ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ
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"LIFE CYCLE ASSESSMENT" LITERATURE REVIEW

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ABSTRACT

The rapid development of construction in recent years has led to environmental pollution, increasing resource consumption and emissions. The European Union's policy of reducing the carbon footprint and rational use of finite and non-exhaustible natural resources is a prerequisite for applying methods that optimize the construction process. This paper aims to present advances in the field of sustainable construction and to introduce the methods developed for life cycle assessment of a facility. As a result of the analysis carried out, the feasibility of applying some of the known assessment methods to hydraulic structures is evaluated.

1. Introduction

The construction industry is one of the fastest growing industries in Europe and worldwide. In Europe, the construction industry is by far the largest employer. According to the European Construction Industry Federation (FIEC [1]), the total number of construction companies on the territory of the European Union exceeds 3 million, of which 95 % are small and medium-sized ones with less than 20 employees. The total number of employees is over 12 million, representing just over 6 % of total employment and just over 27 % of industrial employment. In Bulgaria, according to the Bulgarian Construction Chamber (BCC) [2], the relative share of the construction sector in the Gross Domestic Product (GDP) for the third quarter of 2021 was 4,5 %. The number of employed persons at the end of September 2021

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was 126,8 thousand, or 5,6 % share of the total employed persons in the country. According to the Eastern European Construction Forecasting Association (EECFA [3]), the growth forecast for the total construction output in Bulgaria is 6,5 % for 2021 and 16,5 % for 2022.

The expansion in construction is correspondingly increasing the negative impact on the environment. The sector generates large quantities of greenhouse gases and construction waste, while at the same time being one of the largest consumers of natural resources. This emphasizes the need for a uniform approach to measuring the environmental footprint over the lifetime of a facility. In the following, a review of the life cycle assessment approaches is presented from a point of view of hydraulic engineering structures, and especially of (small) dams, since to our knowledge, this field has not been covered so far.

1.1. Sustainable Development Concept

The zero pollution ambition for Europe is announced in the European Green Pact, which is part of the European Commission's strategy to implement the UN Sustainable Development Goals agenda.

In 2020, the European Commission adopted the new Circular Economy Action Plan [5], which is one of the key elements of the European Green Deal [6]. The EU's transition to a circular economy will reduce pressure on natural resources. It is also a prerequisite for achieving the EU's 2050 climate neutrality target.

The new Action Plan addresses the entire life cycle of products. It addresses the way products are designed, promotes circular economy processes, encourages sustainable consumption and aims at ensuring that waste generation is prevented and also that the resources used are retained in the EU economy for as long as possible.

At its core, sustainable development is seen in three main aspects: social, economic and environmental.

The term “Sustainable Development” was first used in 1987 in the World Commission on Environment and Development (WCED) report “Our Common Future“, also known as the Brundtland Report [7]. According to the report, funded by the United Nations, sustainable development is that which “meets the needs of the present without compromising the ability of future generations to meet their own needs”.

1.2. “Life cycle” definition

The term “Life Cycle” refers to all activities that take place throughout the life of a product or facility. This lifetime covers the period from production/construction to demolition/recycling.

Life cycle assessment studies are concerned with the environmental, social and economic consequences and how to make them as favourable as possible in order to achieve sustainable development. The concept also is seen as a way of thinking to support decision-making activities by planners, developers, etc. There are many definitions of the term Life Cycle Assessment (LCA), some of which formulated as follows:

- LCA is one of the tools used to investigate the “cradle to grave” environmental consequences of making and using products or providing services [8].
- LCA is a method for assessing environmental pressures in order to realize sustainable development [9].

- LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by: compiling an inventory of the relevant inputs and outputs of a product system, assessing the potential environmental impacts associated with those inputs and outputs, and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study [10].

In other words, Life Cycle Assessment (LCA) is the most reliable method for assessing the environmental and human health impacts of a facility over its lifetime.

1.3. Construction process

The application of the life cycle assessment method in the field of structural engineering provides valuable information to designers, builders and specifiers, on the basis of which the processes of extraction, transportation, construction, operation, demolition and recycling of materials can be optimised.

A published report [11] presents the following stages of the construction process: materials production, transportation, construction, operation, end of life.

Or the life cycle, in the case of a dam, is composed of the following stages:

- Material extraction – covers the process of sourcing and processing the required construction materials. It also includes the extraction of fuels needed for the process.
- Transportation – related to the delivery of the construction materials to the site.
- Construction – encompasses all project implementation activities at the construction site.
- Operation – this is the period that starts after the completion of construction activities and continues until decommissioning. It also includes all maintenance activities, current repairs, overhauls, etc.
- End of life – related to decommissioning and removal and is determined by many factors.

All of these activities result in emissions that are calculated by applying the life cycle assessment method.

