EWA KAMIŃSKA[1)]
MARCIN ŚWITAŁA[2)]
TOMASZ KAMIŃSKI[3)]

SELECTED ISSUES OF THE ECOBALANCE ANALYSIS OF RECYCLED MATERIALS USED IN ROAD CONSTRUCTION

WYBRANE ZAGADNIENIA ANALIZY EKOBILANSOWEJ MATERIAŁÓW POCHODZĄCYCH Z RECYKLINGU, WYKORZYSTYWANYCH W BUDOWNICTWIE DROGOWYM

STRESZCZENIE. W artykule przedstawiono zagadnienia inwestycji drogowych w aspekcie analiz środowiskowych oraz kosztowych. Kompleksowa ocena środowiskowych i ekonomicznych parametrów obiektów inżynieryjnych, opiera się na ilościowych informacjach środowiskowych i ekonomicznych oraz bazuje na wynikach analiz oceny cyklu życia, kosztach cyklu życia oraz kosztach całego życia (WLC). W artykule zwrócono uwagę na problem potencjalnego wpływu na środowisko materiałów wykorzystywanych w budownictwie drogowym, pochodzących m.in. z procesu recyklingu, w kontekście oceny cyklu życia produktu (ang. Life Cycle Assessment, LCA). W pracy przedstawiono również wymagania gospodarki o obiegu zamkniętym (ang. Circular Economy) gospodarowania tego rodzaju materiałami. Zwrócono uwagę na analizę LCA, jako istotne narzędzie, umożliwiające pozyskanie kompletnych informacji o wpływie badanych materiałów na środowisko. Kolejnym elementem poruszonym w artykule jest temat oceny efektywności kosztów infrastruktury drogowej. Zwrócono uwagę na koncepcję kosztów całkowitych i zasadę współzależności kosztów. Opisano problem kosztów i korzyści inwestycji drogowych na przykładzie LCCA.

SŁOWA KLUCZOWE: ocena cyklu życia, LCA, recykling, gospodarka o obiegu zamkniętym, LCCA.

ABSTRACT. The paper presents road project issues in terms of environmental and cost analyses. Comprehensive assessment of the environmental and economic performance of engineering structures is based on quantitative environmental and economic information and draws on the results of life cycle assessment, life cycle cost and whole-life cost (WLC) analyses. The paper highlights the issue of the potential environmental impact of materials used in road construction, including those derived from the recycling process, in the context of life cycle assessment (LCA). The paper also outlines the requirements of a circular economy for the management of such materials. Attention was drawn to LCA as an important tool for obtaining comprehensive information on the environmental impact of the materials under study. Another element addressed in the paper is the topic of assessing the cost-effectiveness of road infrastructure. Attention was given to the total cost concept and the principle of cost interdependence. The problem of costs and benefits of road projects is described using the LCCA as an example.

KEYWORDS: life cycle assessment, LCA, recycling, circular economy, LCCA.

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1) Road and Bridge Research Institute, Warsaw; ekaminska@ibdim.edu.pl ✉
1) Road and Bridge Research Institute, Warsaw; mswitala@ibdim.edu.pl
1) Road and Bridge Research Institute, Warsaw; tkaminski@ibdim.edu.pl

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1. INTRODUCTION TO THE ECOBALANCE ANALYSIS USING LCA AS AN EXAMPLE

1.1. REQUIREMENTS RESULTING FROM THE APPLICATION OF EN ISO 14040 AND 14044:2009 [1, 2]

The increasing demand for expansion, maintenance, rehabilitation of road infrastructure and the environmental footprint associated with the projects highlight the need to use recycled materials in everyday practice. Among the methods used to carry out environmental analyses, life cycle analysis (LCA) and derivatives of this methodology (including carbon, water and ecological footprints) [3] have the greatest potential for application.

The LCA is carried out to obtain information on the comprehensive environmental impact of a research facility. In the study, the weaknesses of the solution are taken into account, a thorough assessment takes place and, as a result of the analyses, countermeasures are determined to permanently reduce the environmental impact [4].

