

UDC 628:481:352

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DEVELOPMENT OF WASTE MANAGEMENT SYSTEMS IN THE CONTEXT OF ENERGY POLICY AND THEIR IMPACT ON ECOLOGY AND SUSTAINABILITY: THE EXPERIENCE OF THE SCANDINAVIAN COUNTRIES¹

This article provides a comprehensive exploration of the waste management systems implemented in the Scandinavian countries, with a focus on Denmark, Sweden, and Norway. It focuses on how these pioneering nations have achieved significant progress by prioritizing waste reduction, implementing robust recycling programs, and utilizing advanced technologies.

¹ The research is supported by the budget of the Ministry of Education and Science of Ukraine (research topic 0123U100112 “Post-war recovery of the energy industry of Ukraine: Optimization of waste management taking into account the health of the population, environmental, investment, tax determinants”) and the Executive Agency for Education and Culture of the European Union (Jean Monet module, project No. 101047530 “Healthy economy and policy: European values for Ukraine”).

Moreover, the authors examine how waste management systems in Scandinavian countries influence ecology and sustainability by mitigating pollution, preserving natural resources, and actively contributing to the attainment of Sustainable Development Goals (SDGs). Following the conducted analysis, the authors provide valuable guidelines for the advancement and enhancement of waste management systems, utilizing the Scandinavian experience as an example. These guidelines encompass strategic recommendations and insights aimed at fostering the further development, improvement, and sustainability of waste management practices in various contexts.

Keywords: waste management, waste management systems, sustainability, ecology.

JEL classification: H54, Q01, Q53, Q56

РОЗВИТОК СИСТЕМИ УПРАВЛІННЯ ВІДХОДАМИ В КОНТЕКСТІ ЕНЕРГЕТИЧНОЇ ПОЛІТИКИ ТА ЇХ ВПЛИВ НА ЕКОЛОГІЮ І СТАЛІСТЬ: ДОСВІД СКАНДИНАВСЬКИХ КРАЇН

У сучасному світі управління відходами стає одним із ключових викликів у сфері охорони довкілля, адже воно суттєво впливає на екологію та сталий розвиток. Стрімке зростання населення, урбанізація та індустріалізація призвели до безпрецедентного збільшення обсягів утворення відходів, що створює значне навантаження на екосистеми та загрожує делікатній рівновазі нашої планети. Скандинавські країни досягли значного прогресу в управлінні відходами, надаючи пріоритет їх скороченню, впроваджуючи надійні програми переробки та використовуючи передові технології. Це призвело до суттєвого зменшення забруднення довкілля, збереження природних ресурсів та сприяння досягненню Цілей сталого розвитку. У цій статті досліджуються системи управління відходами, впроваджені у скандинавських країнах, зокрема в Данії, Швеції та Норвегії. Досліджуючи існуючі системи, автори з'ясували, що визначальну роль відіграють стратегічне планування, всебічна політика та комплексний підхід у сприянні стійкості та екологічній безпеці. Скандинавська модель, що характеризується суворим законодавством, потужною інфраструктурою, технологічними інноваціями та непохитною відданістю принципам циркулярної економіки, може слугувати зразком для країн, які прагнуть вирішити багатогранні проблеми управління відходами. Також авторами було підмічено, що успіх управління відходами в скандинавських країнах глибоко вкорінений в історичному контексті, сформованому культурними чинниками та відданістю принципам екологічної відповідальності. Культурні цінності, такі як соціальна відповідальність, співпраця в громаді та висока екологічна свідомість, характерні для скандинавських країн суттєво вплинули на практики управління відходами. Акцент суспільства на колективному благополуччі в поєднанні з високим рівнем довіри до державних інституцій сприяв впровадженню комплексних політик управління відходами. За допомогою цього дослідження автори мають на меті надати політикам, містобудівникам та зацікавленим сторонам цінну інформацію та рекомендації щодо шляхів та підходів до розвитку системи управління відходами та досягнення ЦСР.

Ключові слова: управління відходами, система управління відходами, сталий розвиток, екологія.

