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Economic, Environmental and Social Aspects of Waste Management – the LCA Analysis

Summary: The intention of this article is to discuss the theoretical and practical aspects of the life cycle assessment (LCA) and its application in the modelling of waste management. The research was conducted with the use of the LCA-IWM software for the Ciechanowski Region of Municipal Waste Management, Mazovia Voivodeship. Three scenarios of municipal waste management have been analysed during the research – the municipal waste management system being currently in force (after 1st July 2013) and two fulfilling the Waste Management Plan for Mazovia 2012–2023. Following the concept of sustainability, the scenarios were compared in terms of environmental, economic and social aspects. The research proved that both proposed scenarios have considerable lower environmental impacts than the one being currently in force in the city of Ciechanow. Simultaneously, however, these scenarios generate higher costs per household and per 1 Mg of processed waste. In terms of the social indicators, the three scenarios are comparable. In conclusion, taking into account all indicators of sustainability, two proposed scenarios (scenario 2 and scenario 3) enable to satisfy the objectives of waste management law at commensurate costs and social acceptability.
Keywords: Sustainability**,** life cycle assessment (LCA), waste management, Poland.

Introduction

Life cycle assessment (LCA) is one of the methods of life cycle sustainability analysis (LCSA) that allows the evaluation of integrated waste management strategies from the point of waste generation and collection up to the final recovery and disposal. The application of LCA to the analysis of waste processes is still, however, very limited due to numerous barriers including data source and intensity, costs, poor information transfer, and finally time and expertise required to run the LCA procedures. Considering the above, some support for practitioners might bring the research described in the article. The aim of the research was to critically compare the three possible scenarios for waste management for the city of Ciechanow with the use of LCA technique. Consequently, the article discusses the assessment criteria to measure environmental, economic and social sustainability in the specific case study.

1. The idea of sustainability in waste management

Sustainable development can be perceived as such socio-economic development, in which there is a process of integrating political, economic and social aspects with maintaining environmental balance and the sustainability of natural processes, in order to meet the needs of current and future generations (cf. [1]). Consequently, the pillars of sustainable development are economic prosperity, environmental protection and social equity (see figure 1).

Environmental sustainability in municipal waste management can be defined through two major objectives, which are conservation of resources and reduction of environmental pollution (cf. [3]). Sample indicators for the environmental sustainability in waste management are the conservation of resources through the collection of secondary raw materials, air emissions, fuel and electricity consumption, noise (cf. [9]).

Economic sustainability in municipal waste management can be defined as such integration of waste management options as to operate them at the lowest possible cost – acceptable to the community, local government and a municipal waste treatment facility itself. Sample indicators for the economic sustainability in waste management are the investment costs, the annual maintenance costs, personnel employment costs and finally revenues from recovered materials and energy.

Social sustainability in municipal waste management can be defined as provision of appropriate level of waste services to meet health and comfort requirements of participants. Sample indicators for the social sustainability in waste management are the convenience of use, visual impact, odour, noise, and traffic nuisance (cf. [3]).

Following the Directive 2008/98/EC, all EU Member States "shall take into account the general environmental protection principles of precaution and sustainability, technical feasibility and economic viability protection of resources as well as the overall environmental, human health, economic and social impacts" while managing their waste (cf. [4]). Thus, only communes that fulfill the foundations of environmental, economic and social sustainability can claim that offer the integrated waste management services. To achieve the trade-off between the above is, however, a very challenging task.

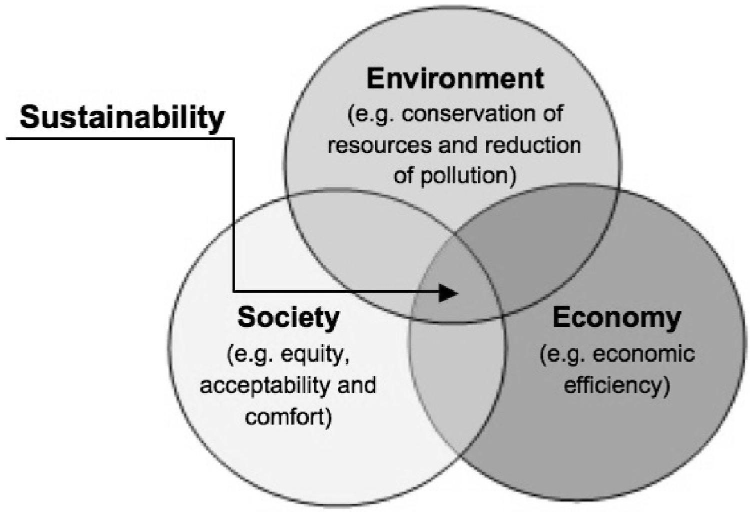

Figure 1. The three spheres of sustainability in municipal waste management

Source: own research.

