The Application of the Life Cycle Assessment Method in Managing the Logistics of Municipal Waste Collection

Izdebski, Waldemar
Faculty of Management, Warsaw University of Technology

Serafin, Sandra
Faculty of Management, Warsaw University of Technology

Tarasevych, Viktor
Department of International Economics, Political Economy and Governance, National Metallurgical Academy of Ukraine

https://doi.org/10.5109/7148445

出版情報：Evergreen. 10 (3), pp.1242-1252, 2023-09. 九州大学グリーンテクノロジー研究教育センター
バージョン：

The Application of the Life Cycle Assessment Method in Managing the Logistics of Municipal Waste Collection

Waldemar Izdebski[1], Sandra Serafin[1*], Viktor Tarasevych[2]
[1]Faculty of Management, Warsaw University of Technology, Poland
[2]Department of International Economics, Political Economy and Governance, National Metallurgical Academy of Ukraine, Ukraine

*Author to whom correspondence should be addressed:
E-mail: sserafin912@gmail.com

(Received April 28, 2023; Revised June 23, 2023; accepted July 14, 2023).

Abstract: The relevance of this topic is due to the high level of importance of sustainable waste management and the need for effective decision-making tools. The purpose of the article is to justify the possibility and expediency of using the life cycle assessment method in managing the logistics of municipal waste management. The research was conducted using general scientific methods of cognition: system analysis, synthesis, generalization, deduction, abstraction, concretization, and formalization. Given the results of the conducted research, the meaning, and essence of the evaluation method life cycle are highlighted. It was determined that the life cycle assessment method is possible and advisable to be used for analyzing the impact of waste on the environment, namely on the quality of the ecosystem, state of health of the population, and use of natural resources. It is noted that this method is an effective tool for ensuring the rational use of natural resources and effective management of waste, allowing optimizing the process of management of logistics of waste according to the criteria of time and cost. Separate attention is assigned to considering the process of adopting management solutions in the part of optimizing logistic processes in the system of managing municipal waste, which is outlined as a choice of one option from several possible ones. It is proposed that the method of life cycle assessment be applied by local authorities in Poland to substantiate management decisions regarding the choice of alternative options for processing, disposal, or dumping of municipal waste based on the criterion of minimizing the harmful impact on the environment.

Keywords: ecology, optimization, adoption of administrative decisions, local government bodies, analysis

1. Introduction

At the current stage of global socio-economic development, the problem of generation, accumulation, and disposal of generated waste is one of the main tasks and areas of activity in the field of environmental protection. If in developed countries, more and more waste is processed, composted, and thermally processed in order to reduce its entry into landfills as much as possible, in Poland, the open method of their disposal is still the most used. This approach has the greatest ecological danger due to the high degree of environmental pollution and the loss of opportunities to reuse material and energy resources that can be obtained in the process of waste processing.

The mentioned circumstances determine the need to improve the waste management system, primarily at the municipal level, which requires further scientific research aimed at finding and implementing effective management methods and tools. One of the methods that can be used to effectively manage municipal waste is the life cycle assessment method. Life cycle assessment is a relatively new, but sufficiently researched abroad method, used in the field of environmental management, which allows identifying environmental threats that arise at individual stages of production and the existence of products or processes.

In recent years, the life cycle assessment method has become the subject of consideration by individual Polish and foreign scientists. For example, the Italian researcher A. Mazzi[1)] presented the main stages of development of the theory of life cycle assessment and the prospects of its application in various spheres of social life. J. Kulczycka et al.[2)] can be noted among the Polish authors who devoted their works to the analysis of the evolution of the life cycle assessment method, they reviewed the world experience and came to the conclusion that in Poland, the development of research on this method is at the stage of "attracting attention", requiring detailed study and development of research in this direction. The analysis of the scientific works of Polish scientists showed that research on the life cycle assessment method is mostly conducted in the field of technical sciences and has an applied nature. In particular, K. Grzesik and M. Usarz[3] consider the life cycle assessment method from the point of view of use in the field of management of logistics mechanisms in order to reduce its harmful impact on the environment, using the example of a specific municipal unit.

Life cycle assessment as a method of environmental safety was investigated by P. Zaleski and Y. Chawla[4] paying special attention to the peculiarities of its implementation in small towns. I. Jonek-Kowalska[5] devoted her own research to studying the positive and negative consequences of applying the life cycle assessment method, as well as determining the level of its effectiveness. K. Kossakowska and K. Grzesik[6] propose to use the life cycle assessment method in the field of logistics management of municipal waste collection, given mechanical and biological processing. In turn, M. Karthik et al.[7] proposed a way to increase the effectiveness of the life cycle assessment method in waste management using innovative intelligent systems. D. Sala and B. Bieda[8] study in scientific research, modeling of municipal waste management systems using life cycle inventory. So, in the Polish scientific space, in recent years, the evolution of the life cycle assessment method and certain aspects of its application in some spheres of activity have been studied, among which the sphere of municipal waste management is not represented, which determines the relevance of scientific developments in this direction.

The purpose of the article is to study the essence, significance, features, and possibilities of applying the life cycle assessment method in the field of municipal waste collection logistics management. To achieve the goal, the following tasks are defined:

– to investigate the essence, advantages, and disadvantages of the life cycle assessment method;

– to consider the models and tools on the basis of which its practical implementation is carried out;

– to determine the expediency of using the specified method in the field of municipal waste management, including for the purpose of substantiating managerial solutions aimed at optimizing the logistics of their collection.

The object of this study is the process of using the life cycle assessment method in the logistics management system of municipal waste management. The subject of the study is the theoretical aspects of municipal waste management based on the life cycle assessment method. The scientific novelty of the research lies in highlighting the applicability and potential benefits of using LCA in the specific context of municipal waste management, particularly in Poland.