Analyses are carried out using a range of methods, enabling comprehensive determination of all significant emissions, production agents used, environmental impact, human health and depletion of natural resources for the study object, with reference to defined system boundaries [5].

The environmental impact of recycling is assessed using IT-based, database-driven tools, e.g. the LCA for Experts from the German company SPHERA or the Dutch tool SimaPro. Most of the data needed for environmental analyses are not publicly available, which poses a problem when calculating the level of carbon footprint is necessary for specific companies/institutions from 2025 onwards. As part of the need to report on the sustainability strategy, obtaining information on this will be essential. The aforementioned IT tools use the LCA methodology, and the built-in calculation methods (e.g. Impact, ReCiPe) and the process and material databases they contain enable the third stage of LCA – life cycle impact assessment (LCiA).

The LCA method has been described and defined in many scientific studies. For the purpose of this publication, a definition of LCA has been adopted, in accordance with the PN-EN ISO 14040:2009 standard, where LCA relates to "the environmental aspects and possible environmental impacts (...) during the life cycle of a product, from raw material acquisition, through manufacturing, use, processing to end-of-life, recycling and final disposal (i.e. cradle-to-grave)" [1]:

The LCA comprises four stages:

- Goal and Scope Definition,
- Life Cycle Inventory Analysis – LCI,
- Life Cycle Impact Assessment – LCiA,
- Life Cycle Interpretation [1].

Within each of the LCA stages listed, the actions required for it must be carried out. First, it is the determination of the purpose of the activity and the scope of the analysis, which results in the selection of the appropriate functional unit[1] and the definition of the product system[2] and the system boundary[3]. The aim of this stage is also to determine the form of application of the analysis results, the reason for conducting the analyses and to select the recipient [6].

The level of detail in the analyses is determined by the type of addressee of the analyses.

There are four main options for defining the boundaries of the ecobalance analysis system. They include:

- "gate to gate" – covering only processes from the production phase; used to determine the environmental impact of a single production phase or process,
- "cradle to grave" – covering the material and energy production chain and all the processes from raw material extraction, through production, transport and the use phase to the end-use phase,
- "gate to grave" – covering processes from the use and end-of-life phase (everything after production completion), used to determine the environmental impact of a product after any processes involved in its manufacture,
- "cradle to gate" – covering all processes from raw material extraction through the production phase, used to determine the environmental impact of the production of a product [7].

In the second step, an analysis of the set of inputs (products, materials, energy streams entering the unit

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[1] Quantitative effect of the product system used as the reference unit

[2] A set of unit processes and elementary product streams fulfilling one or more defined functions and modelling the life cycle of an object

[3] Understood as "the interface between the product system and the environment or other product systems"

process) and outputs (product, material, energy stream, waste, emissions) leaving the unit process is prepared. As a result of this stage of the LCA, a plan is prepared for flows crossing system boundaries [1].

The third stage of the LCA aims to understand and assess the magnitude and significance of the possible environmental impact of a product system throughout its life cycle. The aim of this phase is to provide additional information to help evaluate the results of the analysis of the set of inputs and outputs of the product system in order to better understand their environmental significance. LCiA, includes mandatory (classification, characterisation) and optional (normalisation, grouping and weighting) elements [1]. The mandatory elements of the analysis can be carried out using software supporting LCA calculations, e.g. Gabi, SimaPro, Umberto.

The final stage of the analysis is the formulation of conclusions, an indication of limitations and recommendations resulting from the research carried out in the previous LCA phases, meaning that the life cycle interpretation is a summary of the research results, consistent with the stated aim and scope of the research [8, 9].

The outcomes obtained as a result of the LCA analysis make it possible to compare the degree of nuisance and reusability of worn out components. The results thereof indicate opportunities for product improvement or comparison with other products. In many countries, obtaining specific LCA results makes it possible, for example, to award an environmental product label [10]. The importance of applying the principles of LCA is evidenced by the fact that a number of regulations and policies mark its relevance as a method to estimate the potential environmental impact of an activity and, as a result, to consider it more or less environmentally friendly.

