Sustainable Environmental Waste Management Strategies



Alok Prasad Das
Selcan Karakuş *Editors*

Synergizing Sustainability for Integrated Waste Management

Artificial Intelligence, Economic Stability and Energy Recovery

Springer

Sustainable Environmental Waste Management Strategies

Series Editors

Alok Prasad Das, Department of Life Sciences, Rama Devi Women's University, Bhubaneswar, Odisha, India

Eric van Hullebusch, Équipe ACE, Institut de Physique du Globe de Paris, Paris Cedex 05, France

Sustainable waste management is an absolute imperative in a world that is already dealing with the effects of climate change. This book series seeks to publish an extensive collection of scientific books targeting researchers, scientists, professionals, academics, students, and anyone else involved in the wide, diverse field of sustainable waste management. The series accepts monographs, edited volumes, textbooks, and conference proceedings. Topics covered include but are not limited to environmental pollution and remediation, sources of environmental waste, environmental and human health, sustainable waste management, circular economy, nature-inspired environmental solutions, pollution prevention, and energy-efficient technologies for waste management. The series puts a particular emphasis on developing countries/ the majority world but accepts proposals globally as long as the topic is in scope.

Alok Prasad Das · Selcan Karakuş
Editors

Synergizing Sustainability for Integrated Waste Management

Artificial Intelligence, Economic Stability and Energy Recovery

Springer

Editors
Alok Prasad Das
Department of Life Sciences
Rama Devi Women's University
Bhubaneswar, Odisha, India

Selcan Karakuş
Department of Chemistry
Faculty of Engineering
Istanbul University-Cerrahpaşa
Istanbul, Türkiye

ISSN 3005-1622 ISSN 3005-1630 (electronic)
Sustainable Environmental Waste Management Strategies
ISBN 978-3-032-03717-6 ISBN 978-3-032-03718-3 (eBook)
https://doi.org/10.1007/978-3-032-03718-3

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2026

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

If disposing of this product, please recycle the paper.

Contents

Overview of Sustainable Waste Management 1
Şakir Altınsoy and Nuray Beköz Üllen

Relationship Between Artificial Intelligence and Carbon Footprint 17
Gulcicek Dere

A Multidimensional Approach to E-Waste with Challenges and Strategies for Effective Sustainable Waste Management 35
Elif Tüzün, Meryem Demir Güldal, Tarık Küçükdeniz, and Canan Hazal Akarsu

Waste Management and Its Impact on Environment and Health: Addressing Emerging Waste Challenges in a Post-pandemic World 53
Sweta Sinha, Rahul Singh, Sudhir Lima, Mayank Srivastava, Nitya Garg, and Sona Kumari

Management of Plastic Wastes: History, Current Applications, and Future Perspectives of Recycling, Upcycling, and Reclaiming Technologies 69
Mine Begum Alanalp, Mustafa Fatih Ergin, and Ali Durmus

Innovative Technologies for Heavy Metal Management 99
Murat Torun and Nursel Pekel Bayramgil

Cutting-Edge Technologies for Heavy Metal Waste Management 125
S. Charulatha and K. S. Thangamani

Innovative Strategies for Sustainable Waste Disposal 151
Kiran Bala, Renuka Harit, Arushi Dogra, Raj Kumar, and Alok Prasad Das

Waste Management's Effects on the Environment and Health 163
Yasemin Yilmazoğlu and Emre Yilmazoğlu

Integrated Waste Management: Importance, Legislation, and Research Strategies Towards Sustainability 191
V. P. Sharma, Pragya Sharma, and Alok Prasad Das

Leveraging AI for Intelligent Waste Management in Smart Cities 205
Ritah Nabawagga, Jeanritah Roenah Birungi, Shikta Singh, and Satya Ranjan Dash

Waste-to-Energy Conversion 227
Selcan Karakuş and Alok Prasad Das

Nanotechnology Sustainability and Nano-waste Concerns 245
Gizem Karabulut Sevk and Nuray Beköz Üllen

Sustainable Environmental Solutions Through Nanotechnology: Opportunities, Challenges, and Nanowaste Management 265
Noor Alam Chowdhary and L. S. Songachan

Application of Nanotechnology for Sustainable Agricultural Waste Management and Energy Recycling 297
Soumya Hota, Sudeshna Dey, and Alok Prasad Das

Recent Advances in Valorizing Spent Coffee Grounds for Biodiesel Production with Sustainability Considerations 323
Merve Ceylan, Ibrahim Metin Hasdemir, Ekin Selvi, and Dilek Özmen

Economic Potential of Recyclable Wastes in Municipal Solid Waste: A Case Study of the Marmara Region 345
Mirac Nur Ciner, Serdar Aydın, Emine Elmaslar Özbaş, H. Kurtulus Ozcan, Sinan Güneysu, and Atakan Öngen

Waste Water Treatment Using the Constructed Wetland: Recent and Future Prospects 365
Vivek Raj, Santosh Kumar Karn, Rakesh Kumar, Aman Prakash, Kanchan Kumari, Alok Prasad Das, and Neeraj Choudhary

