical waste with all its specific characteristics.

For this purpose, the paper, after defining and classifying waste, lists the legal regulations, as well as possibilities for sustainable pharmaceutical waste management.

Pharmaceutical waste – definition and classification

According to the Rulebook on Medical Waste Management (13), pharmaceutical waste is a type of medical waste that includes all medications, including their primary packaging and all accessories used for their application, found with legal entities or entrepreneurs engaged in healthcare activities for humans and animals. This waste becomes

unusable due to expiration, quality defects, contaminated packaging, spillage, unused prepared medications, those returned by end-users, or those unusable for other reasons, as well as pharmaceutical waste from the production, wholesale and retail of drugs, and preparation of galenic or magistral medicines and other pharmaceutical waste (14).

Pharmaceutical waste can be:

- Non-hazardous pharmaceutical waste, which does not pose a danger to the environment and human health, and is not treated according to procedures prescribed for hazardous pharmaceutical waste management;
- Hazardous pharmaceutical waste, originating from drugs and disinfectants containing heavy metals, drugs of known and unknown composition, and drugs whose composition cannot be determined, as well as cytotoxic and cytostatic waste (13).

Pharmaceutical waste can be solid, semi-solid, or liquid. Solid (e.g., tablets, capsules, powders) and semi-solid (e.g., ointments, creams) pharmaceutical products are managed by incineration/pyrolysis, encapsulation, and engineered landfills, while wastewater treatment plants are recommended for liquid pharmaceutical waste. However, to date, the sustainability and environmental acceptability profiles of these techniques have been only subjectively ensured, leading to controversial views in many guidelines (15).

Legal provisions in Europe and Republic of Serbia

In EU, there are two main directives:

- Directive 2008/98/EC: This directive defines the basic concepts and principles related to waste management, including pharmaceutical waste. It encourages the application of the waste hierarchy, which prefers prevention, reuse, recycling, and other forms of recovery over disposal.
- Directive 2004/27/EC: This directive, which amends Directive 2001/83/EC, regulates the disposal of pharmaceutical products that have become waste. The goal is to ensure the proper collection and destruction of unused or expired medications.

Analyzing international environmental laws and non-legally binding instruments and initiatives from an environmental perspective, it can be concluded that pharmaceutical products are poorly regulated. Countries that produce pharmaceuticals often pass on the environmental burden of pharmaceutical pollution to consumer countries, driven by the latter's excessive consumption. The GMP (Good Manufacturing Practice) guidelines do not have specific requirements for the disposal of pharmaceutical waste, but they provide provisions related to the quality assurance system. Basic quality control requirements include ensuring that adequate facilities, trained personnel and approved procedures are available to monitor environmental conditions (16). Article 8c of Directive 2008/105/EC (amended by Directive 2013/39/EU) obliges the European Commission to develop a strategic approach to water pollution from pharmaceutical substances (17).

The management of pharmaceutical waste is regulated by a large number of national and international regulations and standards. The most important national regulations are (18):

- Law on Waste Management (19)
- Ordinance on the Method and Procedure for Handling Pharmaceutical Waste
- Law on Environmental Protection (20)
- Program for Waste Management in the Republic of Serbia for the period 2022–2031.

According to these regulations, the holder of pharmaceutical waste is obliged to:

- Prepare a waste management plan in accordance with Article 15 of the Law on Waste Management and organize its implementation if more than 100 tons of non-hazardous waste or more than 200 kg of hazardous waste is generated annually.
- Prepare a report on waste analysis (characterization) and renew it in the event of technological changes, changes in the origin of raw materials or other activities that affect the change in the nature of the waste, and keep the report for at least five years.
- Ensure the application of the waste management hierarchy principle for pharmaceutical waste.
- Store pharmaceutical waste in such a way that it does not adversely affect human health, as well as create the environment and conditions to prevent mixing of different types of waste or mixing with water.
- Hand over pharmaceutical waste to a person authorized to dispose of waste if they are unable to organize waste disposal in accordance with this Act.
- Keep records of waste generated, transferred or disposed of.
- Designate a person responsible for waste disposal (14).