1.2. ANALYSIS OF THE ENVIRONMENTAL IMPACT OF THE FACILITY ACCORDING TO THE REQUIREMENTS OF EN-17472 (2020) AND EN-15804 A2:2020-03 (2019) [11, 12]

According to the EN-17472 (2020) and EN-15804 (2019) standards, environmental impacts are divided into five modules (life cycle stages) as shown in Table 1.

They include the following phases:

- production (A1–A3),
- construction (A4–A5),
- use (B1–B6),
- End-of-Life (C1–C4),
- benefits and burdens (D).

Within the identified five stages of the life cycle, there are modules related to the performance of individual activities, grouped as follows [13]:

- **modules A1–A3** – for roads, the module deals with the environmental impact of the processes involved in extracting the material, mainly from quarries.

Table 1. Life cycle modules in compliance with the EN-17472 (2022) and EN-15804 (2019) standards [11, 12, 13]

Production			Construction		Use							End-of-Life				Potential benefits and burdens
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Supply of raw materials	Transportation	Production	Transportation	Construction – installation process	Use, Installed product	Maintenance	Repair	Replacement	Renovation	Operational energy consumption	Operational water consumption	Deconstruction	Transportation	Waste treatment	Utilization	Recovery, reuse, potential recycling

Depending on the type of pavement (rigid, flexible), the module analyses the environmental impact of extracting a range of aggregates, gravel, sand, infill cement or bitumen. The transportation of raw materials to mix plants and asphalt plants is included in modules (A2) and (A3). Asphalt production processes include energy used for heating and mixing aggregates. Together, these modules make up the production phase, which, because of the processes involved, is also referred to as the "from cradle to gate" phase (system boundaries described in section 1.1.),

- **modules A4–A5** – the impact of material transportation to the construction site is included in module A4. These are the materials found in the wearing course, binder course and subbase. Potential environmental loads specific to the A4 stage, result from soil investigation (demolition and site clearance, excavation and machinery or other processes required for the road construction),
- **modules B1–B6** – the six modules in Group B are related to the road use stage. Module one (B1) deals with carbonisation processes, leachate, brake linings, tyre abrasion. Module two (B2) is related to the road maintenance process (e.g. dust, snow removal), traffic lights or lighting. Module three (B3) considers the environmental impact resulting from repairs of joints and areas of pavement where cracks and damage have been diagnosed. The next module (B4) deals with the impact of replacing the wearing course, lighting, traffic lights, street finishing, cables or pipe networks. Road repairs, on the other hand, are included in the module (B5). The last module (B6) deals with the impact of electricity consumed by road elements (e.g. traffic signals or lighting) and fuel consumed by vehicles,
- **module C1–C4** – module C is related to the environmental impact of pavement dismantling processes, transport to the processing plant, further waste treatment processes and e.g. landfilling,
- **module D** – deals with the benefits of waste management processes (recycling, reuse in subsequent road use cycles). Processes for reusing asphalt as a recycled asphalt pavement, for example, are included at this stage.

2. CONSTRUCTION WASTE MANAGEMENT IN TERMS OF A CIRCULAR ECONOMY AND EU PRINCIPLES FOR A RESOURCE-EFFICIENT AND SUSTAINABLE EUROPE

The EU Circular Economy Action Plan (CEAP) is published as part of the European Green Deal strategy (COM/2020/98) [14]. It contains a description of the objectives and challenges that, if worked out, would allow economic growth to be decoupled from resource use. The CEAP identifies actions that, if achieved, will bring EU countries closer to the implementation of the idea of a "sustainable economic system". The framework for monitoring the circular economy (CE) is based, among other things, on European statistics [15].