Overview of Sustainable Waste Management



Şakir Altınsoy and Nuray Beköz Üllen

1 Introduction

In general terms, waste management consists of the cycle of collecting, transporting, processing, recycling, purifying, and disposing of waste materials and managing, monitoring, and regulating them (Mishra et al., 2023). It focuses on the management of waste materials generated by human activities and reducing the negative effects of waste on human health and natural life (Dey et al., 2023). Waste materials can consist of solid, liquid, gas, or radioactive substances. Activities related to waste management may differ in domestic and industrial wastes depending on the development status of countries (Das et al., 2019; Elsaid & Aghezzaf, 2015). Waste management is necessary for a sustainable and sensitive world. Waste management addresses not only the disposal of garbage or recycling of landfill waste but also what needs to be done to avoid creating waste (Priyadarsini & Das, 2024, 2025). Sustainability should develop important strategies such as reducing waste and moving waste collection to an economical place. There are potential environmental risks associated with waste from industrial establishments. Environmentally friendly waste management principles need to be adopted in a sectoral sense. Previously, the economic system adopted the make, use, and throw away model for most areas. This was the case in automotive, textile, electrical-electronics, white goods, and many other areas. However, today this model has given way to sustainable processes. Waste management has changed from a linear economy to a circular economy. Sustainable and renewable

Ş. Altınsoy
Department of Biomedical Engineering, Faculty of Engineering and Architecture, Istanbul Yeni Yuzyil University, Istanbul, Turkey

N. Beköz Üllen (✉)
Department of Metallurgical and Materials Engineering, Faculty of Engineering, Istanbul University-Cerrahpaşa, İstanbul, Turkey
e-mail: nbekoz@iuc.edu.tr

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2026

A. P. Das and S. Karakuş (eds.), *Synergizing Sustainability for Integrated Waste Management*, Sustainable Environmental Waste Management Strategies,
https://doi.org/10.1007/978-3-032-03718-3_1

energy-generated processes have replaced the use of raw materials (Castaldi, 2014; Elsaid & Aghezzaf, 2015; Yeheyis et al., 2013).

Sustainable waste management is one of the important elements of environmental protection and responsible resource use today. Sustainable waste management aims to support recycling, reduce waste, and recover energy from waste. For this purpose, it is necessary to reduce waste sources, implement effective and efficient programs, generate energy from waste, and support the use of products obtained from waste (Das et al., 2024; Mishra et al., 2019). When technological, institutional, and financial factors are taken into consideration, the path to sustainable waste management is quite long. Waste management approaches should provide options with more effective results in terms of sustainability (Al-Maaded et al., 2012; Chen et al., 2010; Das et al., 2019). This section addresses the strategic perspectives of sustainable waste management. These are generally to identify existing innovations and resources, to analyze the waste management system in the international arena, to define and evaluate the waste management life cycle, and to present effective approaches for sustainable recycling of solid waste. The geographical location and economic situation of countries are also very important in sustainable waste management.

Waste management involves a decentralized process that is linked to the national economy. Advanced waste monitoring technologies used by developed countries have accelerated their development in recent years (Das & Ghosh, 2022; Mohanty et al., 2018). The landfill technique is the most widely adopted method of waste disposal globally due to its easy applicability. Due to its high cost, most waste cannot be recycled. Modern landfill technologies have been developed in developed countries that provide optimum use of waste with minimum pollution risk. Since these areas are constructed with many architectural improvements, they are generally environmentally safer than commonly used landfills (Al-Maaded et al., 2012; Elsaid & Aghezzaf, 2015). These areas typically consist of four layers. The lower layer consists of a dense clay liner covered with high-density polyethylene sheets that restrict the leakage of toxic waste. The second layer contains suitable drainage channels that direct the flow of incoming toxic liquids from the landfill to a treatment plant. The third layer collects the gases formed in the storage area and then uses them for cleaning and different usage processes. The last layer at the top forms the largest reservoir to accommodate solid waste (Saha, 2023). The reason why such an application cannot be applied in underdeveloped countries is the lack of specialized labor. However, deterioration in waste treatment infrastructure is often due to countries' economic stagnation and low environmental awareness. Internationally, waste management has become a vital problem for most countries in the world. With increasing industrialization, this problem has also grown. The main obstacles to overcoming this problem are limited resources, inadequacy of technology to be applied for treatment and disposal, and ineffective implementation of relevant legislation. European countries in particular have made progress in sustainable waste management. They have established standards for sustainable waste management with eco-cities based on environmental protection (Das et al., 2019; Kiddee et al., 2013; Moustakas et al., 2020).

This chapter presents various strategies for sustainable waste management: (i) identifying waste management technology, strategic innovations, and waste monitoring tools, (ii) recognizing countries' waste management strategies, (iii) conducting waste management life cycle assessment by identifying other modeling processes, and (iv) identifying applicable approaches for sustainable recycling and utilization of waste (Das et al., 2019; Elsaid & Aghezzaf, 2015). The geographical location and economic conditions of countries play a significant role in determining waste characteristics. Countries with strong economies have defined a number of economic and LCA models for the selection and performance evaluation of appropriate waste management algorithms. Various innovative solutions are being demonstrated in many countries for the implementation of smart and sustainable waste management plans. Soil, air, and water pollution pose a constant risk to sustainable development. Therefore, waste management is directly related to sustainable development (Pires et al., 2019). This chapter clearly states that traditional waste recycling processes are not as adequate as they should be. Various sustainable waste management strategies are mentioned to solve the problems encountered in waste disposal. A society can achieve sustainable waste management goals with the participation of all stakeholders in the production and consumption areas. In this chapter, sustainable solution suggestions for waste management will also be discussed.