Foreword. In today's world, waste management stands at the forefront of global environmental challenges, exerting a profound impact on ecology and sustainability. Rapid population growth, urbanization, and industrialization have collectively fueled an unprecedented surge in waste generation, straining ecosystems and posing severe threats to the delicate balance of our planet.

The accumulation of non-biodegradable materials, improper disposal practices, and inadequate waste infrastructure contribute to pollution, soil degradation, and the endangerment of biodiversity. As waste continues to proliferate, so do the associated greenhouse gas emissions, exacerbating climate change and compromising air and water quality.

The imperative for sustainable waste management has never been more urgent. Recognizing that waste is not merely a byproduct but a potential resource, nations worldwide are grappling with the challenge of developing systems that prioritize recycling, reuse, and responsible disposal. The consequences of failing to address this global issue extend far beyond landfills, reverberating through ecosystems, affecting wildlife, and impacting the overall health of the planet.

In the face of these challenges, the exploration of successful waste management models, such as those exemplified by the Scandinavian countries, becomes crucial. By understanding and implementing sustainable practices, we can mitigate the environmental toll of waste, preserve our ecological heritage, and pave the way towards a more resilient and sustainable future for generations to come.

Analysis of recent research and publications.

A considerable number of researchers from around the world [1–3] have previously studied the effectiveness of Scandinavian waste management systems, including solid waste management, fat oil and grease waste management, sewage sludge and other organic wastes.

Even bigger number of articles have been published in relation to the influence of waste management on ecology and sustainability [4–7]. However, not enough articles explored the development of waste management systems, thus leading us to the research in question.

The aim of the article. The purpose of this article is to comprehensively examine the waste management systems implemented in the Scandinavian countries such as Denmark, Sweden, Norway, illustrate their positive impact on ecology and sustainability and provide guidelines on the development of waste management systems.

Coverage of the primary material. Over the course of several decades, the issue of environmental pollution in Europe has escalated significantly. Intensive patterns of consumption coupled with inadequate waste management infrastructures have placed considerable stress on natural resources and ecosystems. Notably, packaging and household waste emerge as integral components contributing to this environmental predicament.

According to the data provided by Eurostat, the total waste generated in the EU in 2020 by all economic activities and households amounted to 2 135 million tons or 4 815 kg per capita [8]. Of these, construction accounted for 37.5% of the total in 2020, with mining and quarrying following closely at 23.4% (Figure 1) [8].

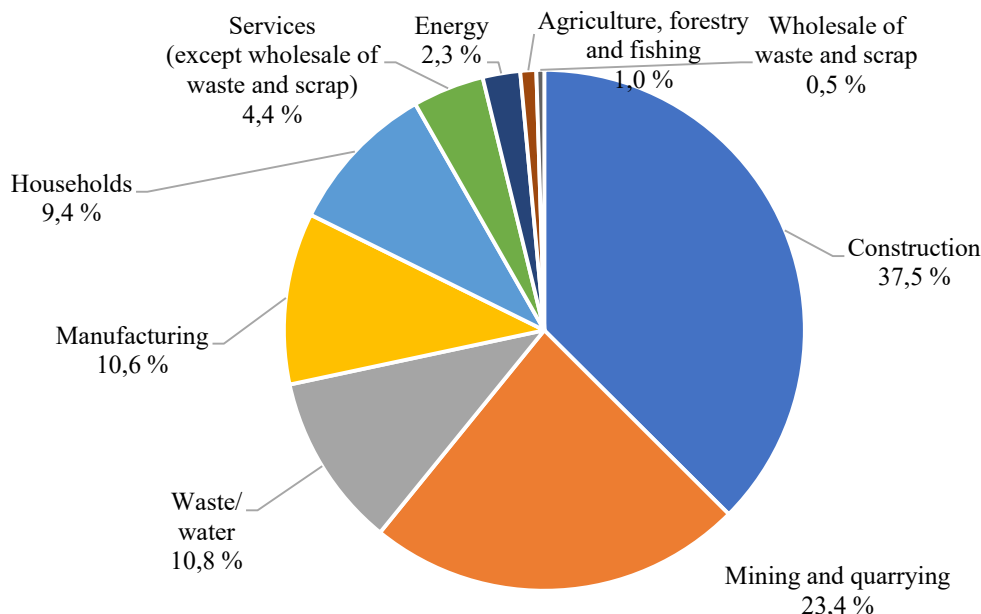


Figure 1. Waste generation by economic activities and households, EU, 2020 [8]