2. Characteristics of the life cycle assessment (LCA)

Life cycle assessment (LCA) is one of environmental management techniques. Following a series of international standards for LCA, particularly ISO 14040:2006 (cf. [5]) and ISO 14044:2006 (cf. [6]), LCA can be defined as a technique for compilation and evaluation of the inputs, outputs and the potential environmental impacts associated with a particular product or process throughout its life cycle. Consequently, the main applications of LCA are in:
- analysing problems related to a particular product (eco-design),
- comparing between a number of products, ad exemplum, different types of packaging materials, and
- improving a given product or process, including a waste management strategy.

According to Arnold Tukker (cf. [8]), the LCA methodology is structured "along a framework that has become the subject of world-wide consensus and that forms the basis of a number of ISO standards. This framework divides the entire LCA procedure into four distinct phases:
- goal and scope definition,
- inventory analysis,
- impact assessment,
- interpretation (see figure 2)".

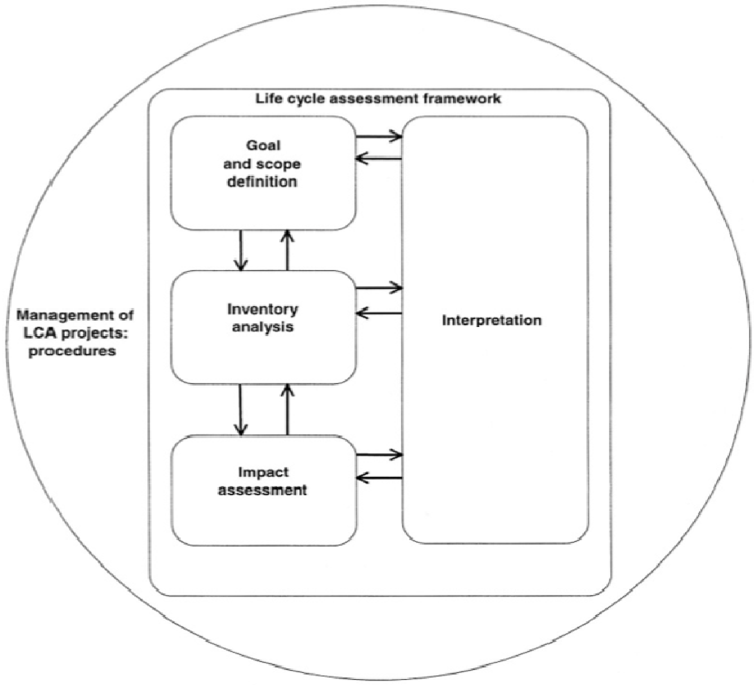

Fig. 2. Model of life cycle assessment (LCA)

Source: Arnold Tukker (cf. [8]).

Goal and scope definition is the first phase of the life cycle assessment (LCA). It incorporates a number of successive operations; the most important are determining the goal of the analysis, the definition of a product system and its functional unit, and finally defining the boundaries of the system. The goal of the study has to be formulated in a clear and appropriate way as to the intended application of the research results. The product system is a set of material and energy connected unit processes that fulfil one or more defined functions. The system boundary is "set of criteria specifying which unit processes are part of a product system" (cf. [6]).

Life cycle inventory (LCI) is the next phase of the life cycle assessment (LCA). It covers the collection and quantification of inputs and outputs for a given product system throughout its life cycle. The inputs and outputs are assigned to each unit process individually. Data collection is carried out in order to draw up a comprehensive balance of the energy, materials and chemicals collected from the environment that enter the system and that leave the system as emissions to the environment. The collected data can be measured, calculated or estimated.