2 Sustainable Waste Management

The extent to which sustainable waste management will be successful varies in terms of the economy, wealth, standard of living, culture, policy, and administrative systems of countries. A strong economy and advanced technology provide an opportunity for the sustainable development of industrialized countries (Mehta et al., 2023). Effective use of material resources, development of elements that will reduce waste production, and implementation of sustainable development projects in economic, social, and environmental terms are required. Sustainable waste management can be achieved with the correct planning of processes. These are listed below (Das et al., 2019; Elsaid & Aghezzaf, 2015; Wilson et al., 2013):

- Reducing the amount of waste produced in all areas
- Encouraging the use of recovered or recycled materials
- Supporting recycling areas and technological facilities
- Ensuring that legal regulations for recycling are made and put into practice

To develop sustainable waste management, it is crucial to identify the types of waste that require sustainable management. These can be considered as natural waste, industrial waste, medical waste, hazardous radioactive waste, construction waste, and e-waste. Among these wastes, hazardous waste poses a serious threat to natural life and living beings. In order to manage hazardous waste within the scope of sustainable waste management, it is necessary to comply with strict legal regulations and use approved carriers and technologically based disposal facilities. Careful

and effective management of clinical and medical waste is mandatory. Following country-specific coding and disposal rules are the standards required for effective management. Sustainable waste management aims to reduce waste and improve recycling. Waste management solutions and the implementation of effective waste management strategies are also necessary to achieve the goals (Wilson et al., 2013; Yeheyis et al., 2013).

3 Principles of Sustainable Waste Management

The waste management hierarchy is the basic application in sustainable waste management that offers different waste management options that reflect relative sustainability (Ghosh & Das, 2017; Pradhan et al., 2023; Sahu et al., 2024a). The 3Rs (reduce, reuse, and recycle) mentioned in the previous section form the infrastructure of the waste management hierarchy. The "prevention process," which is at the top of the waste management hierarchy, aims to minimize possible risks by reducing waste production. Reducing unnecessary consumption in every area of life, not using single-use products, and reducing the amount of packaging in which products are stored will significantly reduce waste production. Reuse is the best medicine for sustainability and offers opportunities for a sustainable waste process. Recycling saves energy, reduces the demand for new products, and helps to create creative ideas for creating new products. In sustainable waste management, waste should be addressed with the concept of the waste hierarchy (Kiddee et al., 2013; Theron & Dowden, 2017). Environmentally, the options for the disposal of waste are limited. For this, as little waste as possible should be produced; therefore, it is at the top of the waste prevention hierarchical pyramid. It is followed by reuse and recovery processes. Landfills and incineration techniques are the least accepted options due to high carbon emissions and are at the bottom of the hierarchy. Sustainability of waste management is possible if the waste materials have the least negative impact during processing and disposal. The mentioned impacts can be considered as environmental, social, and economic impacts. Targets to be adopted for a sustainable waste management model (Das et al., 2019; Elsaid & Aghezzaf, 2015; Lakiotia et al., 2017) include:

- Creating climate-friendly technologies and energy sources
- Creating targets to reduce waste production in every area
- Extending the usability of products over long periods
- Adjusting the use of resources to optimum levels
- Developing processes that protect the balance of the ecological system
- Not preferring to create landfill waste and use the incineration process
- Ensuring that waste is monitored and reported by effective institutions
- Ensuring that suppliers have sustainable standards

4 The Hierarchy of Sustainable Waste Management

The waste hierarchy or waste management hierarchy leads to sustainable processes that minimize waste production and maximize efficiency with effectively used resources. It is the approach and general outline of sustainable waste management. It creates solutions to find answers to the question of "How to deal with waste?" This framework focuses on waste management practices that prioritize environmental sustainability and resource conservation. Waste hierarchy processes can be used in many different applications and remain valid (Castaldi, 2014; Elsaid & Aghezzaf, 2015; Lee et al., 2020). All processes described in the waste hierarchy given in Fig. 1 provide environmental and economic benefits within themselves.

4.1 Waste Prevention/Reduction

At the top of the Sustainable Waste Management Hierarchy is the process of reducing waste. In general, it means reducing the amount of waste to a minimum. Using less packaging at every stage of consumption, avoiding single-use products, and preferring to use reusable products in every area of our lives can be possible. A significant amount of general domestic and municipal waste consists of domestic packaging waste. Preventive activities begin at the design and production stage of products (Chen et al., 2010; Phillips et al., 2002). Consumers support the process by ensuring that products are used for a long time in order to prevent waste. The more waste that can be collected and then processed and disposed of, the more recycled raw materials will be released. This formation reduces costs and reduces environmental impact. Waste prevention/reduction, the highest level of the hierarchy, is a prevention activity also called source reduction or simply reduction. This prevention activity

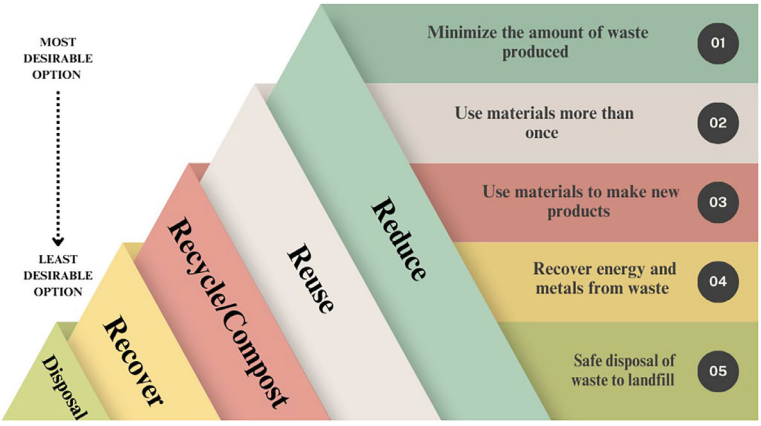

Fig. 1 Schematic representation of waste management hierarchy processes

aims to reduce waste formation at its source. Generally accepted prevention activities may include the following (Elsaid & Aghezzaf, 2015; Phillips et al., 2002; Zorpas, 2016):

- Designing products that reduce resource use at the design stage
- Reducing the packaging ratio of products
- Increasing the durability of products to increase their lifespan
- Encouraging conscious and responsible processes in consumption models

The basic aim of all of these is to prevent waste generation by providing resource optimization. It aims for a process that is achieved through preventive activities without the need for corrective action.