Waste from construction and demolition accounts for more than 30% of all waste generated in the EU. This group includes waste generated during construction, demolition of buildings and infrastructure and during planning and maintenance of road infrastructure [16].

In EU countries, waste management is regulated by the Waste Directive 2008/98/EC, revised in July 2018, and the European Commission Decision (2014/955/EU) of 18 December 2014. [17, 18]. According to the decision, construction and demolition (C&D) waste is defined as: *"waste corresponding to the types of waste covered by Chapter 17 of the list of waste established by Decision 2014/955/EU in the version in force on 4 July 2018"*.

On the national level, the aforementioned regulations are implemented in the Waste Catalogue Regulation which lists waste from the construction, renovation and dismantling of buildings and road infrastructure (including soil and ground from contaminated sites) in group 17 – in particular:

- 17 01 01 – Concrete waste and concrete debris from demolition and renovation works,
- 17 01 07 – mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06,
- 17 01 81 – waste from renovation works and reconstruction of roads,
- 17 03 01* – bituminous mixes containing tar,
- 17 03 02 – bituminous mixes other than those mentioned in 17 03 01,
- 17 05 08 – track ballast (aggregate) other than the one mentioned in 17 05 07,

Table 2. Waste from construction generated and landfilled to date between 2011 and 2021 [thousand tonnes]

No.	Years	Subject to recovery	Disposed of			Transferred to other recipients	Temporarily stored	Total
			of which stored	of which thermal*	Total			
1.	2011	6741.3	37	no data	37	no data	38.9	6817.2
2.	2012	4571.2	8	1.1	9.1	no data	48	4578.3
3.	2013	4571.2	0	0.1	0.1	none	26.9	4598.2
4.	2014	306.3	1.1	0.4	1.5	3774.9	29.4	4112.1
5.	2015	520	0	no data	0	4987.4	26.5	5533.9
6.	2016	5009	229.9	no data	244.5	2076.1	11.6	7341.2
7.	2017	1061	6	no data	7	1782	45	2895
8.	2018	3388	6	no data	17	333	36	3774
9.	2019	1462	7	no data	35	1400	35	2932
10.	2020	4686	5	no data	5	1181	1480	7352
11.	2021	3234	5	no data	36	231	3	3504

*Since 2015 thermal disposal of waste has not been listed in the summaries

Source: Own elaboration based on "Environmental Protection" Reports from 2012-2021, CSO, Warsaw [20].

- 17 06 04 – insulation materials other than those mentioned in 17 06 01 and 17 06 03 [19].

In 2020, a total of 1 787 847 Mg of waste was generated in Poland, including 7352 Mg of waste from construction industry.

Table 2 summarises the forms of construction waste management in Poland, 2011–2020.

Due to the diversity and nature of construction waste, it poses a problem to separate waste related only to road infrastructure from this stream. In the CSO's summaries, the aforementioned waste is included in the group of waste from construction. It should be mentioned that, in accordance with Section 6a of the Waste Act, from the beginning of 2025, construction and demolition waste will be collected selectively, divided into at least six fractions, i.e.:

- wood,
- metals,
- glass,
- plastics,
- gypsum,
- mineral waste (including concrete, bricks, tiles and ceramic materials and stones) [21].

As can be deduced from Table 2, construction waste is managed based on the waste hierarchy principle[4]. Primarily recycled (approx. 63% of waste in 2020), transferred to other companies (approx. 16% of waste in 2020), approx. 20% of waste in 2020 was stored. As noted in the CSO studies, waste is recovered in-house by the generator and transferred to other recipients, respectively for recovery/disposal processes (including landfilling).

According to Lederer, the most important waste materials that can be reused include recycled mineral construction and demolition waste. They can be managed in the form of recycled aggregate in concrete, they can replace gravel in unbound form, there can be a process of asphalt recycling, or replacing the raw material mix in cement by rubble material recycling [22].