Materials and Methods

In the process of conducting scientific research, a number of general methods of scientific knowledge were used. The research is based on a hypothetical method, on the basis of which the assumption of the possibility and expediency of using the life cycle assessment method in the logistics management system of the municipal waste collection was formed.

The deductive method was employed in this study to validate the hypothesis regarding the feasibility and benefits of utilizing the life cycle assessment method in the logistics management system of municipal waste collection. Through deductive reasoning, the researchers examined existing knowledge and theories in the field to establish logical connections and support the hypothesis. By drawing conclusions from general principles and applying them to specific scenarios, the study confirmed the viability of integrating the life cycle assessment method into waste management logistics.

The general scientific method of deduction was also applied to determine the essence of the life cycle assessment method; the synthesis method was used to form conclusions regarding the possibility of applying the life cycle assessment method in the logistics management system of municipal waste collection. The abstraction method was used to form an idea of the management decision-making process in the field of municipal waste management based on the application of the life cycle assessment method, and the concretization method was used to determine the stages of the life cycle and the stages of life cycle assessment.

The formalization method was employed in this study to facilitate the process of drawing conclusions based on the results of the research. By applying formalization, the researchers structured and organized the collected data, analysis, and findings in a systematic and standardized manner. This involved establishing clear criteria, defining variables, and developing a formal framework for evaluating the effectiveness and feasibility of integrating the life cycle assessment method in the logistics management system of municipal waste collection.

The theoretical basis of the research is scientific publications on the topic of waste management, including at the level of municipalities, the study of the impact of waste generation and accumulation on the state of the environment, coverage of various aspects of the application of the life cycle assessment method in certain spheres of life, the use of a logistic approach in waste management at different stages of the product life cycle.

The application of the search method made it possible to use the research articles, monographs, and materials of scientific conferences that are in public access, including in searchable scientometric databases on the Internet. In the course of the study, the works of Polish and foreign scientists were examined. The analysis of the scientific achievements of Polish scientists was performed based on a search for their publications on the query "method of life cycle assessment", "municipal waste" and "municipal waste management" in Google scientific information databases Scholar and Meta, in which more than two hundred publications were reviewed.

It has been established that, according to the given request, the publications were mostly completed in the period up to 2015, and in the last three years (2020-2022) there was not a significant number of publications by Polish scientists devoted to the use of the life cycle assessment method in waste management, which reveal certain aspects of these problems and have a fragmentary nature. In this regard, this study was based on the publications of foreign scientists, which were found in the international scientific search databases ScienceDirect and WorldWideScience.org. In addition, the international standards ISO 14040:2006[9] were used in the research process: Environmental management – Lifecycle assessment – Principles and framework and ISO 14044:2006 Environmental management – Life cycle assessment Requirements and guidelines[10].

Results

Life cycle assessment is a relatively new method used in environmental management, but the first attempts to pay attention to the conservation of natural, primarily energy resources were made at the beginning of the sixties of the last century. The first studies and attempts to implement the life cycle assessment method were applied in order to justify the choice of product packaging material according to two criteria: the amount of waste and the number of natural resources used for the manufacture of packaging. For many years, the life cycle assessment method attracted the attention of scientists in certain fields, the research was narrowly targeted, carried out, in particular, on the order of individual enterprises, and did not differ in its systematicity and globality. At the beginning of the 21st century, simultaneously with the aggravation of environmental problems in the global world space, life cycle assessment is increasingly attracting the attention of scientists as a method that allows estimating, predicting, and reducing the harmful impact of production on the environment.

During this period, not only the worldwide recognition, spread, and improvement of the life cycle assessment method but also its institutionalization and formalization take place. In the first decade of the current century, a number of organizations were created in the field of application of this method, in particular, on the initiative of the United Nations (UN), a digital platform "Life cycle initiative", and the European platform began to operate in the European Union Platform on Life Cycle Assessment (EPLCA), both aimed to draw attention to the use of the life cycle assessment method, to spread knowledge and best practices in its use, and to improve the methodology. The formalization of the life cycle assessment method was carried out through the development and approval of a number of regulatory documents, the most important of which are international ISO standards: ISO 14040:2006[9], and ISO 14044:2006[10]. The active development of the life cycle assessment method is associated with political and public recognition, improvement of the methodology, and formalization of procedures for its use, institutionalization, and standardization[2].

Any product or production process has its own life cycle, which is called "cradle to grave" and consists of five consecutive and interconnected stages (design, production, circulation (distribution and implementation), consumption (use), disposal (dumping, processing) of waste) (Fig. 1)[11].