4.2 Materials Reuse

This stage, which is the second level of the hierarchy, is the reusability of products without undergoing any significant change or requiring any processing. The process that must occur for waste products to be reused is defined at this stage. Reusing a product for similar purposes or a different purpose is the next choice. The status of the product used for reuse should be reviewed, and it should be evaluated whether it meets the necessary standards. Studies have shown that 30% of the products that enter the recycling process are still usable, while this rate is 25% for electronic waste. What is important at this stage is the demand for products produced from waste products, that is, encouraging reuse. To achieve this, it is necessary to donate products that are seen as waste but usable, repair unusable products, give different forms to old products, and create new designs (Cucchiella et al., 2017; Saha, 2023).

With this stage, the life of the products is extended, and the demand for new resources decreases. It also seriously affects the processes of selling and purchasing products. Manufacturers need to work on the reuse of waste products. This situation should be supported by significant incentives and developed with training by an expert team. Effective recycling does not require additional time or energy by preserving the possible structure of the material, for example, the on-site reuse of waste from the demolition of a building or the reuse of remaining materials for a future or ongoing project elsewhere. Apart from this, we should consider recycling as separating, collecting, processing, marketing, and using waste materials (Cucchiella et al., 2017; Das et al., 2019).

4.3 Recycling and Composting

Recycling involves the processes of collecting, separating, and transforming waste into a new product, for example, the collection of paper waste in educational institutions, government offices, and many offices and its reuse for paper production.

Composting is a process that uses organic waste, although it is similar. An example is the composting of vegetable and fruit waste for the purpose of obtaining fertilizer. The recycling and composting process requires less energy and cost than obtaining new products. The economic viability of this stage, which is the third step of the hierarchy, interacts with processes that provide quality waste streams, the storage and shipping status in the waste total process, and the market price of recycled materials. For example, construction waste should be recycled close to where it is removed because it is heavy (Das et al., 2019; Lakiotia et al., 2017). Research shows that even in areas where recycling is possible, approximately 60% of recyclable products are thrown away. Materials such as paper, glass, plastic, and metal are generally recyclable, meaning they can be collected, processed, and transformed into new products. Packaging products in particular need to be easily recyclable. However, even in this area, it has been found that almost 40% cannot be easily recycled. This process, which plays an important role in sustainable waste management, is an important step in the hierarchy as it saves new resources, reduces energy consumption and emissions, and reduces waste in landfills or incinerators (Kiddee et al., 2013).

4.4 Energy Recovery

This level of the hierarchy is detailed in converting non-recyclable waste into electricity, heat, or fuel. There are many ways to obtain energy from waste products in today's technology. In waste-to-energy facilities, waste management processes such as collecting, burning, gasifying, and pyrolyzing waste, as well as landfill gas recovery, are included. The energy obtained from waste incineration can recover some energy from the waste stream. In the first stage, this energy is much less than that obtained by recycling, composting, reusing, or reducing the waste produced. If recycling is not possible, the waste should be evaluated in one of the other recovery options rather than in the landfill. Energy recovery has a lower environmental impact than recycling or reuse. However, it is still a better way than sending waste directly to landfills. For example, burning non-recyclable materials reduces the consumption of fossil fuels needed to generate power. Thus, combustion reduces the amount of waste sent to landfills in addition to providing energy. This stage of the hierarchy is also important for renewable energy production by converting organic waste into electricity, heat, or fuel through technologies such as waste-to-energy plants and anaerobic digestion (Castaldi, 2014; Das et al., 2019; Lakiotia et al., 2017).

4.5 Treatment

In cases where the reuse and recycling of waste is not possible or cannot be recovered for energy production, treatment is the case. This stage may include processes such as chemical treatment, bioremediation, or sterilization to reduce the volume

or hazardous nature of the waste. There is a clear position that incineration is not environmentally friendly due to the emissions released into the air. However, it is the only permitted disposal option for many flammable, volatile, toxic, and infectious hazardous wastes. This is especially true for medical waste due to the potential health risks. Apart from this, hazardous materials such as lead-containing and asbestos-containing products, mercury-containing equipment, and batteries must receive appropriate and necessary treatment in terms of health and safety (Castaldi, 2014; Das et al., 2019; Elsaid & Aghezzaf, 2015; Lakiotia et al., 2017).

4.6 Landfill Disposal

This stage, which constitutes the last step in the waste management hierarchy, is the disposal of waste. This stage, which is the least preferred in the waste hierarchy, is usually the process that sends waste to landfills or incineration facilities without energy recovery. The main goal should be to reduce the dependency on landfills and incineration by removing waste from this final destination. Technological landfills and management practices try to reduce environmental damage. The waste hierarchy is a guide for the life cycle of the waste product. Wastes that cannot be reused, recycled, or converted into energy should be disposed of. As urbanization increases, usable land areas decrease, and the garbage rate increases. This situation is a threat to environmental protection, resource conservation, and human well-being. In order to increase high recycling or reuse rates, a waste management plan should be in place and should be implemented carefully. The waste sustainability index should also be developed (Elsaid & Aghezzaf, 2015; Zorpas, 2016).

5 Circular Economy for Sustainable Waste

The concept of circular economy aims to increase the lifespan of products and maximize their value before responsibly disposing of them. At the heart of sustainable waste management, it aims to reuse waste products and create new materials from recycled resources (Bala et al., 2024; Tripathy et al., 2024). A circular economy in waste management is an economic system that includes more processes to find solutions to problems related to sustainable waste management practices. The traditional linear economy is an alternative process that adopts the take-make-dispose approach. It is based on the principles of reducing, reusing, and recycling resources and materials by creating a closed-loop system to achieve its goals (Elsaid & Aghezzaf, 2015; Saha, 2023; Zorpas, 2016). In order to use natural resources effectively and reduce the negative impacts on the life cycle and the environment, a transition has been made toward a circular economy in sustainable waste management. Strategies based on a circular economy in many industrial areas can provide new sources of income by reducing waste and greenhouse gas emissions and improving product quality.

