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Research article

Achieving the sustainable waste management of medical plastic packaging using a life cycle assessment approach

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ABSTRACT

Hospital waste management often classifies all waste, including uncontaminated plastic packaging, as hazardous, leading to incineration as the primary treatment method. While effective for safe treatment, incineration incurs high costs and significant environmental impacts. This study explores an alternative approach through the segregation and sustainable management of plastic packaging waste derived from medical device use to mitigate these environmental consequences. Using a Life Cycle Assessment, this research evaluates and compares the environmental impacts of three waste disposal scenarios of plastic packaging: hazardous waste incineration, general waste landfill, and plastic recycling. The analysis focuses on 1 kg of plastic packaging waste generated from medical devices at the Limb Vascular Center, Konkuk University Hospital, South Korea. The results show that general waste landfill has an environmental impact of 79.7 % and plastic recycling has an impact of just 11.8 %, highlighting their significantly lower environmental impacts compared to hazardous waste incineration. These findings underscore the significant benefits of adopting more sustainable waste management practices in healthcare and offering valuable insights for enhancing environmental, social, and governance (ESG) practices within hospitals.

1. Introduction

Plastics have become an integral part of modern life, valued for their unique properties, including low cost, durability, and versatility. These characteristics have led to their widespread use across various sectors, including packaging, industrial manufacturing, and agriculture, where they serve as essential materials for mulching, greenhouse covers, and more. As a result,

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plastics have emerged as a major global commodity, with production skyrocketing from 2 Mt in 1950 to an astounding 380 Mt by 2015 [1]. However, this surge in plastic production has been accompanied by a significant increase in plastic pollution, largely driven by the mismanagement of plastic waste disposal.

The pervasive nature of plastic pollution is exacerbated by the material's inherent durability, which allows it to persist in the environment for extended periods. A recent report by the Organization for Economic Co-operation and Development [2] revealed alarming statistics: only 9 % of global plastic waste is recycled, while 22 % is mismanaged, 19 % is incinerated, and a staggering 50 % ends up in landfills. Of this, 22 % escapes formal waste management systems, entering uncontrolled dumpsites, terrestrial and aquatic environments, or being burnt in open pits. These figures underscore the urgent need for improved plastic waste management strategies.

Recent studies utilizing Life Cycle Assessment (LCA) have highlighted the significant environmental impacts associated with various waste management strategies. For example, LCA study in India have demonstrated that integrating recycling, composting, and sanitary landfill methods can significantly reduce environmental burdens such as global warming potential, acidification, eutrophication, and human toxicity [3,4]. Similarly, studies in China have shown that regional differences in land use and food production contribute substantially to greenhouse gas emissions, emphasizing the need for sustainable development and targeted policy interventions ([5]; [6]). These findings underscore the importance of evaluating environmental impacts across different sectors and regions, providing valuable insights for improving environmental sustainability and circular economy.

While the broader issue of plastic pollution has been extensively studied, the specific contribution of plastic waste generated by medical centers remains underexplored. This oversight is concerning, given the critical importance of proper waste management in healthcare settings. Medical waste, if not correctly treated, poses significant risks of infection to patients, healthcare staff, cleaning personnel, and the public. The World Health Organization [7] has reported that improper healthcare waste management practices were responsible for 33,800 HIV infections, 1.7 million hepatitis B virus infections, and 315,000 hepatitis C virus infections globally in 2010 [8]. Despite these risks, healthcare waste is often not separated into hazardous and non-hazardous categories, leading to the incineration of all waste as hazardous. This practice is particularly problematic for plastic packaging waste, which is a primary source of plastic waste in medical settings.

Plastic packaging plays a crucial role in maintaining the sterility and safety of medical devices. It ensures that medical equipment is contaminant-free, thereby protecting patients, healthcare providers, and the broader public from infection. Additionally, plastic packaging facilitates the safe and efficient transportation of medical items [9]. However, after its brief use in hospitals, this packaging is typically disposed of in landfills or incinerated [10]. The disposal of medical plastics, especially commodity plastics like polystyrene (PS), polypropylene (PP), polyethylene (PE), and polyvinyl chloride (PVC), which constitute approximately 70 % of the market for disposable medical devices, poses significant environmental challenges [11].