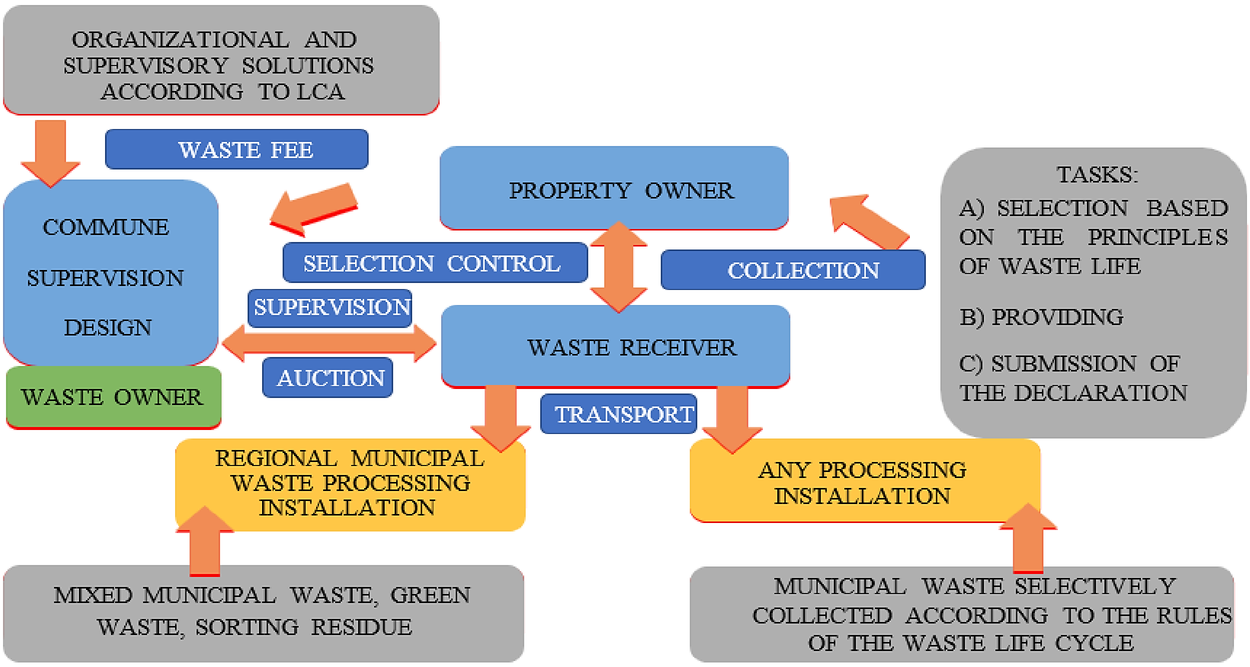

Fig. 1: Assessment of the life cycle of the municipal waste management process.

Source: composed by the authors.

At the first stage, in the process of designing a product, the use of life cycle assessment involves determining its capacity for secondary use of spent material resources and waste processing. In the second stage, in the production process, the main task is the rational use and reduction of losses of material resources, and the use of secondary resources obtained by processing defective products and waste. In the third stage, in the implementation process, the manufacturer faces the task of timely identification and removal of products that have lost their consumer properties for further processing or disposal. The first three stages of the product life cycle are in the producer's area of responsibility and represent his internal logistics in terms of waste management. It should be noted that the first three stages of waste management, it concerns both the generation of waste, which requires management actions aimed at reducing its volume, and its use, processing, and disposal.

In the fourth stage – consumption of products, the main task is to influence consumer behavior, in terms of forming demand mainly for products that have a lower ecological burden among analogs, which are made from secondary resources and have a greater ability to be recycled and recycled. In the last, fifth stage, products that have been completely used or have lost their consumer properties and will no longer be used by the consumer are disposed of. That is, at this stage, the process of using waste is carried out, the effectiveness of which is determined at the first four stages of the product's life cycle. The main task at this stage is to minimize the amount of waste that cannot be processed and disposed of and therefore needs to be buried. The fourth and fifth stages of the product's life cycle are in the zone of extended responsibility of the manufacturer and also fall into the zone of responsibility of other subjects: consumers, heads of local authorities, and the public.

Life cycle assessment is a method of managing the life cycle of a product, which consists in collecting information about the flow of all stages of the life cycle, evaluating input and output material flows, and determining the degree of environmental impact of the product at each of the five stages. It should be noted that the life cycle assessment method alone does not ensure a reduction in the harmful impact of product production on the environment. The main task of the method is the formation of an information base for the justification and adoption of management decisions that have social, economic, and environmental significance in the management of product production.

In a life cycle assessment (LCA), a functional unit quantifies the performance or service provided by a product or system, allowing for comparison. In municipal waste management, it is the management of a certain amount of waste or the services provided over a certain period of time. System boundaries in LCA define the study's scope, including relevant processes, inputs, and outputs. Waste management, covers waste generation, collection, transportation, treatment, and disposal. Boundaries can extend from waste generation to the final stages of management. The selection of functional units and system boundaries should be justified and transparent to ensure comparability and accuracy. LCA with appropriate units and boundaries enables comprehensive assessments and identifies areas for waste management improvement.

In accordance with international standards, life cycle assessment is carried out in four stages: determination of goals and scope of application, inventory analysis, assessment of environmental impact during the life cycle, and interpretation of the obtained results[12)]. The first stage consists in establishing the main goal of applying the product life cycle assessment, defining time and space boundaries, forming an information base, and substantiating research methods and tools. The parameters determined at the first stage are not static, they may be subject to changes at subsequent stages in case of need for their adjustment.

In the second stage, an inventory analysis is performed for each stage of the life cycle of incoming and outgoing material flows that arise in the production process. Given the results of a thorough analysis of the evaluated technology, system, or product, quantitative data are obtained, allowing to objectively choose the most effective method of waste management. Environmental impact indicators, expressed in so-called impact categories, calculated taking into account the ratio between the given impact, are determined on the basis of average European conditions. Hence, the outcomes of the life cycle assessment method do not consider specific local characteristics but enable the identification and establishment of potential categories of detrimental environmental effects. These categories include the consumption of material and fuel resources, emission of harmful substances, negative impacts on human health, global warming, the greenhouse effect, and others.

In the third stage, it is necessary, given the results obtained in the previous stage, to carry out a quantitative assessment of the impact of each category and to rank them according to the degree of impact. These assessments can be performed using various methods, such as CML, IMPACT 2002+, Eco-indicator 99, or ReCiPe, which are most often implemented in computer programs used for life cycle assessment (SimaPro, Gabi). The developed variety of assessment methods testifies to the continuous development and improvement of the life cycle assessment method. The most common method used in Europe is “Eco-indicator 99”. The Eco-indicator 99 method is based on modeling the impact on the environment at the endpoints of the ecological mechanism[13)].