1.4. Hydraulic structures

In Bulgaria, with the development of industry and agriculture, the need for water for power generation, water supply and irrigation was increasing dramatically. Due to the limited national water resources, their study, utilization, management and recovery is inevitable. A number of large and small concrete and embankment dams were built, some of which are unique in their functionality, structural solution and type of construction. The largest number of large dams in our country was built in the 1960s – 95 dams (44 %). Earth-fill dams account for about 92 % of the total number of large dams. Over 70 % of the dams still in operation in Bulgaria were built in the 1960s and 1970s. This coincided with a period of intensive dam construction worldwide.

To date, according to data [12] from the State Agency for Metrological and Technical Supervision (SAMTS), the total number of dams in Bulgaria is 6 844. Of these, 5 086 are municipally owned – 74,3 %, state owned are 766 – 11,2 %, privately owned are 144 – 2,1 %, owned by irrigation associations are 156 – 2,3 %, dams transferred by municipalities to the state and assigned to the State Enterprise "Management and Operation of Dams" (SEMOD) – 376 – 5,5 %, others including with uncleared ownership – 316 – 4,6 %.

2. A review comprising the following groups of sources:

2.1. Regulatory documents and standards

The ambitious targets set by the European Union to become "climate neutral" by 2050 are a prerequisite for the introduction of a number of legislative changes and regulations, some of which include:

- Regulation No. 305/2011 [13]:

The introduction of the document is also reflected in some Bulgarian laws and regulations – in the Law on Spatial Planning [14], in the sectoral legislation on environment, energy and energy efficiency. Consequently, Article 169, which refers to requirements for the design, execution and maintenance of construction works, is supplemented by a requirement for "sustainable use of natural resources".

- BDS EN 15643:2021 [15]:

The document applies to all types of works, both new and existing ones, and is relevant for assessing the environmental, social and economic performance of new facilities over their life cycle and of existing ones over their remaining service life.

- BDS EN 15804:2012+A2:2020 [16]:

This standard provides basic rules for product category (PCR) Type III environmental declarations for all construction products and building services.The assessment of social and economic performance at product level is not addressed in this standard.

- ISO 15392:2019 [17]:

The standard is based on the concept of sustainable development as it applies to the life cycle of construction works, from inception to end of life.

- ISO 21929-1:2011 [18]:

The standard establishes a core set of indicators to be considered in the use and development for assessing the sustainability performance of new or existing buildings related to their design, construction, operation, maintenance, repair and end-of-life.

- ISO 21931-1:2010 [19]:

The standard provides a common framework to improve the quality and comparability of methods for assessing the environmental performance of buildings and associated works.

- ISO 15686-1:2011 [20]:

The standard identifies and establishes generic life-cycle planning principles and a systematic framework for undertaking life-cycle planning for building or works throughout their life cycle (or remaining life cycle for existing buildings or facilities).

- ISO 21930:2017 [21]:

The standard provides the principles, specifications and requirements for the development of an environmental product declaration (EPD) for construction products and services, building elements and integrated technical systems used in construction works.

- BDS EN ISO 14040:2006 [22]:

The standard describes the principles and framework for LCA including: defining the purpose and scope of LCA, describing Life Cycle Analysis (LCA), Life Cycle Impact Assessment (LCIA) and interpreting of the results.

- National Technical Committee "Sustainable Construction" [23]:

Given the importance of the issue of sustainable construction in Bulgaria, the Bulgarian Institute for Standardization established a National Technical Committee, which will act as a mirror of the Technical Committee CEM/TC 350 "Sustainable Construction". The activities of the committee consist in the development of voluntary horizontal standardisation methods for the assessment of new and existing buildings and structures throughout their life cycle in terms of environmental, social and economic aspects of sustainable development, including standards for EPD of construction products.

2.2. Handbooks / Practical Guidelines

An important group of sources are the handbooks, guidelines and recommendations:

- Guidelines for Life-Cycle Assessment: A "Code of Practice", [24]. The publication provides guidelines for conducting and reporting on LCA studies and is based on the views of 50 experts from 13 countries. According to the authors, LCA addresses environmental impacts, human health and resource depletion. It does not consider economic considerations or social effects. Here, LCA comprises 4 stages which are:

  1. Defining objectives and scope – outlining the framework and defining impact categories;

  2. Inventory analysis – all the necessary information needed for the study is obtained;

  3. Impact assessment – the data collected from the previous stage is structured and assigned to the selected impact categories;

  4. Interpretation – the results of the inventory analysis and the impact assessment are summarised and discussed serving further as a basis for decision making.