The global medical plastics market, valued at USD 46.11 billion in 2021, is projected to grow at an annual rate of 7.5 % from 2022 to 2030 [12]. This growth is expected to lead to a corresponding increase in the proportion of plastic waste generated by healthcare systems. Despite the scale of this issue, recycling programs for healthcare waste are strictly regulated due to the high risk of infection transmission, which limits the recycling of potentially valuable plastic materials. The primary method of medical waste disposal remains incineration [9], a practice that significantly contributes to global warming, ecotoxicity, and the depletion of fossil fuels, placing both the environment and human health at greater risk [13].

The improper classification of medical waste presents a significant barrier to effective recycling. Medical waste is diverse and potentially hazardous, requiring careful sorting and handling to ensure safety and environmental protection. When medical waste is not properly classified and separated from general waste, it can contaminate recyclable materials, rendering them unsuitable for recycling and posing health risks to waste workers and the public. Therefore, the implementation of proper waste classification protocols and increased awareness about the importance of waste segregation are essential steps toward improving the recycling of medical waste and mitigating its environmental impact.

Given the increasing costs associated with incineration and the rapid depletion of available landfill space, there is an urgent need for more sustainable approaches to medical and plastic waste disposal. LCA offers a comprehensive methodology for evaluating the environmental impacts of products or processes over their entire lifecycle. LCA analyzes the aggregated environmental impacts of a product from raw material extraction through manufacturing, use, disposal, and transportation [14,15]. Its adaptability makes LCA a valuable tool across various sectors, including product manufacturing, land restoration, public construction, environmental pollution, and waste management [16,17].

This study highlights the importance of selecting optimal waste management strategies to minimize environmental and public health risks, which aligns with our focus on the environmental impacts of medical plastic waste management. However, relatively few studies have applied LCA to healthcare waste management. Case studies from various countries have demonstrated the potential environmental benefits of plastic waste recycling strategies using LCA. For example, Khoo [18] assessed plastic waste management in Singapore, evaluating gasification, mechanical recycling, and pyrolysis, and recommended a combination of recycling and waste-to-energy conversion as the optimal strategy. Similarly, Hossain et al. [19] evaluated plastic waste management in Hong Kong, identifying industrial incineration as the most environmentally preferable treatment method. In China, Liu et al. [20] highlighted the importance of end-of-life management for reducing the environmental impacts of medical plastic waste through material flow analysis and LCA. According to Chung and Meltzer [21], approximately 8 % of total CO_2 emissions in the United States originate from the healthcare sector, largely due to the manufacturing, purchasing, and transportation of medical products. An LCA study on the reuse of central venous catheter insertion kits found that both the manufacturing and utilization of these kits resulted in significant CO_2 emissions and water consumption, with sterilization processes further exacerbating environmental damage. These findings highlight the critical need for sustainable practices in the healthcare sector, particularly in the management of medical plastics.

The present study aims to build on this body of research by elucidating the environmental impacts of different waste treatment methods—incineration, landfilling, and recycling—specifically for medical plastic packaging waste. By focusing on the "sorting" and "recycling" of plastic packaging from medical devices, this study seeks to identify strategies that could reduce the adverse environmental effects associated with current waste disposal practices. The findings of this research have important implications for policy-making, particularly in South Korea, where studies on waste quantification and disposal practices in medical centers are limited.

This research examines the environmental impacts associated with the gate-to-grave lifecycle of plastic packaging waste from medical devices, with a particular focus on the potential for segregation and recycling. Given that plastic packaging waste is more likely to be segregated from other medical waste, it presents an opportunity for more environmentally friendly and economically feasible treatment options. These findings are expected to contribute to the development of more sustainable waste management practices in the healthcare sector, ultimately supporting global efforts to reduce the environmental impact of plastic waste.

2. Methods

2.1. Goal and scope

This study aims to compare the environmental impacts caused by the disposal of medical device packaging waste (MDPW) mainly consisting of plastics. The functional unit was the 1 kg of plastic MDPW discharged by the medical center. The system boundary spans from the plastic material utilization in the market to its disposal. The scope was from the after-use of plastic packaging to its disposal in