The activities related to the reuse of materials are in line with both the principles of sustainable development and the EU guidelines[5] regarding circular economy requirements. Road construction, especially in the aspect of asphalt pavements, can take part in reducing carbon dioxide emissions by reusing asphalt waste. This is one of the objectives of the so-called European Green Deal which aims to achieve a climate-neutral Europe by 2050 [23].

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[4] Prevention, preparation for re-use, recycling, other recovery methods, e.g. energy recovery and disposal. In accordance with Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste OJ L 2018.150.109

[5] European Commission. (2020). Circular Economy Action Plan. For a cleaner and more competitive Europe

According to the European Asphalt Pavement Association (EAPA), the amount of available reclaimed asphalt in Europe is 49.5 Mt. 76% of this material was reused in the asphalt industry, 20% in the production of new asphalt mixes and in the recycling process, e.g. as granular material in unbound road layers. Approximately 4% has not been managed and is landfilled [24].

According to Steger and Bleischwitz, the construction sector, in particular road construction, is one of the three main areas in which the most resources are used in the countries of the European Union [25].

The policies and strategies of EU countries contain a number of provisions on moving towards economically sustainable Europe, despite the observation of adverse phenomena (e.g. population growth, migration, scarcity natural resources, unfavourable climate change or pandemics) that could jeopardize or slow down the achievement of environmental goals [27].

In September 2015, an action plan was adopted that defined a model for sustainable development at a global level (the 2030 Agenda for Sustainable Development) [27].

In line with the trend of waste reuse, at the end of 2021, the Regulation of the Minister of Climate and Environment on the determination of specific conditions for the loss of waste status for reclaimed asphalt pavement waste (Journal of Laws 2021, item 2468) was published in Poland. The provisions of the regulation, in terms of the management system and the demonstration of compliance with the conditions for the loss of waste status by the reclaimed asphalt pavement, for the holder of this waste, have been in force since the beginning of 2023 [28].

3. EXAMPLES OF THE LCA METHOD APPLICATION

The use of LCA is recommended in European Union environmental documents and strategies, including: "Integrated Product Policy", "Green Public Procurement", the " A new Circular Economy Action Plan for a cleaner and more competitive Europe", in eco-labelling, in the "Strategy for changing production and consumption patterns towards sustainable development". Its use allows different scenarios to be compared and the most favourable option to be selected, allowing environmental policy decisions to be made on the basis thereof [29, 30, 31, 32].

Closing the material and energy flow process in the life cycle of a product, meaning the management of resources, energy, waste (including emissions), in a way that reduces their consumption – allows them to be used more sparingly and is an indication for those creating the environmental profile of a facility (the effect of the third stage of the LCA) of which activities to choose, when carrying out an ecobalance analysis [33].

These goals can be achieved in the long term through proper design, maintenance, repair, reuse, re-manufacturing, renovation and recycling, and changing the public awareness.

A number of studies have analysed the use of various material admixtures for road pavement construction, often to expand the possibilities of using other resources than those already used. Attention was paid to the appropriate selection of the functional unit, the assumed lifetime of the facility and what type of environmental impact the results of the analyses were concerned with.

According to one paper, a comprehensive economic life cycle analysis (EIO-LCA) of a concrete pavement with a precast alumina-doped ECC coating was attempted. The impact assessment (LCiA) is presented at the midpoint and endpoint level, for selected impact categories specific to the adopted calculation methods (TRACI, CML). Three hypothetical single-lane pavements were analysed (1 concrete pavement with the following dimensions: 50 m×3.6 m×225 mm; 2 – ECC pavement with the following dimensions: 50 m×3.6 m x 220 mm, 3 – concrete pavement with PCB-ECC overlay, with the following dimensions: 50 m×3.6 m×220 mm). The time frame for the assumptions made was 40 years. The results obtained concerned: the project impact on human health, greenhouse gas (GHG) emissions, demand for cumulative non-renewable energy (CED) and noise reduction [34].