A significant portion of the waste derived from mining and quarrying, as well as from construction and demolition activities, falls under the category of major mineral waste. Therefore, nearly two-thirds (64% or 3.1 tons per person) of the entire waste produced in the European Union in 2020 constituted major mineral waste [8].

In the European Union (EU), a total of 776 million tons of waste, excluding significant mineral waste, were produced in 2020, constituting 36% of the overall waste generated. When considering the population, the average waste generation per inhabitant in the EU was 1.7 tons, excluding major mineral waste, in the same year [8].

The overall recycling rate, i.e. the ratio between total waste generated excluding major mineral wastes and the quantities that were managed through recycling, stood at 46% in 2020 [9].

The above statistics highlight the need for urgent measures and strategies to reduce household waste and improve waste management systems in Europe. The benefits of this process can be achieved through the implementation of effective recycling programs, the promotion of the use of environmentally friendly packaging materials and educational campaigns aimed at reducing household waste.

Scandinavian countries, such as Denmark, Sweden and Norway, also experience a problem of environmental pollution from household waste, in particular packaging and household waste, according to scientific studies and statistics from official sources.

In Denmark, household waste management is an important aspect of the environmental strategy. In recent years, there has been an increase in the amount of recycled packaging, but this process needs further improvements. In 2021, according to the Danish Environmental Protection Agency, the total volume of household waste was around 2.9 million tons. At the same time, more than 25% of this volume is accounted for by packaging. Over the years 2015-2021, the amount of recycled packaging has increased by 15%, but still only a small part of the packaging is recyclable. Regarding food waste, it was recorded that

in 2020 more than 700 thousand tons of food were thrown away [10].

In Sweden, high levels of consumption and promotion of environmental initiatives are hallmarks. Nevertheless, the issue of waste management remains relevant. According to the Swedish Environmental Protection Agency, in 2020, every Swedish resident generated about 494 kilograms of household waste. Approximately 33% of this volume comes from packaging, and the volume of food waste is about 110 kilograms per person annually. Unfortunately, only about 15% of food waste in Sweden is recyclable [11].

In Norway, the use of household waste, especially packaging, remains a significant challenge. For example, more than 80% of national waste is household waste, of which more than half is packaging waste, according to the Norwegian Environmental Protection Agency. In recent years, much of the packaging in Norway has been unrecyclable, which worsens the environmental impact [12].

Certainly, the process of sorting waste is evidently a crucial component of waste management. In Denmark, the sorting of household waste holds significant importance within the environmental strategy, yet it is imperative to acknowledge certain challenges. As per information from the Danish Environmental Protection Agency [10] in 2021, approximately 90% of Danish households are actively participating in waste sorting. Nonetheless, variations exist in the sorting rates across different regions and types of settlements.

Table 1

Sorting of household waste in Denmark

Region	Percentage of households sorting waste
Copenhagen	94%
North	89%
West	87%
South	92%

Source: Danish Environmental Protection Agency, 2021 [10]

In Sweden, where the waste management system is one of the most developed in the world, however, there are challenges in the efficiency of household waste sorting at the household level. According to the Swedish Environmental Protection Agency (Naturvårdsverket), more than 99% of households in Sweden participated in waste sorting programs in 2021.

Table 2

Sorting of household waste in Sweden

Region	Percentage of households sorting waste
Stockholm	99,5%
Gothenburg	98,8%
Malmo	99,2%
Umeå	99,7%

Source: Swedish Environmental Protection Agency, 2021 [11]

In Norway, which is famous for its high environmental awareness, household waste sorting is recognized as an important aspect of sustainable development. According to the Norwegian Environmental Protection Agency (Miljødirektoratet), in 2021, more than 85% of Norwegian households were actively engaged in waste sorting.