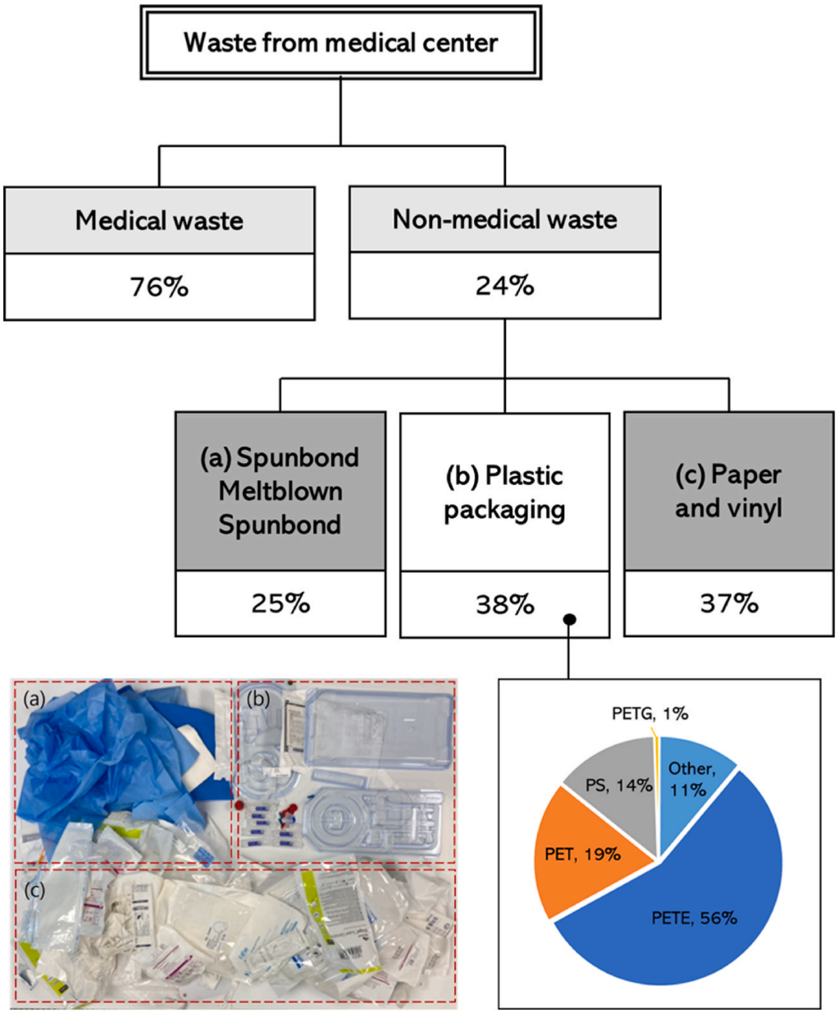

Fig. 1. Components of the medical wastes stream.
The waste is categorized into medical waste and non-medical waste, with further classification into (a) spunbond-meltblown-spunbond materials, (b) plastic packaging, and (c) paper and vinyl, which are the separable non-medical wastes from the medical device and contaminated wastes generated during surgery at Limb Vascular Center. The images display examples of each category, with plastic packaging making up a significant portion of the waste. The pie chart shows the composition of plastic packaging materials, derived from the device for peripherally inserted central catheter (PICC), Permcath insertion (Permcath), and chemoport insertion (Chemoport) surgeries.

waste treatment facilities depending on the different segregation scenarios. Plastic packagings were produced with various types of polymers depending on the suppliers, and most of them were polyethylene terephthalate. The utilization of plastic packaging is to cover the medical devices until they are separated before the surgery, which has negligible impacts on energy or resources. Thus, this stage has not been elaborated on in the material flow. The disposal stage is referred to the regulation in South Korea. It is demonstrated as different scenarios focused on the plastic waste treatment.

2.2. Data collection

The Limb Vascular Center at the Konkuk University Hospital, Seoul, South Korea, was selected as the medical center to investigate MDPW disposal. The surgeries rely on the utilization of specific medical devices, which is inevitable to generate the MDPW. Three types of device insertion surgeries were performed in two operating rooms: peripherally inserted central catheter (PICC), Permcath insertion (Permcath), and chemoport insertion (Chemoport). Surgeries last for a maximum of 15–20 min, and medical devices were used for each and disposed of after a single use.