In 2022, Switzerland compared the environmental impact of stone-mastic asphalt and semi-mastic asphalt, taking into account noise issues. The analyses were carried out for a pavement layer in urban areas with a length of 1 km, a width of 7.5 m (two lanes), a thickness of 30 mm, a traffic load capacity of T4, with an average vehicle speed of 50 km/h for a period of 20 years. The results concerned the impact on: climate change (i.e. global warming potential over a 100-year period as a characterising factor, expressed in [kg CO_2 equivalent], or cumulative non-renewable energy demand [MJ-eq]. Analyses were carried out using the ReCiPe method [35].

A comparative analysis of the environmental impact of sixteen mixtures was carried out for part of a new urban road near Citta di Castello, Italy: CTB with and without RAP, with different cement percentages, three different production methods (CPM, MIP) and recycling procedures. An LCA analysis was used in combination with an uncertainty analysis (CML 2015 method). The road pavement structure corresponding to a 1 km section of a 22 m wide urban main road was analysed together with a CTB (Cement Treated Base) layer over a 20-year time frame. Impact categories that were of interest to the authors included: climate change, acidification, abiotic resource depletion – elements, reserves, abiotic resource exhaustion – fossil fuels, eutrophication, freshwater ecotoxicity, human toxicity, marine ecotoxicity, ozone depletion, photochemical oxidation and terrestrial ecotoxicity [36].

One study analysed the LCA of different types of road pavement technology based on the use of bituminous mixes containing recycled materials (crumb rubber from used tyres and reclaimed asphalt pavements). The maintenance of the wearing course at a 1 m section of asphalt pavement was adopted as the functional unit. The analyses were carried out taking into account different scenarios that: resulted from a combination of production, construction and maintenance activities and by comparing them with a reference case using standard materials. Gross energy demand and global warming potential indices were calculated, in addition to damage categories specific to the ReCiPe method (e.g. human health, ecosystem quality, resource consumption) [37].

According to Polo-Mendoza et al, the boundaries chosen were those of a cradle-to-gate system, containing the processes of material production, its transportation to the asphalt production plants and the production of mineral and asphalt mixes. The production of 1 tonne of mineral and asphalt mix (WMA) was taken as the functional unit. Estimates have been made of ozone depletion, global warming, smog, acidification, eutrophication, carcinogenic and non-carcinogenic respiratory effects, ecotoxicity and fossil fuel depletion [38].

4. EVALUATING THE COST-EFFECTIVENESS OF ROAD INFRASTRUCTURE

Road infrastructure cost management relies heavily on the use of cost information in planning, organising, coordinating and controlling the related activities [39]. The total cost concept is especially useful, highlighting the need for a detailed cost analysis across all life cycle phases of a project. The principle of "interdependence", or cost substitution, which emphasises the complexity of cost relationships and the need to recognise trade-offs is of key importance [40]. In practice, this requires research and expertise in the topics of: interactions between the various life-cycle costs, cost differences between the investment options considered, and the possibility of compensatory exchange. Its goal is to balance cost increases in certain phases against reductions in others. (Increases in costs in one or more phases are offset by reductions in project implementation costs in other periods) [41].

In managing the cost-effectiveness of road infrastrukture, it's crucial to consider the productivity of factors that practically influence cost levels [42]. The concept of cost-effectiveness is most often understood as a management approach aimed at achieving the best performance of the business while minimising the accompanying costs [43].

Among the many cost analysis methods encountered in accounting practice and theory, the LCCA method, referred to as life-cycle cost analysis, which combines a system approach with the principle of cost efficiency, is increasingly mentioned. Overall, it allows an assessment of the long-term economic benefits between competing alternative projects. At the operational level, it is in turn a tool for benchmarking costs for a given period, which forms the basis for selecting the option with the lowest total life-cycle cost. Its main phases cover the period starting from the commissioning of the facility in question until its limit state is exceeded [44]. The scope of the assessment includes both initial expenditure and discounted future infrastructure management costs [45].