Circular economy in waste management is a restorative and regenerative economic system by design. The basic components on which this concept is based are (i) eliminating waste and pollution, (ii) extending the life of products and materials, and (iii) renewing natural systems (Saha, 2023).

Circular economy strategies for sustainable waste management include several approaches: (i) optimizing production processes, reducing losses during storage and transportation, and consequently reducing waste production and (ii) reusing waste materials as input materials in other industries or products. The circular economy approach enables more sustainable waste management practices in all industrial areas, preventing environmental damage and providing economic benefits (Castaldi, 2014; Das et al., 2019; Elsaid & Aghezzaf, 2015; Saha, 2023). The concepts underlying the circular economy, reducing waste, protecting resources and creating economic efficiency, are presented in Fig. 2.

More powerful and effective circular economy strategies should be developed for sustainable waste management. These strategies may require costly processes to implement at the beginning, but economic investment opportunities can be created in the long term. More information should be acquired about the economic benefits obtained through circular economy strategies. The audience that should be actively included in the process is the decisive element, the consumers. For a sustainable waste management and circular economy cycle, there should be solid cooperation between companies, governments, and civil society organizations. As industrial organizations continue to focus on sustainability and environmental responsibility, it is assumed that circular economy strategies will become increasingly important (Saha, 2023).

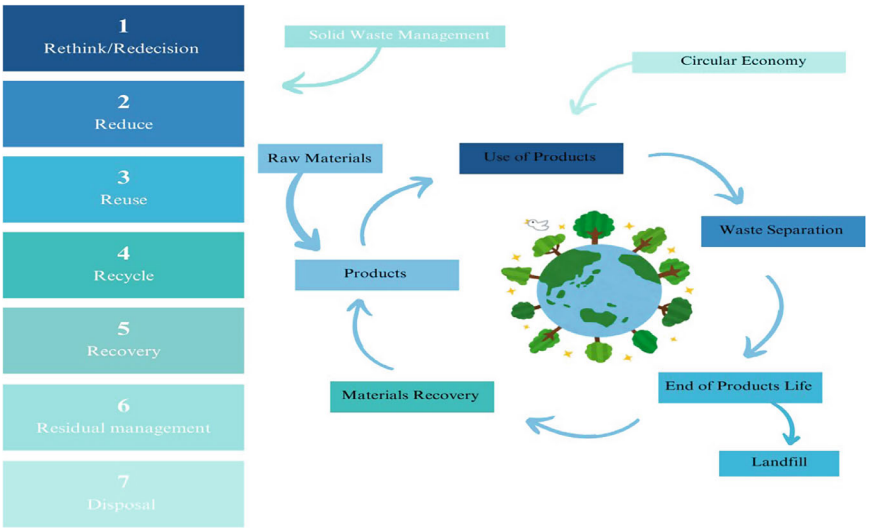

Fig. 2 Concepts forming the basis of the circular economy

6 Significance of Sustainable Waste Management

The importance of sustainable waste management is given below in bullet points:

Energy Recovery: Energy production from waste is a vital component of sustainable waste management, reduces the amount of waste sent to landfills, and also produces renewable energy, which is accepted as more sustainable energy (Das et al., 2019; Moustakas et al., 2020).

Environmental Approach: The main problems in waste management are inadequate waste storage areas and inappropriate disposal processes. When these processes are not effectively controlled, they destroy vital areas such as water and soil and endanger the living spaces of living beings. The protection of the ecological system is the starting point of sustainable waste management (Das et al., 2019; Okedu et al., 2022).

Protection of Resources: Recycling and reuse of waste products can support the protection of resources. The implementation of these periods not only reduces the demand for new raw materials but also preserves energy and reduces carbon emissions (Castaldi, 2014; Elsaid & Aghezzaf, 2015).

Controlling Global Warming: Sustainable waste management plays a key role in both reducing global warming and carbon emissions. Both landfills and burning or burying waste are huge sources of greenhouse gases. We can control global warming by reducing landfill waste, expanding recycling, and activating the energy conversion cycle of waste with technological developments (Elsaid & Aghezzaf, 2015; Phillips et al., 2002).

Carbon Footprint/Reducing Greenhouse Gas Emissions: Areas where landfill waste is located are the source of methane, a very powerful greenhouse gas. With sustainable waste management processes, these emissions, which negatively affect the global balance, can be reduced, and the carbon footprint can be significantly reduced (Elsaid & Aghezzaf, 2015; Theron & Dowden, 2017).

Incorporating Circular Economy: The sustainable waste management process is inherently compatible with the principles of the circular economy. It is a process where waste products can be recycled, reused, and waste is seen as a valuable resource (Castaldi, 2014; Elsaid & Aghezzaf, 2015).

Combating Global Challenges: Problems such as global warming and pollution caused by landfill waste must be combated. Sustainable waste management can be possible by reducing or controlling waste, supporting recycling, and finding alternative environmental solutions to landfills (Castaldi, 2014; Lee et al., 2020).

Protection of Natural Resources: The aim of sustainable waste management is to protect our valuable and existing natural resources. Many materials, especially materials whose basic materials are plastic, paper, and metal, enter the recycling

process. This application reduces the use of natural resources, and thus the ecosystem is protected (Yeheyis et al., 2013).