The total weight of medical waste including MDPW produced during each surgery was measured respectively. MDPW were segregated before the surgery and isolated to avoid contamination with other medical waste. Among medical waste, certain materials like Spunbond Meltblown Spunbond (SMS), paper, or vinyl may avoid direct contamination and can potentially be segregated. However, depending on the situation, they might still be used during surgery (Fig. 1). Unlike these materials, which may be utilized multiple times throughout the procedure, plastic packaging is more predictable in its use and can be distinctly separated. Therefore, segregating plastic packaging immediately before surgery is crucial to ensure that equipment and tools remain clean and uncontaminated. Once the packaging is removed, the medical devices are introduced directly into the sterile environment of the operating room, minimizing the likelihood of contamination by other waste during the procedure.

The polymer types of MDPW were identified based on the suppliers for each surgery and device. To consider the suppliers of medical devices in the three types of surgery (PICC, Permcath, and Chemoport), the frequency of utilization of each product was measured. The medical devices used in the PICC surgery were supplied by five companies: BARD, SaeMyoung, Insight, FINO, and COOK. For Permcath and Chemoport, the two suppliers were BARD and Saemyong and BARD and COVIDIEN, respectively. Thus, nine types of plastic packaging wastes were collected.

2.3. Waste treatment scenario

Three scenarios of MDPW disposal were designed. The scenario on the current implication of waste treatment provides the baseline of LCA comparison with the simulated scenarios followed by the segregation which is a basic strategy for sustainable waste management. They are designed as below.

Scenario 1. Incineration as hazardous waste (HW)

Scenario 2. Landfill as general waste with segregation (GW)

Scenario 3. Recycling of plastic waste with segregation (PR)

HW involves incineration of hazardous waste which is the current status of medical waste incineration without segregation. The type of waste is classified into household waste and industrial waste in South Korea. The industrial waste requires professional treatment of the components. The medical waste is one of the most independently treated, as a type of hazardous waste, and over 90 % is incinerated in certified facilities with exclusive and frequent transport by permitted vehicles [22].

GW treats the MDPW as general municipal solid waste. It is segregated from medical waste, but not further considered as a recyclable resource and landfilled. The landfill of general waste includes both incineration and landfill, however, incineration is not identical to that of hazardous wastes. It does not require special handling, such as the short expiration period of medical waste disposal [11]. This study focused on the environmental impacts of the landfill of MDPW with its transition to general waste.

PR involves the recycling of plastics. Each scenario represents a different waste management strategy, linked to the final disposal through established waste treatment processes. Mechanical recycling was included in the study, with the final recycled products being non-medical grade plastic materials suitable for use in manufacturing items such as non-food-grade containers and construction materials. While the complete recycling of plastic packaging waste can provide a new source as the recyclates which alters the life cycle of plastic production, the environmental impact is limited to its disposal stage in a recycling facility. The reverse impact of the resource generation is compensated without consideration as additional input data.

2.4. LCIA

The LCA followed ISO 14040 and 14044 using SimaPro software (PRe' Consultants, The Netherlands). This program is applicable to a broad range of research subjects and demonstrates exceptional suitability for studies on waste disposal. The primary data is obtained from the collection and investigation of medical waste from the hospitals. This experimental data determined the information of the functional unit and fundamental material flow. The secondary data of each plastic was calculated using ecoinvent 3.8 databases. Due to the absence of inventory focused on waste treatment in Seoul, the global standard and Korean database were applied. The comparison and analysis were conducted with the ReCiPe endpoint method. The damage assessment on global warming and water consumption was calculated by the average of each human health, terrestrial ecosystem, and freshwater system impacts.

3. Results and discussions

3.1. Impact assessment and data description

The environmental impacts of three distinct medical device plastic waste (MDPW) treatment scenarios—Hazardous Waste (HW), General Waste (GW), and Product Recovery (PR)—were systematically compared, as illustrated in Fig. 2. These scenarios represent the spectrum of waste management practices currently employed in the healthcare sector, each with varying degrees of environmental consequences. The HW scenario, which involves the incineration of MDPW alongside other hazardous wastes, has been identified as the most detrimental, contributing significantly to global warming potential and water consumption. This finding is consistent with previous studies that highlight the severe environmental toll of incineration, particularly due to the release of greenhouse gases (GHGs) and the high water usage required for pollution control and operational processes.