Sustainable management

Industrial production has been linked to the use of natural resources practically from its beginnings to the present day. These are non-renewable resources, so questions arise as to how long this can continue. Apart from the negative economic aspects, such a concept is also destructive for the environment.

The so-called linear economy thus becomes one of the main causes of environmental pollution. In contrast to the linear economy, the concept of the circular economy has developed in recent decades. In the circular economy, the green economy or the ecological economy, as it is also known, the basic idea is to recycle waste materials or subject them to specific treatment and reintroduce them into the production process. Sustainable development and sustainable waste management are directly linked to the circular economy (21).

Despite the traditional linear model still being dominant, the circular economy is increasingly attracting attention, not only in literature, but also from major companies

such as Google, Unilever, Renault, etc. The reasons for this are financial, social, and environmental in nature. This concept is based on three principles: reduction, reuse, and recycling of materials. These principles represent a circular system through which materials are recycled, energy is obtained from renewable sources, renewed resources are used to create new value, leading to the restoration of ecosystems as a highly important effect (21).

Reuse and recycling, common for other types of waste, remain problematic for pharmaceutical waste, except for secondary packaging, patient information leaflets and summaries of product characteristics (SmPC), if they have not been in contact with the medication. Although some research has shown that expired drugs can become a significant source of pharmaceutically active substances (examples from research studies are illustrative and, in the authors' opinion, very interesting), it is still not economically viable.

The goal of sustainable waste management is to use resources for as long as possible and to minimize the amount of waste deposited in landfills or treated by incineration. In linear economies, waste is generated even before products are made and operates on the principle of take-make-dispose (10).

The difference between the concept of a linear economy and a circular economy is illustrated in Figure 1. The linear model is based on the principle of manufacturing products, distributing them, using them, and disposing of the used products as waste (left side). The circular economy, on the other hand, is the opposite of the linear economy and represents a model where products are produced, distributed, used, and disposed of in such a way that waste becomes a new resource through recycling and energy recovery (right side). The circular economy focuses on "circulating materials and reusing them," with minimal use of energy and water.

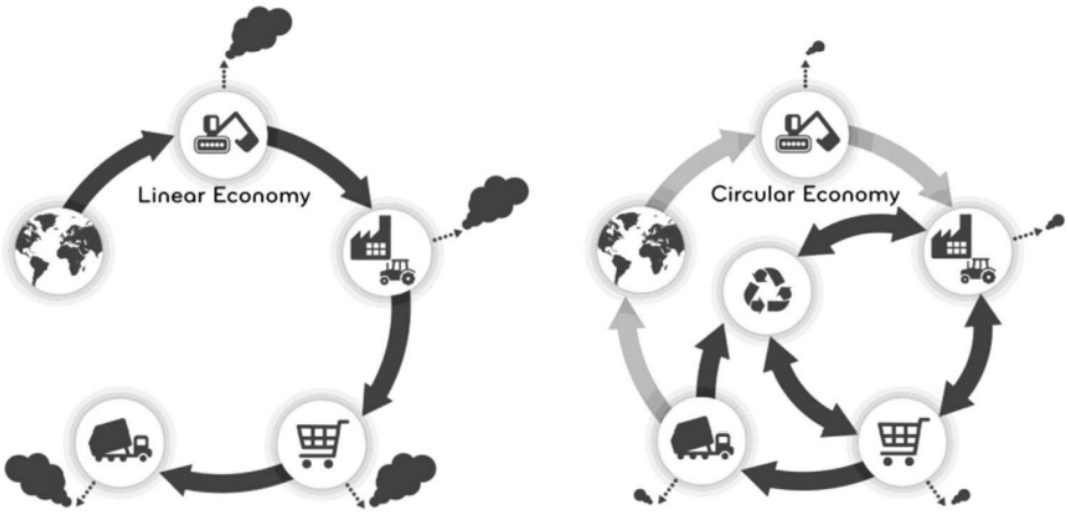

Figure 1. Difference between linear and circular economy (21)
Slika 1. Razlika između linearne i cirkularne ekonomije (21)

A large number of global companies favor this concept. In the most developed countries, through political activities, there is encouragement to transition to a circular economy. One of the weaknesses of this concept is the lack of universality in application, i.e., it is still not possible as a universally applied model (21).