Supporting Sustainable Product Management: Sustainable waste management addresses the entire life cycle from production to use and disposal of the product. Preferring green products and applying green design techniques in production reduces waste generation and increases the efficient use of natural resources (Elsaid & Aghezzaf, 2015; Zorpas, 2016).

Support for Recycling in Industry: Adopting recycling processes in every area of the industry is essential for strong, sustainable waste management. It is a process that supports the growth of the recycling industry and is quite advantageous in the long term. It contributes to a circular economy, the economy is revitalized, the need for new materials is reduced, and a more sustainable area is created (Cucchiella et al., 2017; Yeheyis et al., 2013).

7 Benefits of Sustainable Waste Management

It would be better to list the benefits of sustainable waste management to better understand them. Some of these benefits (Cucchiella et al., 2017; Elsaid & Aghezzaf, 2015; Gunnarsson & Fält, 2020; Ludwig et al., 2012; Okedu et al., 2022) include:

- The greatest benefit of sustainable waste management is focused on the green environment.
- It supports the fight against global warming process by reducing greenhouse gas emissions.
- It reduces energy consumption and provides energy savings.
- It protects natural resources and is one of the pioneers in the fight against climate change.
- It eliminates both visual and bad odors by controlling and reducing waste areas.
- It provides the creation of markets for recycling.
- It helps the formation of more conscious and green industrial institutions.
- It saves labor, time, and resources.

The efforts of sustainable waste management are aimed at reducing pollution, which is a common problem for all living things, and protecting natural resources (Das & Ghosh, 2018; Ray et al., 2024; Sahu et al., 2024b). In addition to its environmental and economic benefits, it also provides social benefits that encourage all humanity to act together. Some of the economic benefits of buying recycled products are given in Table 1. Sustainable waste management will find alternatives by preventing waste from going to landfills or incineration facilities. In general, it tends to manage the process by educating people on this issue and encouraging responsible recycling. Forest areas will be damaged less with recycling, and energy and water consumption will be significantly reduced. These processes help reduce environmental stress and ensure more efficient use of resources. In terms of economics,

Table 1 Some benefits of buying recycled products

Area of influence	Benefits
Local and general governments	• Savings are achieved by using less water and energy in the production of recycled products • Long-term profit is possible by reusing resources • Strong stance of the administrations toward the society is ensured
Sector and industrial organizations	• The increasing demand for recycled products contributes to the growth and development of the existing market • Increasing the product range of the local and general sector • Contributing to the green and circular economy
Society and environment	• New sectors and opportunities opened by recycling provide job opportunities • Safer use of natural resources • Less water and energy consumption • Reduction of greenhouse gas emissions that will reduce air and water pollution

sustainable waste management can provide significant economic savings. The social benefit to be obtained from sustainable waste management is more conscious and improved public health. Green approaches and quality air and water consumption make life more livable and protect the health of all living things. In addition to all these, sustainable waste management also provides job opportunities in areas such as waste collection, separation, and processing (Deviatkin et al., 2023; Esmaeilian et al., 2018; Vargas & de Souza Campos, 2020).

8 Challenges in Sustainable Waste Management

Insufficient environmental awareness, unconscious social attitudes, and loss of motivation have prevented the acceptance of new technologies that will improve sustainable waste management and approaches toward innovation. The challenges facing the development of sustainable waste management are as follows: high costs in waste collection, uncontrolled waste monitoring process, inadequate budget allocation, inadequate equipment and lack of qualified personnel, inadequate training and public awareness on waste management, inadequate technological processes and developments, lack of laws and regulations on waste management, visual problems experienced in waste collection areas, etc. Overcoming these challenges is possible with innovative solutions and investment in infrastructure. This process requires joint efforts between governments, industries, and individuals (Morrissey & Browne, 2004; Phillips et al., 2002). Dependence on traditional waste disposal methods is also one of the main challenges in sustainable waste management. There is a tendency toward landfilling and incineration for waste disposal to a large extent. This process,

which leads to environmental pollution and resource depletion, can be eliminated with investment and infrastructure development. The ease of use and low cost of disposable products often hinder efforts to reduce waste at source. Education, awareness campaigns, and incentives may be an option to reduce waste production. Reusing waste products is a way to reduce waste and conserve resources. Lack of infrastructure for waste collection and processing and limited consumer availability of recycled materials make reuse efforts difficult. Creating new markets for recycled products and incentives to raise awareness among businesses about using recycled products are potential solutions. The lack of a complete waste management system is a significant challenge. The development and implementation of advanced recycling and waste treatment technologies require significant investment and expertise. The adoption of new waste management technologies can be hindered by technological limitations. Overcoming these limitations requires research and development efforts as well as collaboration between industry and government organizations (Brunner & Rechberger, 2015; Gunnarsson & Fält, 2020; Okedu et al., 2022).

9 Conclusion

Sustainable waste management needs to be addressed for the future of our world. Waste management has become a prerequisite for healthy, safe, and sustainable living spaces. Waste should be considered as a resource rather than a problem. The process can be carried out from many perspectives, from implementing the waste hierarchies discussed in this section to waste-to-energy conversion and zero-waste targeting. Sustainable waste management, which strives for a greener future, requires innovation, patience, dedication, awareness, and discipline. Unbalanced living conditions have caused an imbalance in the ecosystem through the production, consumption, and unnecessary use of natural resources. Today, it is understood that the most sustainable way to manage waste is recycling and composting. One of the aims of this section is to address and understand the paths leading to sustainable waste management. Scientific and industrial studies on the waste cycle are still insufficient, and, therefore, every step taken is important. The concept of sustainable waste management develops a methodology that encompasses all living things on earth. With this methodology, the decision-making process, strategic development, evaluation, and implementation are achieved. The success of the waste management system depends on technical elements such as collection, disposal, and recycling, as well as public and social management processes. In developed countries, there are integrated waste management facilities. The use of these facilities, which facilitate waste management, should be expanded in low-income countries. Solutions for sustainable waste management should be developed locally and adapted to local needs and conditions. Waste management services should be at a cost that can be afforded locally. Research shows that sustainable waste and resource management applies to developing countries and that more stable progress is carried out reasonably. Technological advances have made it possible to solve environmental problems in more economical

and trouble-free ways. Developments in technology, depending on the status, type, amount, and characteristics of the waste, will create more economical and sustainable waste management systems.