Life cycle impact assessment (LCIA) is the third phase of the life cycle assessment (LCA). It defines the relationships between the environmental inven-

tory and defined impact categories, and category indicators. Consequently, the mandatory elements of that stage are as follows:
— selection of impact categories, category indicators and characterisation models,
— assignment of LCI results to the impact categories (classification),
— calculation of category indicator results (characterisation).

In practice, due to the fact that the LCIA phase is very complicated, there are adequate computer programs, ad exemplum simapro, umberto, LCA-IWM to support the analysis.

Life cycle interpretation is the last phase of the life cycle assessment (LCA). It is a procedure for the identification, qualification, verification and evaluation of the information obtained in the previous two phases (LCI and LCIA). Therefore, this phase ought to explain the limitations of the analysis as well as to enable the formulation of conclusions and recommendations regarding the reduction of environmental impacts.

To confront the environmental performance with economic and technical aspects, the technique of LCA can be supported by the procedure of multi-criteria decision analysis (MCDA). This is a formalised and structured process for selecting between alternatives, basing the decision on several criteria. In the case of integrated waste management systems, the criteria encompass environmental, economic and social sustainability.

To make the LCA analysis of waste management for the city of Ciechanow, the LCA-IWM programme will be applied. The LCA-IWM programme was developed within the European Programme entitled "The use of life cycle assessment tool for the development of integrated waste management strategies for cities and regions with rapid growing economies (LCA-IWM). It enables to enter the current environmental (ex. waste quantity and quality), economic and social indicators (ex. population age, average household size, gross domestic product per capita) into the programme. According to the authors from European universities, ad exemplum Technical University Darmstadt (TUD), the LCA-IWM programme was tested in 55 European cities and this makes it credible (cf. [2]).

3. Case study – a description of waste management scenarios

The city of Ciechanow is a medium size city, located in the central part of Poland in the Mazovia voivodeship. The city has around 45 000 inhabitants; 52% of the population are women. There are approximately 21000 Mg of municipal waste generated in Ciechanow yearly that gives 469 kg per person (Municipal Waste Treatment Facility in Ciechanow) (see table 1). The whole population of the city is covered by the municipal waste collection with some sort of separate waste collection that is at the level below 10%. Disposal at the landfill site remains the predominant form of municipal waste management. The city of Ciechanow is a member of the Association of Communes from the Ciechanow Region.

Table 1. Generation of municipal waste in Ciechanow in 2011

Waste fraction	Mass [tons/year]	Mass [kg/cap/year]
Paper and cardboard	4300	95
Glass	2000	44
Metals	600	13
Plastics	2300	52
Organic waste	6900	155
Hazardous waste	100	2
WEEE	400	9
Bulky waste	100	1
Other	4400	98
Municipal solid waste (in total)	21100	469

Source: own research upon the data of Municipal Waste Treatment Facility in Ciechanow.

Three following scenarios of municipal waste management have been modelled for the city of Ciechanow.

Scenario 1

This is the municipal waste management system being currently in place – before and after 1st July 2013. The system is run by the municipal waste treatment facility from Ciechanow (PUK Sp z o.o.). Municipal waste is collected selectively at source with the division for paper and cardboard, glass, plastics and metals, and the remaining. Regarding the municipal waste processing – besides landfilling at the sanitary landfill site in Wola Pawlowska (PUK Sp z o.o.), there is sorting of dry recyclables and composting of biodegradable waste (primarily garden waste) (see figure 3).

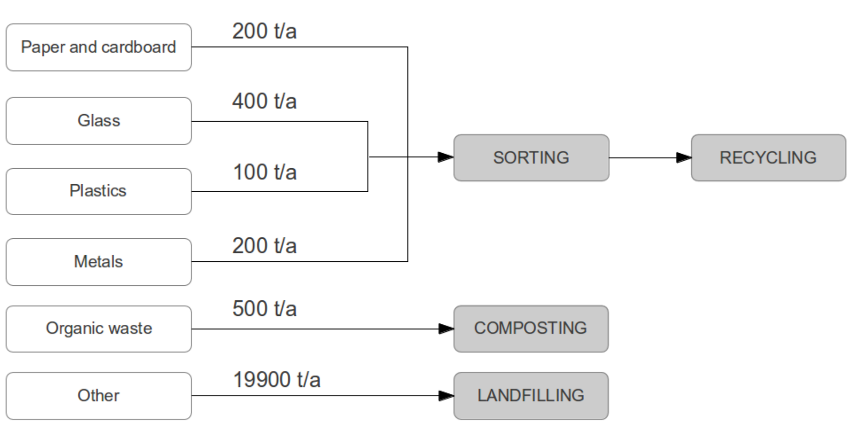

Fig. 3. Scenario 1 – the current municipal waste management system in the city of Ciechanow
Source: own research.