The method of using Eco-indicator 99 requires first determining the categories by which the impact on the environment will be assessed, after which the results of the analysis of the product's overall impact on the environment are included in the selected categories[14]. The Eco-indicator 99 method was created as a result of the improvement of the Eco-indicator 95, an environmental analysis tool aimed at determining the overall environmental burden of a product or process[14]. The value of the indicators of the impact category is calculated on the basis of material and energy flows, as well as emissions of harmful substances and waste during the life cycle of the product being evaluated. On this basis, more than two hundred normative environmental indicators, adopted in the Eco-indicator 99 methodology, are calculated for the materials and processes most often used at all stages of the product's life cycle. The total value of the environmental indicator is expressed in points, and for some standardized indicators of environmental impact categories, the values of weighting coefficients are set.

At the last, fourth stage of the life cycle assessment, proposals, and measures aimed at minimizing the harmful impact on the environment of the production of the studied product are developed. During this stage, the environmental friendliness of the product or process is finalized, and the better its characteristics in this aspect, the more advantages the manufacturer gains. These advantages include reduced material and energy intensity of production, lower material costs, the establishment of a positive image as a socially responsible manufacturer, and more.

The life cycle assessment method can be used to support management decision-making, as it allows identifying environmental problems, and determining the economic and energy effect of the selected production technology, which helps in improving the waste management system. Thus, the life cycle assessment method is an effective tool for reducing the use of natural resources, including energy resources, provided that an adequate supply of goods and services is maintained, and the waste generated in the production process is effectively managed.

The life cycle assessment method is a complex and time-consuming process; therefore, it is performed using specially developed models. It should be emphasized that this method operates with a large amount of accurate data and requires the use of tools that simulate ecological mechanisms and effects caused by the product's negative impact on the environment. Several models have been developed to assess the life cycle of waste management systems, including IWM-2, ORWARE, WISARD, WRATE, EASEWASTE, and LCA-IWM.

Traditional models used in the life cycle assessment method are supported by universal computer programs, for example, EASETECH25, SimaPro, GaBi, and Umberto. The SimaPro program deserves special attention, which is considered one of the best tools for applying life cycle assessment and is often used to compare different technologies in environmental management. In addition, the life cycle assessment method allows for determining the harmful impact on the environment and losses caused by household waste, which confirms the possibility of its application in the municipal waste management system in order to choose the most effective way of handling it.

The effectiveness of waste management at all stages of the product life cycle can be ensured by using logistics as an effective tool, which is conditionally divided into waste generation logistics and waste consumption (use) logistics. Through the combination of these two types of logistics, it is possible to achieve the formation of a single complex waste management system with one organizational structure[15]. A key feature of the application of the life cycle assessment method in the municipal waste management system is the targeting of products that have turned into waste. The main goal of managing the logistics of municipal waste collection is the choice of optimal solutions for their further handling: collection, processing, utilization, or disposal.

At the same time, life cycle assessment is applied at the fifth stage of the product life cycle. The functional unit of management is the amount of generated municipal waste (usually in tons) per resident. It is expedient to apply the life cycle assessment method to build the optimal infrastructure of the municipal waste logistics management system. In Poland, following the Law "On Waste"[16], the powers of waste management are decentralized to local self-government bodies (communes). In addition, since 2018, a general electronic database on waste management has been in operation.

Each local self-government body in Poland is entrusted with the function of ensuring the separate collection of waste and secondary raw materials, with the separation of waste subject to biological degradation (green, food). At the same time, communes are responsible for the collection of highly hazardous waste and their further transfer for disposal. Polish legislation in the field of waste management provides for the possibility of communes creating waste management associations. At the same time, it is worth noting that the payment to carriers engaged in waste logistics is realized based on the actual amount of waste removed. To organize the logistics process, special electronic systems (scales, navigators) are used, which are equipped with carriers' cars.

They record the route, the fact of waste collection and its weight, as well as its transportation to the final point of disposal (composting, incineration, recycling points). The limit of liability for irrational waste management, which is carried out contrary to the current legislation of Poland, is quite significant, including imprisonment. In this way, conditions are created to motivate the creation of an optimal waste management system within each municipal unit, because in Poland it is forbidden to move waste beyond the boundaries of defined administrative units.

In recent decades, in Poland, the traditional positioning of waste as a pollutant has shifted towards considering it as a resource, especially in view of the position of a sustainable circular economy, which all developed countries strive for. At the same time, life cycle assessment in waste management plays a significant role, has many modifications, and is quite successfully used in practice, because it is both an effective method of analysis and an effective tool for environmental management. The methodology of life cycle assessment in the Polish version of implementation is considered an appropriate tool that supports the decisive processes of management of the waste management cycle, providing at the same time a comprehensive and multifaceted analysis of the impact on the environment. The results of the application of the life cycle assessment method in the management of the logistics of municipal waste collection are tangible from a positive aspect already today, however, there is still room for further development and improvement.

The municipal waste management system is quite complex, and its effectiveness has a significant impact on the ecological state of the region, so its effectiveness should be evaluated according to the following criteria: ecological and economic effect and social perception[17]. The complexity and multifaceted nature of the tasks that arise in the process of managing the logistics of municipal waste management dictates the need for methodical and informational support for making management decisions related to the optimization of logistics processes. Any decision in any sphere of life, including management, is the result of a choice. If a person who has to make a managerial decision is faced with numerous possible options, which he evaluates according to numerous criteria, and at the same time makes an intuitive unfounded choice, this can lead to an unfavorable result.

A person who makes a management decision not only makes a certain choice from a list of alternative options but also takes responsibility for the consequences of the decision. The process of making a managerial decision consists of logical, interconnected mental and calculation operations that lead to the necessary result – deciding by choosing the option that is optimal in the opinion of the person deciding all that was considered. In the process of making a managerial decision, it is necessary to evaluate as many factors as possible (dependent and independent of the manager) that influence the decision. Of particular importance is the acquisition, analysis, assessment, and rethinking of information about the source of the problem, its dimensions, significance, causes, and consequences of the impact. That is, the decision made is a choice made based on information from the past and present, but its implementation concerns the future period (Table 1).