Sustainable waste management helps address broader issues of linear consumption society and offers solutions to many problems caused by waste. If the hierarchy of sustainable waste management is not respected, all materials and goods are sent to landfills or incinerators instead of being reused (10).

Examples of sustainable waste management

While widespread adoption of the circular economy cannot happen overnight, some industries are making significant progress by adopting its initiatives and activities.

There are numerous positive examples from the automotive, fashion, furniture, and food industries.

Paper and cardboard products are the largest component of municipal solid waste. They are biodegradable, less harmful than plastic, and therefore environmentally friendly (22).

Recycling cardboard packaging helps reduce waste, save natural resources, and improve environmental quality, but the quality and properties of the obtained recycled paper materials should not be overlooked. Paper collection system is one of the most important prerequisites for quality paper recycling. Delivered paper must be free of impurities, moisture, etc., so as to produce top-quality recycled paper (23).

Secondary packaging of pharmaceutical products (made of cardboard), patient information leaflet and SmPC can only be recycled if collected in the prescribed manner.

Food waste is the second largest component of municipal solid waste and has significant social, environmental, and financial impacts (10).

Waste management hierarchy

The waste management hierarchy represents a widely accepted and recommended order of priority actions, ranking activities by their importance in waste management. The waste management hierarchy is depicted as an inverted pyramid, as shown in Figure 2, with waste prevention (reducing the amount of waste) being the most desirable option, followed by reuse, recycling (3R – Reduce, Reuse, Recycle), then regeneration, and finally disposal, which is the least desirable activity in waste management. The hierarchy promotes the conservation and sustainable use of non-renewable resources and encourages greater use of renewable resources.

Figure 2. Waste management hierarchy (24)
Slika 2. Hijerarhija otpada (24)

1. **Waste prevention and reduction** refer to the reduction of the amount of waste, the consumption of resources and the hazardous properties of waste. They represent the first and most important step in the hierarchy. It is achieved by using more modern production methods and by changing consumer habits (24). Single-use products should be avoided whenever possible, as they embody a linear economy. It is necessary to encourage the purchase of products that can be repaired and reused (10).
2. **Reuse,** i.e., the repeated use of products for the same or a different purpose. By reusing products, the life of the product is extended before it becomes waste, resulting in savings in money, energy and other resources.
3. **Waste recycling** is a process in which waste becomes a raw material for the production of the same or another product. It occupies a central place in the waste hierarchy. Recycling reduces the amount of waste that has to be disposed of in a landfill. This process requires money, energy and other resources, making it a less desirable option.
4. **Renewal or utilization** is any process by which a use for material or energy purposes is achieved. An example is the use of waste as fuel in the combustion process to generate electricity or heat.

5. **Waste disposal** represents the least desirable activity in the waste management hierarchy (next to incineration without energy recovery), as the material and energy values of the waste are permanently removed and is only carried out when there is no other suitable solution.

The National Waste Management Strategy – with a program for alignment with the European Union – was adopted by the Government of the Republic of Serbia on July 4, 2003. It is a fundamental document that ensures the conditions for rational and sustainable waste management at the level of the Republic (19).

In Serbia, the public has recognized waste management as a problem, although not as their own, but rather as a problem for which the state, local authorities and industry are responsible. The only method of waste management in Serbia is disposal in local landfills, most of which do not meet basic hygienic and technical-technological conditions (25).

Directive 2008/98/EC:

- Establishes the waste hierarchy,
- Confirms the "polluter pays" principle, where the original waste producer must pay the costs of waste management,
- Introduces the concept of "extended producer responsibility",
- Differentiates between waste and by-products,
- Introduces provisions related to environmental preservation, regulation of responsibility in waste disposal, special conditions for specific categories of waste, plans, and targets related to waste.

There is significant intra-European trade in waste, with Switzerland and Norway taking in much waste from the EU. Countries like Denmark, Sweden, and the Netherlands rely on waste imports to fuel their waste-to-energy plants.

Regarding municipal waste recycling, Germany leads with a rate of 67%, and only seven other countries have achieved the EU target rate of 50% (Slovenia, Austria, the Netherlands, Belgium, Switzerland, Denmark, and Italy). In contrast, countries such as Romania, Turkey, Malta, and Montenegro recycle less than 20% of municipal waste.