Table 3

Sorting of household waste in Norway

Region	Percentage of households sorting waste
Oslo	87%
Bergen	85%
Stavanger	88%
Trondheim	86%

Source: Norwegian Environmental Protection Agency, 2021 [12]

The success of Scandinavian waste management is deeply rooted in a historical context shaped by cultural factors and a commitment to environmental stewardship. Scandinavia's waste management journey can be traced back to the late 20th century when these nations faced environmental challenges, including pollution and resource depletion. The region's historical reliance on natural resources for sustenance and livelihoods likely played a role in fostering a strong connection to the environment.

Cultural values such as social responsibility, community cooperation, and a strong sense of environmental consciousness have significantly influenced waste management practices in Scandinavia. The societal emphasis on collective well-being, combined with a high level of trust in public institutions, has facilitated the implementation of comprehensive waste management policies.

Furthermore, the Nordic cultural mindset, characterized by a commitment to egalitarianism and sustainability, has contributed to the development of progressive environmental policies. Citizens actively participate in recycling initiatives, and there is a cultural norm of responsible consumption, promoting the idea of reducing, reusing, and recycling.

Certainly, while the commendable practice of high-level waste sorting is evident, challenges persist in the form of inconsistent waste management systems among different

regions and cities within the Scandinavian countries, such as Denmark, Sweden, and Norway. Notably, varying local government approaches, including diverse markings and sorting rules, contribute to confusion and misclassification of waste by the public.

Moreover, the issue extends to the quality of sorting, with recycled materials like plastic, glass, or paper often containing contaminants. Improper sorting practices and inadequate removal of product residues exacerbate the challenge of recycling these materials effectively.

To tackle these issues, a strategic focus on standardizing sorting systems, bolstering public awareness campaigns, and fostering innovation in recycling processes becomes imperative for sustained environmental improvement.

In Denmark, innovations in waste management and their use for energy creation and sustainable packaging are recognized as key aspects of the sustainability strategy. The Danish model of using garbage for energy production is based on waste incineration technology with heat and electricity. According to the Danish Environmental Protection Agency (Miljøstyrelsen), in 2022 more than 30% of waste was used for electricity generation and about 20% for heat production.

Table 4

Use of garbage for energy production

Type of waste	Denmark	Sweden	Norway
Household waste	35%	50%	60%
Industrial waste	25%	30%	20%
Other waste	15%	20%	20%

Source: Danish Environmental Protection Agency, Swedish Energy Agency, Norwegian Energy Agency, 2022 [10; 13; 14]

Also, Denmark is actively working on the development of eco-friendly packaging using recycled materials. According to a report by the Danish Environmental Protection Agency, in 2021, more than 40% of recycled materials, including plastic, were used to produce sustainable packaging [10].

In Sweden, in turn, solving the problem of garbage through further use for energy and the creation of ecological packaging is an important element of the strategy for sustainable development and conservation of natural resources.

Sweden is defined by its high-tech system of using garbage for energy production. According to the Swedish Energy Agency (Energimyndigheten), in 2022, more than 50% of household waste was used to generate heat and electricity [13].

In Norway, where environmental conservation and sustainable energy development are at the forefront, the use of garbage for energy production and the creation of sustainable packaging are recognized as key areas for reducing waste and reducing the environmental footprint. For example, more than 80% of household waste is used for energy production through incineration and heat treatment processes. According to the Norwegian Energy Agency (Norges vassdrags-og energidirektorat), in 2022 more than 60% of electricity and heat was produced from garbage [14]. In Norway, more than 40% of recycled materials, including plastic and paper, are used to produce sustainable packaging. This includes both traditional products and innovative solutions to reduce the use of virgin materials.

The above data suggest that further efforts are needed to develop and improve waste management systems in these Scandinavian countries. It is important to consider innovative recycling strategies, implement incentives to reduce the use of harmful packaging materials, and improve recycling systems.