In contrast, the GW scenario, which primarily involves landfill disposal, shows a moderate reduction in environmental damages compared to HW. Although modern landfills are managed more scientifically today with resource and energy recovery [23], the improvement remains relatively modest. This indicates that while landfilling mitigates some immediate impacts, it does not sufficiently address long-term ecological consequences. Issues such as leachate contamination, soil pollution, and the accumulation of persistent pollutants like microplastics persist. Moreover, landfills require significant land area and entail long-term space needs, contributing to their substantial environmental footprint [24]. On the other hand, the PR scenario, which emphasizes the recovery and recycling of plastic materials, not only mitigates these impacts but also generates a net positive effect by offsetting the environmental harm associated with the production of new plastic packaging materials. This scenario exemplifies the principles of a circular economy, where waste is minimized, and resources are reused, leading to substantial environmental benefits.

A closer examination of the global warming impacts, which represent one of the most critical environmental challenges today, reveals that the segregation of MDPW can lead to a substantial reduction in GHG emissions. Specifically, by shifting from HW to PR, emissions can be reduced by approximately 30 % to as low as 12 % of the baseline emissions associated with the incineration of unsorted waste. This reduction is primarily due to the decreased need for virgin plastic production, which is one of the most GHG-intensive processes in the lifecycle of plastic materials. Additionally, the PR scenario contributes positively to water conservation, a critical aspect of sustainable waste management, given the significant water usage in both plastic production and waste treatment

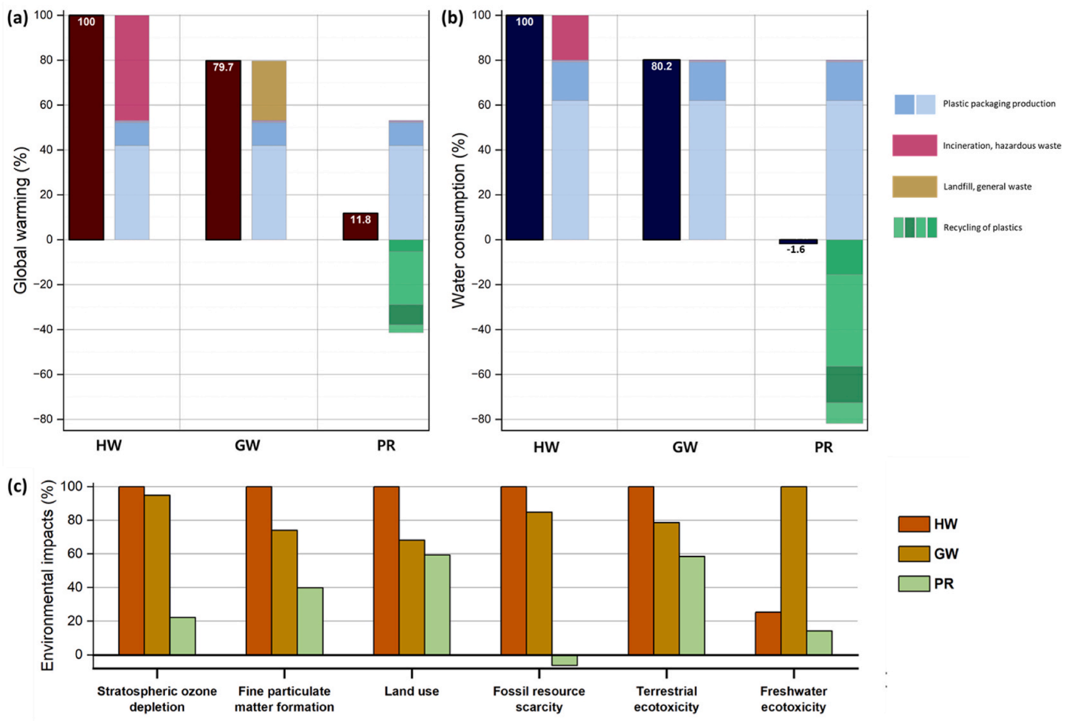

Fig. 2. Environmental impacts (%) of medical plastic waste treatments calculated by the life cycle assessment.
HW denotes the hazardous waste treatment scenario without the medical device packaging waste(MDPW) is segregated. GW and PR denote the general waste treatment and plastic recycling of MDPW, respectively. The left bars with the label show the total impact of global warming(crimson) and water consumption(navy) calculated from the positive and negative impacts of each process represented by the right bars. MDPW from the Limb Vascular Center, Konkuk University was applied to the ReCiPe endpoint method. The (a) global warming and (b) water consumption impacts cover the damage to human health, terrestrial ecosystems, and freshwater ecosystems, and (c) six impact categories were compared between HW, GW, and PR.

processes. As shown in Fig. 2a and b, the PR scenario's ability to conserve water while reducing GHG emissions underscores its dual role in promoting environmental sustainability.