The calculations carried out as part of the analysis take into account the variability of the value of money over time and are based on the NPV (Net Present Value) method. Particularly important appears to be the fact that the LCCA makes it possible to demonstrate that any operational savings (i.e. utility savings resulting from the solutions adopted at the project design stage) are sufficient to justify the choices of accepted and implemented, often more expensive, solutions [46].

The LCCA analysis distinguishes between two main categories of costs, namely: manager costs and user costs. The first group usually includes the following costs: (a) primary and future costs – related to engineering services, contract administration, construction supervision, (b) primary construction costs, (c) costs of future emergency renovations and repairs, preventive works, future upgrading or construction and related engineering and administrative costs, (d) reconstruction costs, and (e) the residual value at the end of the analysis period understood as a negative cost. User costs, on the other hand, include expenses resulting from vehicle operations, delays and accidents [47].

Literature offers many examples of LCCA being used to address road asset management issues. The authors, Mikolaj and Remek, discuss the usefulness of this method with the example of a system supporting the management of road pavements in the Slovak Republic, distinguishing two main areas of benefit, i.e. internal and external. In the first group they include a reduction in road use expenses which consist of vehicle operating and travel costs. External benefits, on the other hand, are mainly savings from measures that reduce emissions, noise levels and road accidents [48].

It is worth noting that the life cycle method can be used for a variety of purposes. In addition to cost analysis, environmental analysis is also gaining popularity. A comparative life-cycle analysis for two types of road pavement (concrete and asphalt) in terms of the environmental impacts of different technological solutions can serve as an example. In the example in question, the research was carried out according to the cradle to grave life cycle which consists of four phases: production, construction, use and end of life. The time frame of the analysis covered a period of 30 years with several successive implementation options in the following scopes: construction (five), maintenance and rehabilitation (four), and road use (four) assuming different fuel consumption savings within the projected vehicle traffic. The results indicate that the use of more durable pavements, although a more costly solution on the investment side, provides greater environmental and economic benefits over the life cycle [49].

5. SUMMARY

The paper presents the background of construction waste management in legal, financial and environmental terms. The results of selected environmental analyses on the application of LCA in road construction are also presented, as a tool to quantify the impacts resulting from the use of traditional and alternative materials. The findings suggest that road projects should be comprehensively carried out, considering technical, social, economic, and environmental criteria, including sustainable project principles.

This is particularly related to the release of significant greenhouse gas emissions into the environment, non-compliance with circular economy principles (e.g. low or no efficiency in the use of natural resources), at least at one of the LCA stages. Given the large number of stakeholders involved in the project process, it is important for them to act in a coherent manner and to simplify the procedures necessary to obtain permission to reuse a range of materials, together with the dissemination of knowledge that such a possibility exists [50].

Projects aimed at developing road infrastructure, including the construction of new transport routes and interchanges, as well as upgrading existing ones, play a crucial role in fostering social, economic, and environmental growth, both nationally and regionally [51]. The reference literature points out that road infrastructure is the backbone of any economy. The more a region remains saturated with infrastructure elements, the more development opportunities it offers [52]. It should be noted that the road infrastructure responsible for transport accessibility has been identified as critical infrastructure for the efficient functioning and development of a modern state, society and economy [53].

The work presented here aims to draw attention to the need to publicise the carrying out of ecobalance analyses associated with the implementation of road projects. Although they have been carried out for many years, their popularity and ability to be used to meet the demands of running the operations that are perceived as environmentally-friendly and resource-efficient, have only recently been recommended. This is due to a number of provisions in EU documents promoting sustainable activities and the reduction of greenhouse gas emissions.

The issue of the environmental impact of objects, systems or processes is of interest to many scientific disciplines, ranging from economics (Life Cycle Costs), social issues (Social Life Cycle Assessment), management (Life Cycle Management) to the problem of environmental assessments (Life Cycle Assessment), where it is one of the key issues in explaining the complex relationship between the studied system and the surroundings (environment) and the interactions occurring between them (material flow streams, emissions).

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