For environmental sustainability in waste management, it is essential to create a waste management system that reduces the effects of energy consumption and air, soil, and water pollution. For economic sustainability in waste management, the financial picture in the waste management system must be accepted by all segments of society. For a sustainable system in environmental and economic terms, all waste management infrastructures such as storage areas, incineration facilities, waste types, and amounts must be addressed. Alternatives with minimum environmental impact and low cost for low-pollution recycling and energy recovery are the reasons for the emergence of different treatment systems. Pyrolysis, gasification, the combination of the two, and thermal treatment options of composting systems are increasingly gaining interest as economical and green alternative methods for waste recycling. To make sustainable waste management effective, all types of waste such as industrial, agricultural, and construction waste must be treated in order to be included in economic life. Although sustainable waste management is seen as a technical issue, it is understood that it is a political and economic issue in terms of the functioning of the process.

References

Al-Maaded, M., Madi, N. K., Kahraman, R., Hodzic, A., & Ozerkan, N. G. (2012). An overview of solid waste management and plastic recycling in Qatar. *Journal of Polymers and the Environment, 20*(1), 186–194. https://doi.org/10.1007/s10924-011-0332-2

Bala, K., Anshul, Verma, S., Dogra, A., Das, A. P., Kumar, R., & Nandini. (2024). Sustainable management for urban plastic waste generation. *Sustainable Management of Urban Plastic Waste Through Circular Economic Approaches*, 211–236. https://doi.org/10.1201/9781003465447-13

Brunner, P. H., & Rechberger, H. (2015). Waste to energy–key element for sustainable waste management. *Waste Management, 37*, 3–12.

Castaldi, M. J. (2014). Perspectives on sustainable waste management. *Annual Review of Chemical and Biomolecular Engineering, 5*(1), 547–562. https://doi.org/10.1146/annurev-chembioeng-060713-040306

Chen, X., Geng, Y., & Fujita, T. (2010). An overview of municipal solid waste management in China. *Waste Management, 30*(4), 716–724.

Cucchiella, F., D'Adamo, I., & Gastaldi, M. (2017). Sustainable waste management: Waste to energy plant as an alternative to landfill. *Energy Conversion and Management, 131*, 18–31.

Das, A. P., & Ghosh, S. (2018). Bioleaching of Manganese from mining waste materials. *Materials Today: Proceedings, 5*(1), 2381–2390. https://doi.org/10.1016/J.MATPR.2017.11.459

Das, A., & Ghosh, S. (2022). Role of microorganisms in extenuation of mining and industrial wastes. *Geomicrobiology Journal, 39*, 173–175. https://doi.org/10.1080/01490451.2022.2038953

Das, S., Lee, S.-H., Kumar, P., Kim, K.-H., Lee, S. S., & Bhattacharya, S. S. (2019). Solid waste management: Scope and the challenge of sustainability. *Journal of Cleaner Production, 228*, 658–678.

Das, A., Ray, S. K., Mohanty, M., Mohanty, J., Dey, S., & Das, A. P. (2024). Ecotoxicity of microplastic wastes and their sustainable management: A review. *Environmental Chemistry and Ecotoxicology, 6*, 144–152. https://doi.org/10.1016/J.ENCECO.2024.05.003

Deviatkin, I., Horttanainen, M., & Havukainen, J. (2023). Sustainability of waste management systems: final disposal. In: Içinde S. O. Idowu, R. Schmidpeter, N. Capaldi, L. Zu, M. Del Baldo, & R. Abreu (Eds.), *Encyclopedia of Sustainable Management* (ss. 3356–3365). Springer International Publishing. https://doi.org/10.1007/978-3-031-25984-5_413

Dey, S., Das, A., Mallick, K., Sahu, A., & Das, A. P. (2023). Environmental petroleum waste: Pollution, toxicity, sustainable remediation, pp. 159–175. https://doi.org/10.1007/978-3-031-48220-5_7

Elsaid, S., & Aghezzaf, E.-H. (2015). A framework for sustainable waste management: Challenges and opportunities. *Management Research Review, 38*(10), 1086–1097. https://doi.org/10.1108/MRR-11-2014-0264

Esmaeilian, B., Wang, B., Lewis, K., Duarte, F., Ratti, C., & Behdad, S. (2018). The future of waste management in smart and sustainable cities: A review and concept paper. *Waste Management, 81*, 177–195.

Ghosh, S., & Das, A. P. (2017). Bioleaching of manganese from mining waste residues using Acinetobacter sp. *Geology, Ecology, and Landscapes, 1*(2), 77–83. https://doi.org/10.1080/24749508.2017.1332847

Gunnarsson, J., & Fält, E. (2020). *Sustainable Waste Management: Identifying and Analysing the Present and Future Waste Situation in Linga Linga.* https://www.diva-portal.org/smash/record.jsf?pid=diva2:1461685

Kiddee, P., Naidu, R., & Wong, M. H. (2013). Electronic waste management approaches: An overview. *Waste Management, 33*(5), 1237–1250.