Table 1: The process of making optimal logistical decisions.

No. of stage	Stage	Description
1	Goal and task setting	In this stage, the objectives and tasks of the optimal logistical decision-making process are established. The target function, which represents the desired outcome, is defined to guide the decision-making process.
2	Modelling	The modelling stage involves constructing a model that represents the logistics system and captures relevant variables, constraints, and relationships. This model serves as a tool for analyzing different scenarios and evaluating the potential outcomes.
3	Approval of the constructed model	Once the model is developed, it undergoes a review and validation process. Experts and stakeholders assess the model's accuracy, completeness, and suitability for addressing the specific logistical challenges in municipal waste collection.
4	Decision making	Based on the approved model, decision-making takes place. This stage involves evaluating various alternatives, considering factors such as environmental impact, cost-effectiveness, and social considerations, to determine the optimal logistical decision.
5	Implementation and control	The chosen decision is implemented, and its execution is closely monitored and controlled. This stage ensures that the adopted decision is put into practice effectively, and any necessary adjustments or corrective actions are taken as required.

Source: composed by the authors based on [17].

Making a management decision in the presence of a set of alternative options requires the use of multi-criteria analysis. At the same time, the main task is to justify the assessment criteria and determine their leverage. Multi-criteria analysis involves the use of both quantitative and qualitative criteria, but the latter must be defined in quantitative terms for the possibility of their comparison.

For the most part, multi-criteria methods of supporting managerial decision-making are divided into three groups. The first includes selection (optimization) methods, according to which the decision-maker determines the best options according to a defined set of evaluation criteria. The second group includes the ranking method, according to which the decision-maker ranks alternative options from the best to the worst. The third group is represented by classification (sorting) methods, according to which the decision-maker divides the plurality of alternative options into subgroups in accordance with accepted standards. Numerous situations that require making important managerial decisions have contributed to the development of multi-criteria methods of supporting managerial decision-making based on a choice among a set of alternative options. One such method is the life cycle assessment method.

The application of the life cycle assessment method requires complex changes in the current management system of the logistics of municipal waste management. The application of the life cycle assessment method makes it possible to optimize both the time and the cost of the entire process of managing the logistics of municipal waste management. The management system becomes more transparent, which allows warning and avoiding violations that arise as a result of the activities of individual participants of the logistics system. Improving the quality and transparency of the waste management logistics control system makes it possible to increase the quality and efficiency of the work of individual employees of enterprises engaged in waste collection.

An important task in the management system of the logistics of municipal waste collection is the determination of the sphere of responsibility of individual participants of the system, which requires the construction of an effective information transmission system, and the establishment of effective communication links between them. The use of the life cycle assessment method allows for minimizing errors in the construction of the balance of losses and benefits arising from the consequences of using a certain method of waste disposal. For example, the results of the conducted analysis can be used to compare the quality and efficiency of individual treatment facilities or other municipal waste disposal technologies. One of the most important results of the introduction of the life cycle assessment method is the possibility of performing a complex and thorough analysis of a specific management model of waste management logistics.

In addition, the introduction of the life cycle assessment method into the municipal waste management logistics control system makes it possible to improve the management of information that is used both for the needs of the system organizer and for the needs of individual participants. Access to information is crucial for the organization of the logistics management system and its management as a whole[18)]. Therefore, it can be argued that the application of the life cycle assessment method in managing the logistics of municipal waste collection is not only possible but also expedient in view of the advantages of the method and the effect of its implementation.

In Polish realities, it is advisable to use the life cycle assessment method at the level of local communities in order to optimize the municipal waste management system based on the comparison of alternative options for their utilization, processing, and disposal. At the same time, it should be assumed that waste disposal is the least acceptable technology, which has the maximum ecological burden on the environment of all the existing ones. Preference should be given to technologies of reuse and recycling of waste[19)]. However, the final decision must be made on the basis of an assessment of a number of conditions at the local level: volumes, composition, properties of waste, climatic features of the region, and the need for waste processing products (secondary raw materials, biofuel, fertilizers). In addition, an important criterion for selection is economic and social efficiency, which should be determined by assessing the effectiveness of capital investments and current costs, the cost of waste disposal (processing), the tariff policy in the field of rubbish collection services, the ecological effect of reducing the harmful impact on the environment, public health, etc.

Discussion

The conducted research showed that the life cycle assessment method can be applied in municipal waste management systems. Given the advantages and benefits of its implementation, which were disclosed above, it is possible to recommend this method for use by local authorities in Poland, subject to its further improvement of the methodology taking into account local conditions.

Fundamental research problems of municipal waste management based on the application of the life cycle assessment method were conducted by M. X. Paes et al.[20)]. Theoretical developments were tested by scientists on the example of a medium-sized municipality in the city of Sorocaba in Brazil. The difference between the approach presented in the published scientific work and the traditional ones is an attempt to use environmental and economic indicators within the framework of combining methods of life cycle assessment and life cycle cost calculation. The opinion is continued by the research team of Polish authors J. Kulczycka et al.[2)]. The authors suggested that the evaluation of the impact on the external environment should be carried out with the help of a complex system that takes into account the stages of production and processing of solid household waste. The economic analysis was based on the inclusion of capital and current costs in the cost of external environmental consequences, which allowed estimating the level of total costs for the local community, comparing the results of using different life cycle assessment models. The research aligns with previous studies on LCA in municipal waste collection. It confirms the effectiveness of LCA in evaluating environmental impacts and emphasizes the need for further advancements.

According to the results of the integration of ecological and economic analysis, it was proved that the best results can be achieved by combining composting, mechanical biological treatment, and recycling of waste, which significantly reduces their negative impact on the environment. The life cycle assessment method based on mechanical and biological treatment is proposed to be used by K. Kossakowska and K. Grzesik[6]. The authors came to the conclusion that the application of life cycle assessment allows implementing of a comprehensive analysis into the practice of management decision-making in the municipal waste management system, and the integration of economic and environmental indicators using the concept of life cycle assessment provides a consistent diagnosis of complex and extensive systems. The research aligns with existing LCA studies on municipal waste collection, confirming the effectiveness of the method and emphasizing the integration of economic and environmental indicators.