Although energy use of waste sounds like a sustainable way to handle waste and is part of the circular economy, it does not contribute much to energy production, nor is it very environmentally friendly, according to some reports.

In Spain, Portugal, Greece, and most Eastern European countries, landfilling remains the predominant form of waste treatment (26).

Ways to make waste management more sustainable

Primary waste separation is necessary because companies generate different types of waste. Therefore, in addition to standard waste garbage cans, separate bins should be provided for specific types of waste to ensure proper waste separation at source (10).

Reuse is a cheaper method compared to recycling. When something is no longer needed, it is advisable to donate it to increase sustainability. This could include old office

equipment, renovation materials, surplus food from shops/restaurants, and non-sales items from non-food stores. If waste is not controlled, it can have significant and damaging consequences (10).

In addition to the need to continue and deepen research on the impact of pharmaceutical waste on the environment, there are issues of legislation, and perhaps the biggest problem of raising people's awareness of the importance of proper handling of pharmaceutical waste (27).

Sustainable management of waste in the pharmaceutical industry

The circular economy and sustainable waste management as its central component do not have a universal model.

When the activities prescribed for sustainable waste management in general are applied, the sustainable management of pharmaceutical waste includes reduction, reuse, recycling, energy recovery and disposal. These activities should be carried out by manufacturers, prescribers, distributors, pharmacists and users (27).

Reduction involves rational management of stocks of raw materials, semi-finished products and finished products in the industry (in relation to production), and finished products in healthcare facilities (in relation to hospitals, health centers, pharmacies) (27).

Due to Good Manufacturing Practice (GMP) regulations, which are the basic standard in the manufacture of pharmaceutical products, and the often-high prices of active ingredients, their emissions to the environment during production are considered negligible. It is assumed that these emissions are low in Europe and North America. However, data from other parts of the world are not published, nor are the emissions of APIs during transportation and storage (28).

Thanks to advances in medicine and pharmacy, people's life expectancy is increasing. However, as we age, various bodily functions naturally decline, leading to the onset of chronic diseases. At the same time, people are increasingly turning to dietary supplements to improve their quality of life, or are being influenced by marketing. As a result, people are increasingly taking five or more medications at the same time, some of which are available over the counter, leading to polypharmacy (27).

The combination of different medications can lead to adverse effects (drug interactions), some of which can be serious and require hospitalization. There is evidence of a link between polypharmacy and an increased number of hospital admissions.

Due to the adverse effects of polypharmacy, treatment may be discontinued, leading to an accumulation of unused medication, which then constitutes pharmaceutical waste (27).

The beginning of the reduction of pharmaceutical waste can be sought in more intensive disease prevention. Educating healthcare professionals about prevention and the harmfulness of self-medication is one way to reduce the total amount of pharmaceutical waste. One way to reduce waste would be for manufacturers to extend the shelf life of certain medicines whenever possible and optimize packaging. Manufacturers should offer

a greater variety of pack sizes and avoid large packs, as inadequate packaging is sometimes the only reason for waste generation (22).

A mechanism for rational prescription and dispensing of medicines in the Republic of Serbia is facilitated by the electronic pharmacy. Active TTA (Therapeutic Time Availability) restrictions take into account the calculation of the history of filled prescriptions and prescribed dosages in the last 6 months; the services optimize the therapeutically necessary and sufficient amount of the drug for the duration of the prescribed chronic therapy (29).

The role of distributors is inventory management and appropriate storage of medicines. Physicians should prescribe prescription drugs rationally and critically. Rational prescribing, biodegradable drug prescribing, and personalized therapy are also mechanisms that can reduce drug wastage. Pharmacists can contribute through appropriate inventory management, improving drug preparation, optimizing dispensing processes, and redispensing unused medications (22, 30).

Although redispensing has the potential to reduce pharmaceutical waste, it is not yet a practice; moreover, it is prohibited in the Republic of Serbia. A pharmacist is not allowed to dispense medicines that were previously dispensed by patients and returned to the pharmacy. These medicines are considered pharmaceutical waste, and appropriate records are kept in accordance with certain standards (31).