The highest negative impacts on air quality and ecosystem toxicity were observed in the HW scenario, particularly due to the incineration process. Incineration is known to exacerbate air quality degradation through the release of pollutants that contribute to ozone depletion and fine particulate matter formation. These pollutants not only have direct harmful effects on human health but also contribute to broader environmental issues such as smog formation and climate change. However, our analysis indicates that these negative effects can be significantly mitigated through effective waste segregation strategies. For instance, segregating plastic waste before incineration can reduce ozone depletion by 5 %–78 % and fine particulate matter formation by 26 %–60 %, depending on the specific waste stream and the efficiency of the segregation process.

Meanwhile, the GW scenario poses significant risks to freshwater ecosystems, primarily through the leachate generated in landfills. Leachate, which is often laden with toxic chemicals, heavy metals, and microplastics, can contaminate groundwater and surface water bodies, leading to long-term ecological damage. The potential for acidification and eutrophication in affected water bodies further exacerbates the environmental impact, as these processes can lead to the loss of biodiversity and the disruption of aquatic food webs. The environmental impacts of landfills, as indicated by the data, are thus heavily concentrated on aquatic ecosystems, emphasizing the need for targeted interventions to manage leachate and prevent water contamination.

In stark contrast to the HW and GW scenarios, the PR scenario did not exhibit significant negative impacts in any of the environmental impact categories assessed. On the contrary, the recycling efforts within the PR framework were shown to alleviate fossil resource scarcity by approximately 6 %, underscoring the environmental benefits of adopting circular economy practices in the medical sector. This finding is particularly relevant in the context of the global push towards reducing reliance on fossil fuels and transitioning to more sustainable resource management practices.

A case study conducted at the Limb Vascular Center, Konkuk University, South Korea, revealed that plastic packaging waste constitutes 9.12 % of the total waste generated. This statistic underscores the substantial potential for environmental impact reduction through effective waste segregation and recycling initiatives. If these practices are implemented successfully, the center could see a reduction in its overall environmental footprint by up to 10 %, contributing significantly to broader sustainability goals. Despite the inherent challenges in regulating the volume of medical waste generated, particularly in the context of surgical procedures where sterility and safety are paramount, the study suggests that transitioning to more sustainable waste treatment methods can lead to significant environmental benefits without compromising the quality of medical services provided.

The study further quantified the global warming impacts of different waste treatments for 1 kg of plastic packaging waste collected from the Limb Vascular Center. The results showed GHG emissions of 5.26 kg CO_2 eq for HW, 4.19 kg CO_2 eq for GW, and a markedly lower 0.62 kg CO_2 eq for PR. The substantial reduction in GHG emissions in the PR scenario is largely due to the production of recycled resources, which offset the need for virgin plastic production—a process known to be highly energy-intensive and environmentally damaging. If the use of recycled plastic materials or byproducts from the recycling process were integrated as input resources in subsequent lifecycle stages, the total CO_2 equivalent impact could be reduced even further.

However, it is important to note that the healthcare sector faces unique challenges in implementing such sustainable practices. Due to stringent sanitation and safety requirements, regenerated plastic materials are often not suitable for reuse within the same lifecycle as medical devices. This limitation necessitates a cautious approach to the integration of recycled materials in healthcare settings. Nonetheless, the study suggests that with a well-organized infrastructure for MDPW segregation, recycled plastic could be effectively reused in non-critical applications, such as packaging, thereby potentially reducing overall greenhouse gas emissions by approximately 9 % across the healthcare sector.

Plastic production, which involves multiple stages that contribute to GHG emissions, is further exacerbated by the practice of incineration—whether the waste is treated as hazardous or general. Incineration not only releases GHGs but also results in the loss of potentially recyclable materials, effectively doubling the environmental impact of plastic production. Although the municipal incineration of plastics other than PET was not the primary focus of this LCA, it is evident that current waste management practices are far from optimal and contribute significantly to the environmental burden associated with the healthcare sector.