K. Grzesik and M. Usarz[3] are convinced of the effectiveness of using the modeling process, which allows for quantitatively assessing the potential impact on the environment, as well as the economic aspects of municipal waste management systems. The authors also proved the expediency of implementing this method into the system of strategic planning and development of state policy in the field of waste management. Results of this and K. Grzesik and M. Usarz[3] studies contribute to the understanding of LCA's potential in decision-making processes and underscores the relevance of advancing LCA research and application in the field of waste management.

P. Zaleski and Y. Chawla[4] emphasize in scientific works the synergy of applying the life cycle assessment method in municipal waste management with the basic principles of the circular economy, and it is impossible to disagree with them. In addition, scientists deepened the development in the field of the concept of product life cycle assessment, and the results of their research should be used in the process of scientific and methodological substantiation of ways to improve the management of the logistics of handling municipal waste at the state and regional levels in Poland, and especially within the limits of small municipalities.

I. Jonek-Kowalska[5] raises controversial issues regarding municipal waste management, highlighting the most difficult points that require further research. Special attention is paid to the need to abandon the disposal of multi-component waste and to implement a strict monitoring system of the logistics management and waste management process. The study's findings are in line with other LCA studies on municipal waste collection. They validate the effectiveness of LCA for assessing the environmental impact of product production and consumption. The research underscores the necessity of suitable models, tools, and documentation to facilitate LCA implementation.

On the other hand, A. Mesjasz-Lech[21] considers the issue of handling municipal waste within the framework of applying the life cycle assessment method. The author proposes a concept of zero waste, which requires reverse logistics. At the same time, scientist is convinced that it is impossible to reduce the amount of municipal waste without the proper organization of waste flows and the corresponding infrastructure, and this kind of management is the function of reverse logistics. An interesting and important point is the fact that the ecological and economic efficiency of the organization of waste flows mostly goes beyond the boundaries of a specific municipality and has a much larger field of effectiveness[22-24]. Both of the studies underscore the necessity of appropriate models, tools, and regulatory frameworks to facilitate LCA implementation in waste management.

Among foreign studies, it is also appropriate to pay attention to the scientific work of Indian scientists K. Sh. Bhupendra and K. Ch. Munish[25], dedicated to the analysis of the life cycle cost method in household waste management. This study provides a comparison of the economic efficiency of different municipal waste management scenarios from the point of view of the life cycle concept, which makes it possible to justify management decisions by assessing costs and planning waste management strategies. The study was conducted on the basis of the city of Mumbai in India, which accumulates more than 9 thousand tons of solid household waste every day, most of which is sent to landfills.

The problem of burying a larger share of waste in open landfills is also relevant in local Polish communities, therefore, the use of the results of the significant research has practical significance for Poland. The authors proposed six integrated scenarios of municipal waste management, which are a combination of different methods of waste management: recycling, composting, anaerobic digestion, incineration for electricity generation, and landfill with biogas recovery. In order to carry out an assessment in order to choose the optimal scenario, the authors suggested using the method of current value analysis with an estimate of current costs and received income from waste processing. The current research underscores the necessity of suitable models, tools, and regulatory frameworks. In comparison, the Indian study focuses on the economic assessment of waste management scenarios using the life cycle cost method. Together, these studies contribute to the broader comprehension and practical implementation of LCA in making informed waste management decisions.

V. Subramanian et al.[26] devoted their research to the study of scientific approaches to the introduction of safe products based on a combination of life cycle assessment and risk assessment at the early stages of their development. Scientists have proven that the combination of life cycle assessment and risk assessment is advisable to be used at the stage of product design for the purpose of early diagnosis of the environmental safety of production. At the same time, the authors include the use of safe chemical materials, reduction of harmful emissions into the environment, and safe disposal of waste in the concept of safety. The results of this study are of interest for further scientific developments in the direction of finding means for early diagnosis of the impact of product waste on the environment.

That is, at the product development stage, it would be advisable to evaluate the volume, composition, properties, recyclability, and safe disposal of waste, which arise both during the production process and at the final stage of the life cycle when the product itself turns into waste[27-30]. The application of such an approach in the municipal waste management system can significantly reduce the total amount of waste generated on the territory of local communities and reduce the share of waste that cannot be processed and needs to be disposed of by landfilling. That is, the application of the proposed approaches, provided they are adapted to Polish realities, would allow local authorities in Poland to achieve a significant reduction in the environmental burden of waste at the level of local communities. The research's findings, along with the study by V. Subramanian et al.[26], emphasize the value of incorporating life cycle assessment and related methodologies in waste management strategies. They provide valuable insights into addressing environmental concerns and improving waste management practices at different stages of product development and disposal.

M. Ikhlayel's[17] research results are useful from the point of view of the possibility of implementation in the municipal waste management system in Polish local communities Khalil in terms of the development of solid waste management systems in developing countries. The author applied a systematic approach to life cycle analysis and proved that municipal waste management is a complex problem for the sustainable development of local communities due to its internal connection with many environmental and economic factors, which confirms the conclusions presented in this article. The author devoted her own research to the analysis of the practice of uncontrolled disposal and disposal of household waste in Lebanon and to the assessment of its impact on the preservation of the environment. For this purpose, the scientist modeled thirty alternative systems of waste management, which can be used in Poland as well. Based on the results of evaluating the ecological and economic indicators of each system, the author concluded that waste processing in combination with composting significantly reduces the harmful impact on the environment.