The relevant government authorities can contribute to sustainability by enacting laws that lead to waste reduction through their implementation. Due to the multiple causes of pharmaceutical waste at all reuse levels of the pharmaceutical supply and use chain, a single measure is not sufficient (30).

Reuse: The pharmaceutical industry requires a lot of packaging and poses a challenge for sustainability. Pharmaceutical products are shipped worldwide, and they can be handled in an environmentally friendly way. One initiative for sustainable packaging management is the Reuse, Reduce and Recycle Initiative to reduce waste (32).

The pharmaceutical company Merck (Darmstadt, Germany) operates a closed-loop recycling system for the best types of solvents for preparative chromatography. They are supplied in steel containers that can be used several times. Customers return empty containers to Merck, where they are cleaned and refilled. There are currently around 32,000 containers in circulation in Europe. The return rate is around 90% (33).

Recycling: Studies have investigated methods for separating active ingredients from drugs for recycling. One of these was concerned with investigating the solid-liquid extraction process for obtaining a pure substance from expired paracetamol, tetracycline and ibuprofen preparations. The study investigated whether the highest purity of the active pharmaceutical ingredient (API) can be achieved by removing most of the excipients by using different solvents. With the optimal solvent composition, a very pure API can be efficiently extracted (58.7% for paracetamol, 73.1% for ibuprofen and 67.6% for tetracycline) (34).

One study focused on the extraction of ibuprofen from Brufen® tablets with expired shelf life by solid-liquid extraction using an ionic liquid solvent (tetrabutylammonium chloride with citrate buffer and deionized water). It was found that the extraction efficiency was 97.9% for ibuprofen with sufficient purity for reuse in drug manufacturing. However, the disadvantage of these methods of extracting active ingredients is the toxicity and volatility of the solvents used and the cost of recycling (35).

The recycling of active ingredients from expired drugs is possible, as studies have shown that they remain stable. In a study of paracetamol preparations, one of the most commonly used medicines from various forms and manufacturers with an expired shelf life, it was found that the paracetamol content does not change significantly over a period of time after the expiration date, which is important from the point of view of the generation of pharmaceutical waste. Although the use of expired drugs is prohibited, retesting such batches may be worth considering. This study also pointed to the prospect of developing new, more environmentally friendly methods of chemical degradation of various drugs to obtain useful reagents for organic synthesis and industrial production (36).

Theophylline showed a stability of about 90%, even 35 years after the expiration date. The investigation of a 35-year-old preparation followed an acute poisoning with the same substance. The case illustrates the long-term stability and pharmacological activity of some pharmaceutical products that can be used for recycling, which is a desirable activity in sustainable pharmaceutical waste management. In addition to sustainability, it can also be more economically viable (37).

Amantadine and rimantadine remained stable after 25 years of storage and retained their therapeutic effect even after heating to 85°C (38).

The greatest potential for recycling products from the pharmaceutical industry is seen in packaging recycling. For materials to be sustainable, they must be recyclable, compostable or biodegradable. Various materials, including glass packaging, that can be reused and recycled are being researched and developed. Sustainable solutions currently account for 10–25% of the pharmaceutical primary packaging market. This number is expected to grow as pharmaceutical companies continue to increase their efforts to protect the environment. Pharmaceutical companies should use sustainable materials, optimize transportation to limit greenhouse gas emissions and use new technologies to create so-called smart packaging (32).

By using materials such as PET, PE and glass, it is possible to reduce the amount of material used. Reusable and recyclable packaging is already widely used. New developments include biodegradable materials such as plastics and even packaging containing starch, gelatine and other edible materials. 3D printing can be used to produce packaging in a way that requires less energy and reduces waste (32).

The company Hemofarm (Vršac, Serbia) recycles waste generated during the production of infusion bottles made of low-density polyethylene in the packaging department. Bottle caps and closures for infusion bottles are made from recycled low-density polyethylene (39).