The waste management strategies implemented in Scandinavian countries, including Denmark, Sweden, and Norway, have yielded significant positive environmental and sustainability benefits. The impact of these strategies can be analyzed in terms of the reduction in pollution, conservation of natural resources, and contributions to achieving Sustainable Development Goals (SDGs) related to waste and environmental protection. Among them:

1) Reduction in Pollution through landfill waste and air/water contamination:

The emphasis on reducing reliance on landfills in Scandinavian waste management systems has led to a substantial decrease in landfill waste. This reduction mitigates the environmental hazards associated with landfills, such as soil contamination and the release of harmful chemicals into groundwater.

By incorporating advanced waste-to-energy technologies and promoting cleaner waste disposal methods, the Scandinavian countries have effectively minimized air and water contamination associated with traditional incineration and landfill practices. This has led to improved air quality and reduced water pollution, positively impacting ecosystems and public health.

2) Conservation of Natural Resources through recycling and resource recovery as well as circular economy principles:

The implementation of robust recycling programs and resource recovery initiatives has played a pivotal role in conserving natural resources. Scandinavian nations have effectively reduced the extraction of raw materials by promoting the circular economy, where materials are recycled and reused, diminishing the need for continuous resource extraction.

The integration of circular economy principles in waste management contributes to the longevity of resources, promoting sustainable practices that align with the ecological balance and reduce the overall environmental footprint.

3) Contribution to Sustainable Development Goals (SDGs) related to Waste Management and community and economic sustainability:

The Scandinavian waste management strategies align closely with various SDGs, particularly those related to responsible consumption and production (SDG 12), clean water and sanitation (SDG 6), and life on land (SDG 15). By effectively managing waste, these countries contribute to the global effort to achieve sustainable development targets, promoting responsible resource use and environmental protection.

Engaging communities in waste management practices and supporting the development of a sustainable waste industry contribute to broader SDGs, including those related to social and economic sustainability (SDGs 8, 11).

While Scandinavian countries have achieved notable success in waste management, they face several challenges in maintaining and enhancing their achievements. These challenges encompass technological advancements, public

education, behavior change, and economic and social considerations associated with diverse waste management strategies.

1) Technological Advancements and Future Waste Management:

As waste management technology continues to evolve, adopting new and advanced technologies poses challenges. Integrating emerging technologies such as smart waste monitoring, advanced sorting techniques, and improved recycling processes requires substantial investments, and there may be resistance or delays in the adoption of these innovations.

The rapid growth of electronic waste (e-waste) presents a particular challenge. Effectively managing and recycling electronic products demand continuous adaptation to evolving technologies, and developing efficient e-waste recycling facilities is crucial for maintaining environmental sustainability.

2) Public Education and Behavior Change:

Despite initial successes in waste reduction, sustaining public awareness and engagement remains a challenge. Ongoing efforts are needed to ensure citizens remain informed about the importance of waste sorting, recycling, and responsible consumption.

Shifting consumer behavior towards sustainable practices requires consistent and targeted educational campaigns. Overcoming ingrained habits and promoting long-term behavior change is a complex task that demands continuous public engagement and education initiatives.

3) Economic and Social Considerations of Waste Management Strategies:

The economic viability of waste management strategies is crucial for long-term success. Balancing the costs associated with advanced technologies, recycling infrastructure, and waste reduction initiatives can be challenging. Economic considerations must align with environmental goals to ensure the financial sustainability of waste management practices.

Waste management policies may have varying impacts on different socio-economic groups. Ensuring that waste management strategies are socially equitable and do not disproportionately affect marginalized communities is an ongoing concern. Addressing issues of accessibility to waste disposal and recycling facilities is essential for inclusive and fair waste management practices.

Addressing these challenges requires a multi-faceted approach, involving collaboration between government bodies, private sectors, and communities. Continuous investment in research and development, coupled with strategic communication and community engagement, will be pivotal in overcoming these challenges and maintaining the success of Scandinavian waste management systems. Additionally, policymakers must consider the economic and social implications of waste management strategies to foster a balanced and sustainable approach to their development.