These conclusions made it possible to formulate the proposal presented in the article to local authorities in Poland in the process of evaluating alternative options for dealing with municipal waste to give preference to their reuse and recycling. In addition, the author proved that the different composition of waste plays an important role in the environmental characteristics of the system of their management, so this factor should be taken into account when making management decisions in terms of optimizing the logistics of handling municipal waste. In general, according to the results of the study, it was concluded that municipal waste management is a broad concept and should be determined at the local level, while the most urgent environmental problems should be solved by each country separately. The findings of M. Ikhlayel's[17] provided a fairly informative basis for understanding the process of analyzing local authorities in Poland when assessing waste management alternatives. Overall, these studies contribute to the improvement of waste management practices and decision-making processes.

N. Sharma et al.[31] conducted a global review of the closed-loop economy and the concept of life cycle assessment in terms of their application in construction, namely in the demolition of buildings, that is, at the final stage of the product life cycle. In Poland, a significant problem is the collection and disposal of construction waste, which accumulates, including at household waste collection points[32),33], so the results of the conducted research are relevant and interesting for both scientists and local authorities. The authors of the study identified more than thirty strategies for the management of building demolition waste, which can be considered as alternative options in the decision-making system for the management of construction waste management by local authorities in Poland.

Particular attention should be paid to such components of the defined strategies as standardization of building materials, extended responsibility of builders and manufacturers of building materials, inspection, and audit before demolition, and blockchain technology[34),35]. The global review by N. Sharma et al.[31] focuses on the management of construction waste during demolition, suggesting alternative strategies for local authorities, including this practice as a basis for considering the suitability of the model for Poland. These findings contribute to the understanding of waste management practices and offer practical recommendations for improving sustainability.

The considered results of research by foreign scientists not only confirm the validity of the conclusions and proposals given in this article but also form a vector of further scientific research in this issue.

Conclusions

The conducted research showed that one of the effective methods of determining the environmental impact of the production and consumption of products is life cycle assessment. This method has been used in various sectors of the economy since the middle of the last century, given the fact that each product or process has its own life cycle, which consists of five stages from design to disposal, and at each stage, it is necessary to determine its environmental load, from rational use of natural resources for waste disposal.

The life cycle assessment method can be applied in logistics management systems for the handling (including collection) of municipal waste. The expediency of using life cycle assessment in the field of municipal waste management is determined by the availability of a sufficient number of models and analysis tools, unified software for conducting the necessary calculations, and regulatory documentation in terms of the methodology for applying this method. The advantage of using the life cycle assessment method in waste management systems at the regional level is the possibility of obtaining ecological, social, and economic effects, which primarily consist in reducing environmental pollution and harmful effects on the health of the local population, obtaining economic benefits due to the rational use of natural resources, including through the use of secondary raw materials, obtaining fertilizers and energy sources from waste processing. The method itself does not reduce the environmental load of products and the harmful impact of waste on the environment, but it can be used as a tool that helps in the process of making management decisions in terms of optimizing the logistics of municipal waste management.

Currently, in Poland, the research of the life cycle assessment method and its use in practice is at the first stage of evolutionary development ("attention"), which determines the relevance of further scientific and applied developments in this direction. In particular, measures aimed at improving Polish legislation in terms of further solving environmental problems and bringing it into line with EU requirements require scientific justification. In addition, methodological developments aimed at improving analysis models and software, and their adaptation to Polish realities, are interesting for local authorities from the point of view of the practical application of the life cycle assessment method in municipal waste management systems.

References

1) Mazzi, A. 2020. Introduction. Life cycle thinking. In: *Life Cycle Sustainability Assessment for Decision-Making* (pp. 1-19). Amsterdam: Elsevier.
2) Kulczycka, J., Lelek, L., Lewandowska, A., Zarebska, J. 2015. Life Cycle Assessment of Municipal Solid Waste Management – Comparison of Results Using Different LCA Models. *Polish Journal of Environmental Studies*, 24(1), 125-140.
3) Grzesik, K., Usarz, M. 2016. A Life Cycle Assessment of the Municipal Waste Management System in Tarnów. *Geomatics and Environmental Engineering*, 10(2), 29-38.
4) Zaleski, P., Chawla, Y. 2020. Circular Economy in Poland: Profitability Analysis for Two Methods of Waste Processing in Small Municipalities. *Energies*, 13(19), 5166.
5) Jonek-Kowalska, I. 2022. Municipal Waste Management in Polish Cities – Is It Really Smart? *Smart Cities*, 5(4), 1635-1654.
6) Kossakowska, K., Grzesik, K. 2019. Life Cycle Assessment of the Mixed Municipal Waste Management System Based on Mechanical-Biological Treatment. *Journal of Ecological Engineering*, 20(8), 175-183.
7) Karthik, M., Sreevidya, L., Nithya Devi, R., Thangaraj, M., Hemalatha, G., Yamini, R. 2021. An efficient waste management technique with IoT based smart garbage system. https://www.sciencedirect.com/science/article/pii/S2214785321050380
8) Sala, D., Bieda, B. 2019. Life Cycle Inventory (LCI) Modeling of Municipal Solid Waste (MSW) Management Systems in Kosodrza, Community of Ostrov, Poland: A Case Study. https://www.intechopen.com/chapters/65542
9) Environmental management – Lifecycle assessment – Principles and framework. 2006. https://www.iso.org/standard/37456.html
10) Environmental management – Life cycle assessment Requirements and guidelines. 2006. https://www.iso.org/standard/38498.html.
11) Kulczycka, J. 2009. Reflecting the life cycle assessment method in environmental policy. *Economics and Environment*, 1(35), 52-61.
12) Guven, D., Ozgur Kayalica, M. 2022. Life-cycle assessment and life-cycle cost assessment of lithium-ion batteries for passenger ferry. *Transportation Research Part D: Transport and Environment*, 115, 103586.
13) Klugmann-Radziemska, E., Kuczyńska-Łażewska, A. 2019. The use of recycled semiconductor material in crystalline silicon photovoltaic modules production - A life cycle assessment of environmental impacts. *Solar Energy Materials and Solar Cells*, 205, 110259.
14) Suchorab, P., Iwanek, M., Żelazna, A. 2021. Profitability analysis of dual installations in selected European countries. *Applied Water Science*, 11, 34.
15) Angie, N., Tokit, E.M., Rahman, N.A., Anuar, F.S., Mitan, N.M.M. 2021. A preliminary conceptual design approach of food waste composter design. *Evergreen*, 8(2), 397-407 (2021). https://doi.org/10.5109/4480721
16) Waste Act. 2013. https://leap.unep.org/countries/pl/national-legislation/waste-act-0
17) Syafrudin, Budihardjo, M.A., Yuliastuti, N., Ramadan, B.S. 2021. Assessment of greenhouse gases emission from integrated solid waste management in Semarang city, Central Java,