Energy recovery: Pyrolysis is one of the processes used in waste treatment. Pyrolysis is the thermal degradation of organic compounds in the absence of oxygen at very high temperatures. It has been proposed as an environmentally and economically sustainable treatment for pharmaceutical waste, as an alternative to incineration or disposal of pharmaceutical products, extraction of active ingredients and all other compounds. Low temperature pyrolysis was carried out using paracetamol immediate release tablets containing 500 milligrams of paracetamol; the liquid and gaseous products were analyzed by GC-MS (gas chromatography-mass spectrometry). The GC-MS results showed that the predominant component of the pyrolysis liquid was the active pharmaceutical ingredient (paracetamol). Other compounds detected were long-chain alkanes and acids, while the pyrolysis gas consisted mainly of light hydrocarbons, including carbon monoxide, carbon dioxide, methane and ethylene. The liquid and gaseous pyrolysis products can be used, as the active pharmaceutical ingredient (API) can be recycled to produce new tablets, and other compounds can be used as fuel or chemical feedstock. Paracetamol has been used as the drug of choice because it is the most commonly used over-the-counter painkiller. Paracetamol has been found to have the highest concentration in the aqueous medium of all analgesics (40).

Elimination: Although all measures have been taken, some of the waste must still be disposed of. The most common method of waste disposal is incineration or burning. Incineration is a controlled burning process and is considered to be one of the most effective methods of removing hazardous components from waste (41).

However, if incineration is not properly controlled, typically in terms of temperature, it can lead to secondary contamination with dioxins and furans, which are classified as carcinogenic pollutants. In this sense, the plasma process should be preferred for the treatment of pharmaceutical waste (9).

In most EU countries, as shown in Table I, the collection of pharmaceutical waste, which may be either voluntary or mandatory, is carried out through pharmacies. The funding of waste disposal is usually the responsibility of the state, government, or local authorities, and sometimes of the pharmaceutical industry.

Table I **Examples of collection, method and funding for a few EU countries (42)**

Tabela I **Primeri programa, metoda i načina finansiranja sakupljanja otpada za neke zemlje EU (42)**

Country	Collection program	Collection method	Funding
Austria	Voluntary collection by pharmacies	Unused medicine should be returned to pharmacies or to public collection points	Collaborative funding by local governments and pharmacies
Czech Republic	Pharmacies are required to take back unused medicine	Pharmacies	Funded by the state through regional authorities

Denmark	Locally organized collection programs	Pharmacies or designated municipal collection points	Local government
Estonia	Mandatory take back collection systems via pharmacies and municipal collection points	Pharmacies and hazardous waste collection points	Pharmacies finance the waste collection process, municipalities partially finance local collection
Finland	Collection systems via pharmacies and collection points. Municipalities are responsible for collection, transportation and disposal of UEM	Community pharmacies and municipal collection points	Local municipality
France	Nacional EPR scheme (Cyclamed)	Mandatory EPR-scheme. Retail pharmacies act as collection sites	Industry
Hungary	Nacional EPR scheme (Recyclamed)	Collection bins at pharmacies and other medicine outlets (e. g., petrol stations)	EPR, financed by the pharmaceutical industry, as a percentage of sales
Ireland	Pharmacies are expected to accept any medicines returned	Via pharmacies and take back initiatives (DUMP – Dispose of Unused Medicine Properly)	Largely by pharmacies
Italy	National EPR scheme (Assinde)	Collection bins are available in pharmacies, healthcare centres, on streets or at hazardous waste collection sites	Pharmaceutical industry. In addition, some municipalities organize their own collection systems
Latvia	Voluntary collection by pharmacies	Pharmacies and hazardous waste collection centres	Pharmacies (voluntary), municipalities
Lithuania	Collection by pharmacies	Pharmacies	Pharmacies cover costs of collection. Government responsible for financing disposal
Luxembourg	“Superdrecksckescht”: collection system in co-operation with pharmacies	Waste can be returned to community pharmacies, to mobile collection centres, or to recycling centres directly	Government funded treatment Facilities
Poland	Voluntary collection points in some pharmacies, otherwise municipal offices and health care centres	Waste can be returned to waste collection points or pharmacies	Municipalities are required to collect UEM at least in civic amenity sites
Portugal	National collection system (SIGREM)	Pharmacies	Funded through an EPR by pharmaceutical industry

It is very important for pharmaceutical waste to be properly collected, sorted, labeled and transported. Since the public does not know that pharmaceutical waste is hazardous waste, awareness needs to be raised, and changing people's behavior would make a positive difference. One simple way to do this is to provide instructions on the outer packaging or in the package leaflet for the disposal of unused medicines or packaging after use. This practice has been introduced in the countries of the European Union, as well as in our country (23).