Scenario 2

It was assumed that the municipal waste management system would be such organised as to fulfil the foundations of the Waste Management Plan for Mazovia 2012–2023. To meet its objectives, municipal waste will be still collected selectively at source and subsequently processed in the regional facility in Wola Pawlowska. In three years time at the latest, the facility ought to offer:

— the semi-automatic sorting processes together with the production of refused derived fuel, having the capacity of 65 thousand tonnes of municipal waste annually,
— aerobic processing of 30 thousand tonnes of the organic fraction of municipal waste yearly in the BIODEGMA in-vessel system to produce compost,
— deposition of municipal solid waste residues at the sanitary landfill site equipped with a leachate collection system and a landfill gas control system converting landfill gas into energy.

Scenario 3

The municipal waste management system in the third scenario is another option for fulfilling the objectives of the Waste Management Plan for Mazovia 2012–2023. To meet its objectives, municipal waste will be still collected selectively at source but will be processed in the regional facility in Kosiny Bartosowe and Uniszki-Cegielnia (USKOM Sp z o.o.). The facility offers:

— the semi-automatic sorting processes having the capacity of 250 thousand tonnes of municipal waste annually,
— an installation for bio-stabilisation of municipal waste having the capacity of 100 thousand tonnes of municipal waste annually,
— deposition of municipal solid waste residues at the sanitary landfill site equipped with a leachate collection system and a landfill gas control system converting landfill gas into energy.

4. Results – the life cycle impact assessment (LCIA)

The life cycle assessment (LCIA) provides the comparison of the scenarios in terms of their environmental, economic and social impacts. Due to lack of the necessary information on the planned re-construction of the municipal waste treatment facility in Wola Pawłowska, this stage has been excluded from the analysis. Chosen results of the research are presented below.

The environmental impacts of the scenarios were presented with the use of the following impact categories recommended by CML 2001 method:

— depletion of abiotic resources,
— global warming
— human toxicity

— photo-oxidant formation,
— acidification,
— eutrophication.

Environmental impacts are presented in the form of an equivalent number of residents that are specific to each category of impact. The basis for their calculation are the equivalent emissions representative for the given category calculated for a period of one year and a citizen of Europe. Negative values indicate a decrease in environmental impacts, whereas positive values reveal environmental burden (see figure 4).

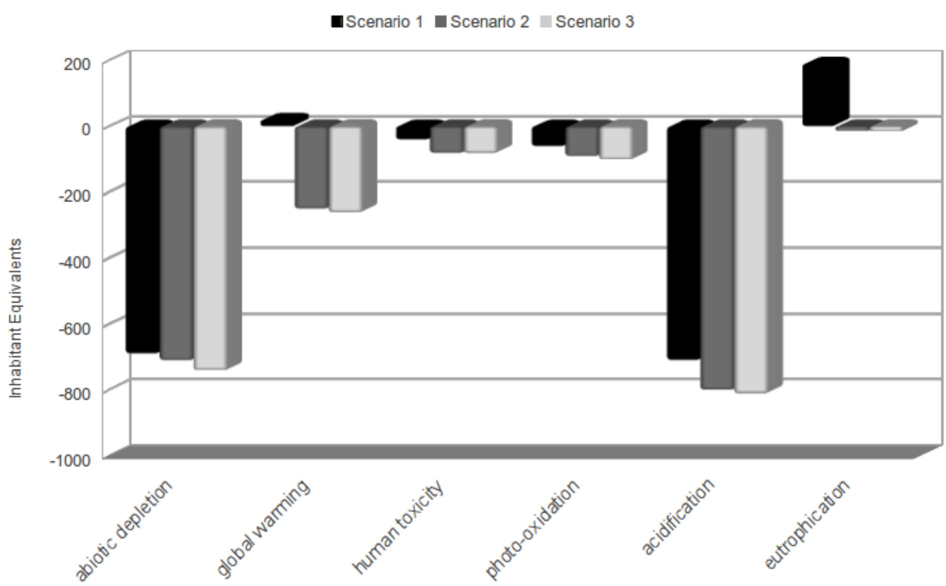

Fig. 4. Environmental impacts of the analysed scenarios for the city of Ciechanow

Source: own research.