Drawing upon the experience of Scandinavian countries in waste management provides valuable insights into the development of effective waste management systems. Here are key aspects of this development, informed by the Scandinavian experience:

1) Stringent Legislation and Policy Frameworks:

– Comprehensive legislation: Scandinavian countries have enacted comprehensive legislation and policies that

prioritize waste reduction, recycling, and environmental protection.

- Extended producer responsibility (EPR): Implementing EPR programs, where producers bear responsibility for the entire lifecycle of their products, has been integral to waste management policies.

2) Robust Infrastructure and Collection Systems:

- Efficient collection systems: Establishing well-organized and efficient waste collection systems, with a focus on source separation and proper disposal practices.

- Investment in treatment facilities: Developing advanced treatment facilities, including state-of-the-art recycling plants, composting facilities, and waste-to-energy plants to maximize resource recovery.

3) Technological Innovation:

- Smart technologies: Embracing smart technologies for waste monitoring, collection optimization, and sorting processes to enhance efficiency and accuracy.

- Advanced recycling methods: Investing in advanced recycling methods to improve the quality of recycled materials and promote a circular economy.

4) Public Engagement and Education:

- Community participation: Fostering community engagement through educational programs, awareness campaigns, and incentives to encourage responsible waste management practices.

- Behavioral change initiatives: Implementing behavioral change initiatives that emphasize sustainable consumption, waste reduction, and the importance of recycling.

5) Circular Economy Principles:

- Resource efficiency: Promoting circular economy principles by encouraging resource efficiency, designing products for recyclability, and supporting initiatives that prioritize reuse and extended product life.

6) Monitoring and Reporting:

- Data-driven decision-making: Establishing robust monitoring and reporting systems to collect data on waste generation, composition, and recycling rates for informed decision-making.

- Continuous evaluation: Regularly evaluating the performance of waste management systems and adjusting strategies based on the collected data.

7) International Collaboration:

- Information sharing: Actively participating in international forums to share experiences, best practices, and technologies with other nations.

- Global initiatives: Contributing to global initiatives aimed at addressing transboundary waste issues, fostering cooperation on waste management research, and collaborating on sustainable waste practices.

8) Economic Considerations:

- Circular business models: Encouraging the development of circular business models that promote

waste reduction, recycling, and resource recovery while creating economic opportunities.

- Green job creation: Aligning waste management strategies with economic goals, including the creation of green jobs and sustainable economic growth.

By incorporating these elements, countries can learn from the Scandinavian model and develop waste management systems that are not only environmentally sound but also economically viable and socially beneficial. The Scandinavian experience serves as a beacon for nations striving to achieve sustainability goals through effective waste management practices.

Conclusions and prospects for further research.

In conclusion, the examination of the waste management systems implemented in the Scandinavian countries such as Denmark, Sweden, Norway, underscores the crucial role that strategic planning, comprehensive policies, and holistic approaches play in fostering sustainability and environmental resilience. The Scandinavian model, characterized by stringent legislation, robust infrastructure, technological innovation, and a commitment to circular economy principles, serves as a beacon for nations seeking to address the multifaceted challenges of waste management.

The positive environmental impacts of Scandinavian waste management strategies are evident in the significant reduction of pollution, conservation of natural resources through recycling, and contributions to Sustainable Development Goals (SDGs). By prioritizing resource efficiency, extended producer responsibility, and advanced recycling methods, these nations have created a framework for waste management that aligns with global aspirations for a sustainable future.

However, challenges persist, ranging from the integration of cutting-edge technologies and sustained public education to economic considerations and the need for social equity. The successful Scandinavian approach is a testament to the importance of continuous innovation, public engagement, and international collaboration to address the evolving complexities of waste management.

As we reflect on the lessons derived from the Scandinavian experience, it becomes evident that the development of effective waste management systems requires a concerted effort from governments, industries, communities, and individuals. By focusing on standardizing sorting systems, improving public awareness, and fostering innovation in recycling, nations can navigate the intricate landscape of waste management with an eye towards environmental preservation, economic sustainability, and social responsibility. The Scandinavian journey in waste management serves as an inspirational narrative, urging the global community to adopt forward-thinking strategies for a cleaner, greener, and more sustainable future.

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