Conclusion

The rising standard of living results in increased production of municipal waste in urban areas, as well as other types of waste, including pharmaceutical waste, which poses a particular problem from the perspective of environmental protection and preservation. Managing pharmaceutical waste is of great importance, but it is also a complicated and costly process. Establishing an adequate waste management system is of particular importance to achieve the best overall outcome for the community and the environment. Waste management is regulated by several legal acts, whose implementation falls under multiple ministries, complicating enforcement. Experiences from European Union countries show that the concept of sustainable management yields the best results, but it also has significant shortcomings and limitations.

To make pharmaceutical waste management sustainable, pharmaceutical companies need to align their goals and interests with global sustainability objectives. This means making their processes greener and reducing their negative environmental impact. Increasing transparency in reporting on these efforts would help build trust among all parties involved. The majority of companies are committed to sustainability and are making significant efforts in this direction. Driving positive change and achieving a sustainable future cannot be accomplished without active collaboration that would include the industry, the academic community, and legislators.

The scientific community needs to intensively explore sustainable pharmaceutical waste management possibilities. Harmonizing regulations across various countries is essential, as this is a global issue, and pollutants do not recognize borders. Pharmacists in public pharmacies should position themselves as healthcare professionals in this field and work on educating and raising awareness about pharmaceutical waste. They should stay updated on and adopt new knowledge in this area and relevant legislation. The changes in the pharmaceutical industry will determine its impact on improving individuals' quality of life and the hope of leaving a better world for future generations.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

Branislava Nikolić: Conceptualization; Investigation; Writing - original draft; Writing - review & editing.

Nađa Nikolić: Investigation; Methodology;

Anica Milošević: Conceptualization; Supervision;

Andrijana Milošević Georgiev: Supervision; Validation; Writing - review & editing.

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Mogućnosti za održivo upravljanje otpadom farmaceutske industrije

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Kratak sadržaj

Farmaceutska industrija svojim aktivnostima značajno utiče na životnu sredinu, pre svega stvaranjem farmaceutskog otpada. Farmaceutski proizvodi se mogu emitovati u vodenu sredinu u svakoj fazi njihovog životnog ciklusa: od proizvodnje, preko upotrebe, do odlaganja. Najveći deo farmaceutskih proizvoda koji se ispuštaju u životnu sredinu, posebno u otpadne vode, dolazi od izlučevina pacijenata. U radu je, nakon definisanja i klasifikacije otpada, navedena zakonska regulativa, kao i mogućnosti održivog upravljanja farmaceutskim otpadom.

Noviji koncept upravljanja farmaceutskim otpadom ima za cilj da farmaceutska industrija ostane uspešna i da postane održiva. Održivi razvoj i održivo upravljanje otpadom direktno su povezani sa cirkularnom ekonomijom. Održivo upravljanje farmaceutskim otpadom obuhvata: smanjenje, ponovnu upotrebu, reciklažu, upotrebu energije i odlaganje. Ove aktivnosti treba da sprovode proizvođači, propisivači, distributeri, farmaceuti i korisnici. Hijerarhija upravljanja otpadom predstavlja široko prihvaćen i preporučen redosled prioritetnih radnji, pri čemu je prevencija otpada (smanjenje količine otpada) najpoželjnija opcija, a zatim ponovna upotreba, reciklaža, zatim regeneracija, i na kraju odlaganje, što je najmanje poželjna aktivnost u upravljanju otpadom.

Pozitivne promene u održivosti farmaceutske industrije ne mogu se postići bez aktivne saradnje koja bi uključivala farmaceutske kompanije, akademsku zajednicu i zakonodavce. Naučna zajednica treba da intenzivno istražuje mogućnosti održivog upravljanja farmaceutskim otpadom. Usklađivanje propisa u različitim zemljama je od suštinskog značaja, a farmaceuti u javnim apotekama treba da rade na podizanju svesti šire populacije o farmaceutskom otpadu.

Ključne reči: farmaceutski otpad, održivost, hijerarhija otpada, opasan otpad