Considering the environmental aspects, both proposed scenarios have considerably lower impacts than the scenario 1. The greatest differences are in terms of global warming, acidification and eutrophication. The reason is the modification of the waste management technology from landfilling into mechanical-biological processing. Furthermore, only the second and the third scenarios enable to fulfil the legal requirements, for instance, in reducing the amount of biodegradable waste being landfilled (see figure 5).

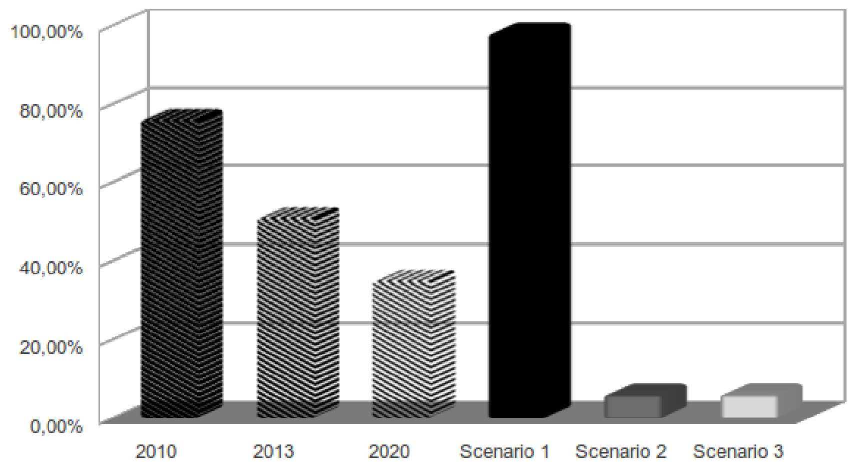

Fig. 5. Amount of biodegradable waste landfilled (as % of biodegradable waste produced in 1995) versus the analysed scenarios for the city of Ciechanow

Source: own research.

The economic issues related to municipal waste management were also analysed within the research (see table 2). The study proved that both proposed scenarios generate higher costs per household and per 1 Mg of processed waste than the one that is currently operating. Although, there are plenty reasons for that the most significant seems to be again the alteration of the technology for waste management. Simultaneously, however, these two scenarios give higher revenue from recovered materials and energy.

Table 2. Comparison of the economic efficiency of the analysed scenarios for the city of Ciechanow

Annual cost	Scenario 1	Scenario 2	Scenario 3
per 1 Mg of waste (€/Mg)	28	45	47
per household (€/capita)	38	62	64
per person (€/person)	14	22,4	23,7
Revenue from recovered materials and energy (€)	14 161	110 354	100 115
The difference between revenues and expenditures of municipal waste management (%)	183	111	107

Source: own research.