Indonesia. *Evergreen*, 8(1), 23-35 (2021). https://doi.org/10.5109/4372257

18) Ibadurrohman, K., Gusniani, I., Hartono, D.M., Suwartha, N. 2020. The Potential Analysis of Food Waste Management using Bioconversion of The Organic Waste by The Black Soldier Fly (Hermetia illucens) Larvae in The Cafeteria of The Faculty of Engineering, Universitas Indonesia. *Evergreen*, 7(1), 61-66 (2020). https://doi.org/10.5109/2740946
19) González, L. G., Cordero-Moreno, D., Espinoza, J. L. 2021. Public transportation with electric traction: Experiences and challenges in an Andean city. *Renewable and Sustainable Energy Reviews*, 141(C). https://ideas.repec.org/a/eee/rensus/v141y2021ics1364032121000630.html
20) Paes, M. X., Medeiros, G. A., Mancini, S. D., Bortoleto, A. P., Puppim de Oliveira, J. A., Kulay, L. A. 2020. Municipal solid waste management: Integrated analysis of environmental and economic indicators based on life cycle assessment. *Journal of Cleaner Production*, 254, 119848.
21) Mesjasz-Lech, A. 2019. Reverse logistics of municipal solid waste – towards zero waste cities. *Transportation Research Procedia*, 39, 320-332.
22) Bayzhanova, S.B., Kudabaeva, A.K., Dzhanahmetov, O.K. 2013. On the question of ecological safety of leather production. *Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil'noi Promyshlennosti*, (6), 154-157.
23) Tashpulatov, S.S., Sabirova, Z.A., Cherunova, I.V., Nemirova, L.F., Muminova, U.T. 2020. A device for studying the thermophysical properties of bulk textile materials and their packages by the regular mode method in air. *Periodico Tche Quimica*, 17(34), 940-950.
24) Cherunova, I.V., Stefanova, E.B., Tashpulatov, S.Sh. 2021. Development of an algorithm for forming the structure of composite fiber insulation with heat-accumulating properties in clothing. *IOP Conference Series: Materials Science and Engineering*, 1029(1), 012041.
25) Bhupendra, K., Sh., Munish K. Ch. 2021. Life cycle cost analysis of municipal solid waste management scenarios for Mumbai, India. *Waste Management*, 124, 293-302.
26) Subramanian, V., Peijnenburg, W., Vijver, M., Blanco, C., Cucurachi, S., Guinee, J. 2022. Approaches to implement safe by design in early product design through combining risk assessment and Life Cycle Assessment. *Chemosphere*, 311, 137080.
27) Chernets, O.V., Korzhyk, V.M., Marynsky, G.S., Petrov, S.V., Zhovtyansky, V.A. 2008. Electric arc steam plasma conversion of medicine waste and carbon containing materials. In: *GD 2008 - 17th International Conference on Gas Discharges and Their Applications* (pp. 465-468).
28) Paton, B.E., Chernets, A.V., Marinsky, G.S., Korzhik, V.N., Petrov, V.S. 2005. Prospects of using plasma technologies for disposal and recycling of medical and other hazardous waste. Part 1. *Problemy Spetsial'noj Electrometallugii*, (3), 49-57.
29) Paton, B.E., Chernets, A.V., Marinsky, G.S., Korzhik, V.N., Petrov, V.S. 2005. Prospects of using plasma technologies for disposal and recycling of medical and other hazardous waste. Part 2. *Problemy Spetsial'noj Electrometallugii*, (4), 46-54.
30) Tyliszczak, B., Pielichowski, K. 2013. Novel hydrogels containing nanosilver for biomedical applications - Synthesis and characterization. *Journal of Polymer Research*, 20(7), 191.
31) Sharma, N., Kalbar, P., Salman, M. 2022. Global review of circular economy and life cycle thinking in building Demolition Waste Management: A way ahead for India. *Building and Environment*, 222, 109413.
32) Zaporozhets, A., Babak, V., Isaienko, V., Babikova, K. 2020. Analysis of the Air Pollution Monitoring System in Ukraine. *Studies in Systems, Decision and Control*, 298, 85-110.
33) Komilova, N.K., Ermatova, N.N., Rakhimova, T., Karshibaeva, L.K., Hamroyev, M.O. 2021. Urboekological situation and regional analysis of population health in Uzbekistan. *International Journal of Agricultural Extension*, 9(Special Issue), 65-69.
34) Shckorbatov, Y., Pasiuga, V., Kolchigin, N., Batrakov, D., Kazansky, O., Kalashnikov, V. 2009. Changes in the human nuclear chromatin induced by ultra wideband pulse irradiation. *Central European Journal of Biology*, 4(1), 97-106.
35) Berisha, A., Osmanaj, L. 2021. Kosovo scenario for mitigation of greenhouse gas emissions from municipal waste management. *Evergreen*, 8(3), 509-516 (2021). https://doi.org/10.5109/4491636