The impacts attributable to the collection, sorting, and recycling processes in the PR scenario were also meticulously quantified. Approximately 40 % of the environmental impacts were linked to the collection and sorting stages, while the remaining 60 % were attributed to the recycling process itself. While the recycling procedure requires energy and materials similar to those in general waste treatments, the overall environmental benefits of recycling outweigh these inputs. The recycling of plastic packaging from medical devices significantly contributes to the reduction of GHG emissions that would otherwise result from the production of virgin plastic. If the positive impacts of using recycled plastic materials during the production stage were fully accounted for, GHG emissions could be reduced to less than half of those observed under hazardous waste incineration scenarios.

3.2. Limitations and assumptions

In this study, we demonstrated the importance of separating MDPW from hazardous medical waste in medical centers for general municipal waste landfill or plastic recycling. We acknowledge the need to evaluate the realism of the scenarios considered.

Scenario HW, which involves disposing of all medical plastic packaging waste as hazardous waste, reflects the current practice in many medical facilities due to stringent regulations and safety concerns.

Scenario GW, which involves treating the waste as general solid waste with segregation, is feasible but requires significant changes in waste management practices and regulatory adjustments.

Scenario PR, involving recycling, is realistic given advancements in recycling technologies, but the quality of recycled materials must be considered.

The system boundaries were concentrated primarily on the operational phases of MDPW management, excluding the transportation and infrastructure of segregation. This is due to the uncertainty of implication, which is possibly investigated in the following case study. The geographical specificity of medical waste treatment in this study was limited to Seoul, South Korea.

Hazardous waste consists of chemical or infectious waste that requires immediate incineration. Our analysis assumed the incineration without energy recovery to provide a conservative estimate of environmental impacts. This assumption aligns with current practices in the region where energy recovery is not typically implemented in medical waste incineration. The incineration of general waste is excluded, while a precise analysis can be conducted based on the sharp differences in transportation and the frequency according to waste disposal regulations. However, the comparison of incineration will be addressed in future research.

Regarding alternatives to plastic packaging, such as bioplastics, it is important to note that these alternatives were not considered in the current study. The management and handling of these alternative materials would require a separate, controlled environment. This suggests a potential need for decentralization or the separate handling of the medical waste loop, which could be facilitated through policy interventions. Future research could explore the implications of incorporating biodegradable plastics into medical waste management. Although biodegradable plastics are not yet widely applicable in the packaging market, they hold promise for future developments. An extended study could consider these materials and their potential impact on waste management practices.

3.3. Application to sustainable waste treatment

The healthcare sector, one of the largest global industries, plays a critical role in delivering essential services. Increasingly, healthcare systems, including those governed by the WHO and the European Union, are aligning their operations with the United Nations Sustainable Development Goals (SDGs) [25]. These goals, particularly SDG 3, emphasize good health and well-being, placing healthcare facilities at the forefront of improving public health, expanding access to care, and promoting health initiatives. In addition, hospitals contribute to SDG 6 by ensuring access to clean water and sanitation, and to SDG 7 by adopting sustainable energy practices. SDG 9 further encourages innovation and infrastructure development, which are crucial for enhancing the efficiency and sustainability of healthcare delivery. By embracing sustainability principles aligned with SDGs 12 (responsible consumption and production) and 13 (climate action), healthcare systems can significantly contribute to a more sustainable future. Achieving these goals, however, requires collaboration across healthcare institutions, governments, and other stakeholders, as emphasized in SDG 17.

The challenge of managing plastic waste in healthcare is particularly pressing. While recycled medical plastics may not be suitable for all applications due to contamination risks, they can be effectively repurposed in less sensitive uses, such as in the production of non-food-grade containers or construction materials. However, conventional plastic waste disposal practices, including incineration alongside other medical waste, significantly contribute to global warming potential and human health risks, particularly carcinogenic and non-carcinogenic toxicities. Our analysis specifically identified certain types of plastics—such as PET, PS, and PETG—as the most detrimental in terms of global warming potential and human health toxicity during various disposal methods, including unsegregated incineration, waste separation, and recycling. PET, in particular, was found to have a disproportionately high environmental and health impact.

Despite efforts by hospitals to separate plastic waste and engage in recycling, these practices still impose substantial environmental and health risks, especially concerning PET plastics. The findings of this study underscore the urgent need for medical device and packaging manufacturers to adopt more sustainable practices. Reducing reliance on PET-like plastics and integrating biodegradable alternatives into product design could be a critical step toward more sustainable waste management.