Lakiotia, E. N., Moustakas, K. G., Komilisc, D. P., Domopouloua, A. E., & Karayannisa, V. G. (2017). Sustainable solid waste management: Socio-economic considerations. *Chemical Engineering*, *56*. https://www.academia.edu/download/114626948/111.pdf

Lee, R. P., Meyer, B., Huang, Q., & Voss, R. (2020). Sustainable waste management for zero waste cities in China: Potential, challenges and opportunities. *Clean Energy, 4*(3), 169–201.

Ludwig, C., Hellweg, S., & Stucki, S. (2012). *Municipal solid waste management: Strategies and technologies for sustainable solutions*. Springer Science & Business Media.

Mehta, D., Paliwal, D., & Tege, S. (2023). Sustainable waste management: An approach towards sustainability. *International Journal of Emerging Technologies and Innovative Research, 5*(9), 101–104.

Mishra, S., Ghosh, S., van Hullebusch, E. D., Singh, S., & Das, A. P. (2023). A critical review on the recovery of base and critical elements from electronic waste-contaminated streams using microbial biotechnology. *Applied Biochemistry and Biotechnology, 2023*, 1–30. https://doi.org/10.1007/S12010-023-04440-X

Mishra, S., Rout, P. K., & Das, A. P. (2019). Solar photovoltaic panels as next generation waste: A review. *Biointerface Research in Applied Chemistry*, *9*(6).

Mohanty, S., Ghosh, S., Bal, B., & Das, A. P. (2018). A review of biotechnology processes applied for manganese recovery from wastes. *Reviews in Environmental Science and Bio/Technology 2018 17*(4), 791–811. https://doi.org/10.1007/S11157-018-9482-1

Morrissey, A. J., & Browne, J. (2004). Waste management models and their application to sustainable waste management. *Waste Management, 24*(3), 297–308.

Moustakas, K., Rehan, M., Loizidou, M., Nizami, A.-S., & Naqvi, M. (2020). Energy and resource recovery through integrated sustainable waste management. İçinde *Applied Energy* (C. 261, s. 114372). Elsevier. https://www.sciencedirect.com/science/article/pii/S0306261919320598

Okedu, K. E., Barghash, H. F., & Al Nadabi, H. A. (2022). Sustainable waste management strategies for effective energy utilization in Oman: A review. *Frontiers in Bioengineering and Biotechnology, 10*, Article 825728.

Phillips, P. S., Clarkson, P., Barnes, N. J., & Adams, J. (2002). A UK county sustainable waste management programme. *International Journal of Environment and Sustainable Development, 1*(1), 2. https://doi.org/10.1504/IJESD.2002.000714

Pires, A., Martinho, G., Rodrigues, S., & Gomes, M. I. (2019). Sustainable solid waste collection and management. *Springer International Publishing*. https://doi.org/10.1007/978-3-319-93200-2

Pradhan, G., Tripathy, B., Ram, D. K., Digal, A. K., & Das, A. P. (2023). Bauxite mining waste pollution and its sustainable management through bioremediation. *Geomicrobiology Journal*, 1–10. https://doi.org/10.1080/01490451.2023.2235353

Priyadarsini, S., & Das, A. P. (2024). Analytical and structural characterization of waste lithium-ion batteries for their effective recycling strategy. *Environmental Chemistry and Ecotoxicology*. https://doi.org/10.1016/j.enceco.2024.12.004

Priyadarsini, S., & Das, A. P. (2025). Lithium bioleaching: A review on microbial-assisted sustainable technology for lithium bio-circularity. *Journal of Water Process Engineering, 69*, Article 106744. https://doi.org/10.1016/j.jwpe.2024.106744

Ray, S. K., Dey, S., Das, A. P., & John, A. (2024). Microplastic waste management through greener technologies : A review. *Sustainable Management of Urban Plastic Waste Through Circular Economic Approaches*, 237–261. https://doi.org/10.1201/9781003465447-14

Saha, A. (2023). Circular economy strategies for sustainable waste management in the food industry. *Journal of Recycling Economy & Sustainability Policy, 2*(2), 1–16.

Sahu, A., Dey, S., Mallick, K., Priyadarsini, S., Behera, I. D., & Das, A. P. (2024a). A review on advanced technology for sustainable management of synthetic microplastic waste. *Sustainable Management of Urban Plastic Waste Through Circular Economic Approaches*, 262–279. https://doi.org/10.1201/9781003465447-15

Theron, C., & Dowden, M. (2017). *Strategic sustainable procurement: Law and best practice for the public and private sectors*. Routledge. https://www.taylorfrancis.com/books/mono/https://doi.org/10.4324/9781351274487/strategic-sustainable-procurement-colleen-theron-malcolm-dowden

Tripathy, B., Dey, S., Dubey, N. K., Lo, W.-C., & Das, A. P. (2024). An omics-based approach for managing the risk of COVID-19-generated wastes, pp. 51–66. https://doi.org/10.1007/978-3-031-50840-0_4

Vargas, D. B., & de Souza Campos, L. M. (2020). Waste management in higher education institutions: A state-of-the-art overview. In *Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA*, pp. 75–86. https://www.ieomsociety.org/detroit2020/papers/16.pdf

Wilson, D. C., Velis, C. A., & Rodic, L. (2013). Integrated sustainable waste management in developing countries. *Proceedings of the Institution of Civil Engineers—Waste and Resource Management, 166*(2), 52–68. https://doi.org/10.1680/warm.12.00005

Yeheyis, M., Hewage, K., Alam, M. S., Eskicioglu, C., & Sadiq, R. (2013). An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability. *Clean Technologies and Environmental Policy, 15*(1), 81–91. https://doi.org/10.1007/s10098-012-0481-6

Zorpas, A. A. (2016). Sustainable waste management through end-of-waste criteria development. *Environmental Science and Pollution Research, 23*(8), 7376–7389.