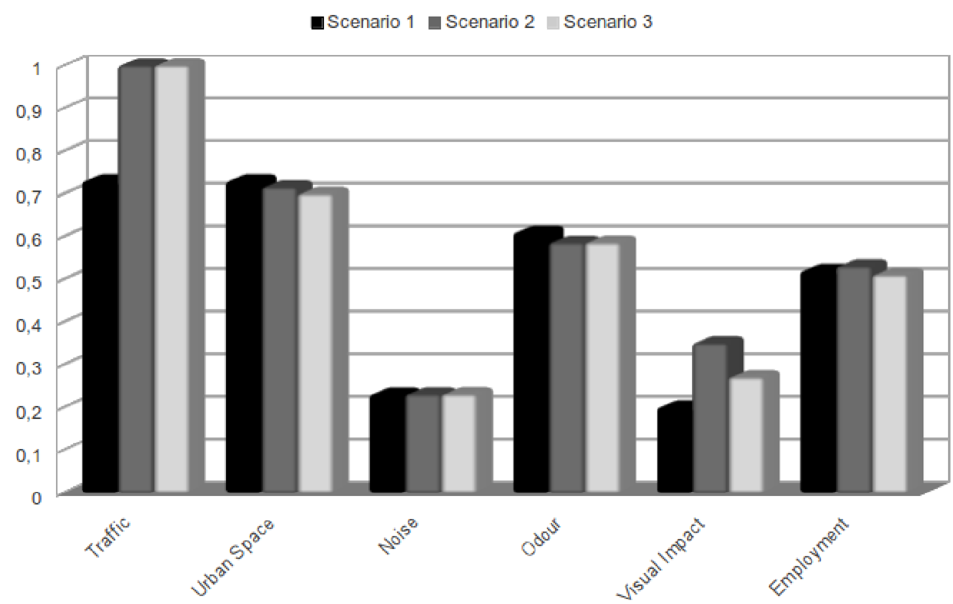

Fig. 6. Social indicators of the analysed scenarios for the city of Ciechanow

Source: own research.

The social indicators of municipal waste management were analysed for each scenario and phase individually. The research proved that there are no considerable differences in most social factors between scenarios (see figure 6). From the social point of view the value 0 represents the best situation whereas the value 1 the worst situation. Consequently, the social indicators of odour, employment rate or noise are comparable for each scenario. The differences are in such social indicators as the visual impact, the traffic nuisance and the urban space consumption. The second scenario – the one that employs the expansion of the municipal waste treatment facility in Wola Pawlowska generates the greatest visual impact and the space consumption. On the other hand, the third scenario – the one with MBP installation located approx. 30 km from the city of Ciechanow is responsible for the utmost traffic difficulties.

Conclusions

The completion of described research brought multidimensional advantages. On the one hand, the study proved that the environmental management method of life cycle assessment (LCA) could be applied for both the planning and the optimising of waste management systems from the sustainability perspective. Although LCA method is not free of shortcomings, it definitely supports the decision process and enables to reduce the risks of mismanagement of waste management systems and related to it serious environmental, financial and social consequences (cf. [9]). Furthermore, the applied programmes for conducting the life cycle impact assessment (LCIA) give the opportunity to review the analysed systems in meeting the stringent requirements of the waste law. On the other hand, the research examined the specific case study of the waste management system for the city of Ciechanow. Taking into account all indicators of sustainability – environmental, economic and social, only the scenario 2 and 3 are able to satisfy the objectives of waste management law at commensurate costs and social acceptability. The reason is that only these two scenarios offer the adequate waste processing in the form of mechanical-biological treatment.

Literature

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Ekonomiczne, środowiskowe i społeczne aspekty zarządzania gospodarką odpadami – analiza techniką LCA

Synopsis: Celem niniejszego artykułu jest przedstawienie podstaw teoretycznych oraz praktyczna aplikacja narzędzia zarządzania środowiskowego, jakim jest ocena cyklu życia (LCA), w modelowaniu gospodarki odpadami. Badanie wykonano z wykorzystaniem oprogramowania LCA-IWM dla ciechanowskiego regionu gospodarki odpadami, gmina Ciechanów, woj. mazowieckie. Analizie poddano trzy możliwe scenariusze gospodarki odpadami – aktualnie obowiązujący (po 1 lipca 2013 r.) oraz dwa zgodne z Wojewódzkim Planem Gospodarki Odpadami dla Mazowsza na lata 2012–2017 z uwzględnieniem lat 2018–2023. Zgodnie z założeniami koncepcji zrównoważonego rozwoju, scenariusze porównano pod kątem aspektów środowiskowych, ekonomicznych i społecznych. Badania pokazały, iż oba proponowane scenariusze (scenariusz 2 i scenariusz 3) mają znacznie niższe oddziaływania środowiskowe niż aktualnie realizowany system gospodarki odpadami w mieście Ciechanów. Równocześnie jednak oba powyższe scenariusze generują znacznie wyższe koszty w przeliczeniu na gospodarstwo domowe i Mg odpady. Ze społecznego punktu widzenia scenariusze nie wykazują istotnych różnic. Reasumując, mając na uwadze wszystkie analizowane wskaźniki zrównoważonego rozwoju, należy stwierdzić, iż tylko scenariusz 2 i scenariusz 3 zapewnia realizację celów prawa gospodarki odpadami przy stosunkowo umiarkowanych kosztach i akceptowalności społecznej.
Słowa kluczowe: Zrównoważony rozwój, ocena cyklu życia (LCA), zarządzanie gospodarką odpadami, Polska.