This study is among the first to comprehensively assess the environmental impacts associated with the incineration, separation, and recycling of medical device plastic waste (MDPW) within the healthcare sector. The insights provided here can serve as a valuable model for medical centers in South Korea and globally to evaluate their plastic waste management practices and their associated environmental and health impacts. By extending this assessment to all medical centers in Seoul or across the nation, the study reveals the significant contributions of these institutions to global warming and human health toxicities stemming from current plastic waste disposal practices.

To further enhance sustainability, medical centers should align with Environmental, Social, and Governance (ESG) criteria, which promote the production of low-carbon, eco-friendly products. During discussions on ESG frameworks specific to healthcare, leaders in the US emphasized the E-pillar's focus on environmentally friendly products, sustainable materials, conservation of natural resources, sustainable energy use, and waste management [26]. ESG rating providers evaluate industries based on criteria such as sustainable packaging, carbon emissions, waste generation, raw material sourcing, and the effects of climate change [27]. Implementing LCA methodologies can significantly aid healthcare industries and ESG rating providers in reducing environmental impacts and improving healthcare performance in line with the E-pillar criteria, particularly concerning global warming potential.

The COVID-19 pandemic has exacerbated the issue of plastic waste in medical centers, with a sharp increase in the use of single-use plastics. Despite the environmental threats posed by this surge in plastic waste, the issue has not received adequate attention. The detrimental effects on land, water, and human health underscore the urgent need for effective plastic waste management strategies. Governments and medical centers must prioritize these strategies and advocate for eco-friendly alternatives to single-use plastics. Additionally, manufacturers have a responsibility to design packaging materials with low carbon footprints, sourced from sustainable materials.

For the medical industry to contribute meaningfully to SDGs 3 (Good Health and Well-being) and 12 (Responsible Consumption and Production), it must overhaul its plastic consumption and waste generation practices. This requires not only further research but also heightened awareness among all stakeholders to foster a culture of sustainability in plastic use and disposal. Progress will depend on a collaborative effort involving governments, healthcare professionals, manufacturers, policymakers, and patients. Leveraging LCA as a decision-support tool will be instrumental in achieving these essential sustainability goals.

4. Conclusion

This study highlights the substantial environmental benefits of adopting sustainable waste management practices in healthcare, specifically through the segregation and recycling of MDPW as opposed to conventional hazardous waste incineration. The LCA findings reveal that transitioning from hazardous waste incineration to general waste management and plastic recycling strategies can lead to significant reductions in environmental impacts. Specifically, general waste landfill reduces global warming impact by 79.7 %, while plastic recycling further cuts the damage by an additional 11.8 %, compared to baseline hazardous waste practices.

These results underscore the urgent need for healthcare institutions to reconsider their waste management strategies, particularly in light of the growing environmental challenges posed by plastic waste. By implementing waste segregation and recycling protocols, healthcare facilities can not only minimize their carbon footprint but also mitigate the broader environmental impacts associated with traditional waste disposal methods, such as air and water pollution. Furthermore, the study highlights the critical role that healthcare institutions can play in promoting environmental sustainability by aligning their waste management practices with global sustainability goals. The reduction in GHG emissions and the conservation of resources achieved through these practices not only contribute to the well-being of the planet but also support the healthcare sector's commitment to public health and responsible resource use.

In conclusion, the evidence provided by this study makes a compelling case for the adoption of sustainable waste management practices within the healthcare sector. By embracing these strategies, healthcare institutions can significantly reduce their environmental impact, thereby contributing to a more sustainable future. These findings should serve as a call to action for policymakers, healthcare administrators, and industry stakeholders to prioritize the integration of sustainable practices in medical waste management, ultimately driving progress toward global environmental and sustainability objectives.

Data availability

All data generated or analyzed during this study are only included in this published article.

CRediT authorship contribution statement

Yoora Cho: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Piumi Amasha Withana:** Writing – original draft, Investigation, Data curation. **Jay Hyuk Rhee:** Writing – review & editing. **Song Tak Lim:** Methodology. **Juin Yau Lim:** Writing – review & editing. **Sang Woo Park:** Resources. **Yong Sik Ok:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Grammarly, ChatGPT, iThenticate in order to enhance the readability of the manuscript and eliminate language issues. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Yong Sik Ok reports financial support was provided by National Research Foundation of Korea and support was provided by the Technology Innovation Program. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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