- The Training Manual [25]: The manual describes LCA and activities related to environmental, social and economic impacts as a way of thinking – the so-called: Life Cycle Thinking. The process is presented in the following steps:

  1. Introduction to LCA and its relationship to environmental decision support;

  2. Overview of LCA;

  3. An in-depth presentation of the main issues in LCA;

  4. Specialization modules on selected topics.

- The book [26] examines the problem of ageing infrastructure and how this leads to deterioration and reduced service life. It describes the mechanism of ageing, the impact of the environment on the facilities. Models of ageing behaviour based on different types of predictions – empirical, deterministic and probabilistic, are discussed, too.

2.3. Research works

There are particular research works which should be outlined here, as follows.

A special study dealing with LCA of concrete dam construction compared to a rock-fill solution is [27]. The need to construct new dams in the coming years is the main focus of this study. It consists of comparing two different types of dams: concrete and earth-fill ones, in terms of the carbon footprint they leave. The LCA covers the whole process including extraction of materials, their transportation, construction process, operation and the demolition and removal of the facilities. The results of the study show the environmental impact of the use of different types of materials and construction technologies and serve as a guide for the choice of one or another method of construction.

Another review work is [28]. The environmental impact assessment stage is the most critical step of the analysis, as it processes a huge amount of information acquired during the inventory analysis. As a result of the processing, comprehensible impact indicators were created depending on the impact categories in the particular case. Two main approaches were used in the modelling: the "midpoint" and the "endpoint" ones. This work presents the different approaches used in the environmental impact assessment. They were divided into the following 4 groups:

- "Midpoint approach": It is an approach that treats the occurrence of a problem before it has caused some damage. The methods that are based on this approach are: CML; EDIP 2003: TRACI.
- "Endpoint approach": This approach is related to the damage caused as a consequence of a particular phenomenon. The methods that are based on this approach are: EI99; EPS 2000; Eco Scarcity; JEPIX.
- Integrated approaches: such methods are: RECIPE; LIME; IMPACT 2002+; LUCAS.
- Other known approaches: MEEup; BEES; Ecologocal footprint; USEtox; EDP; IPCC; CED; CExD; Emergy; CExC; CEENE.

2.4. Reports

Some selected special reports have to be mentioned here, as follows:

- Key Figures 2019; Construction activity in Europe Edition 2020 [29]: The report was produced by the European Construction Industry Federation (FIEC) in 2019 and consists of an analysis of statistics in the field of industrial and civil construction across the European Union.
- Economic report of the construction sector [30]: The report was prepared by the Bulgarian Construction Chamber (BCC) in 2021 and contains information on the state of the construction sector in Bulgaria. It includes data on general construction activity, labour market, investment intentions, forecasts, etc.

- Construction Forecast Report [31]: The report was prepared by the Eastern European Construction Forecasting Association (EECFA) in 2021 and forecasts growth in construction activity over the coming years.
- Our Common Future / Brundlant Report [7]: The report was funded by the World Commission on Environment and Development and published in 1987. It is considered to lay the foundations for sustainable development.
- Europe Energy Policy [4]: Drawn up by the European Commission in 2007 and describing the Community's first energy policy strategy.
- New action plan on circular economy [5]: It was adopted by the European Commission in 2020. A plan based on a circular economy is at the heart of the Green Deal.

2.5. Assessment methods

The assessment methods for buildings and facilities that are based on life cycle assessment are currently as follows:

- LEED [33] – Leadership in Energy and Environmental Design – an American system established by the United States Green Building Council (USGBC) in 1993 to certify green buildings. The system is applicable to almost all types of buildings – existing and newly designed, making them more sustainable and energy efficient.
- BREEAM [33] – BRE Environmental Assessment Method – this was the first method of assessing sustainable construction, created in 1990 by the British Institute for Sustainable Development. Initially the standard was applied to the construction of new buildings, then it was extended to renovation and retrofit of existing buildings.
- DGNB [34] – a system established by the German Council for Sustainable Construction. The system is similar to the previous two, but also focuses on the technology of implementation and the location of the site. The Bulgarian Green Building Council adapted the system for Bulgaria under an international contract with the German Green Building Council.
- HQE [35] – a French system created in 1996 by the High Quality Environmental Association. The system covers the entire life cycle of a building (construction, renovation and operation). It is applied to non-residential buildings, residential buildings and single-family houses, as well as urban planning and development.

3. Conclusions

- The rapid development of construction in recent years has led to environmental pollution, increasing resource consumption and emissions. The European Union's policy of reducing the carbon footprint and rational use of renewable and non-renewable natural resources is a prerequisite for applying the proper methods that optimise the construction process.

- LCA is an innovative approach for assessing the environmental and human health impacts of a construction throughout its lifetime.
- The known environmental impact assessment systems (LEED, BREEAM, DGNB, HQE) focus mainly on residential and non-residential buildings. They are a tool for the sustainable design and operation of buildings and facilities but not for infrastructure sites, and even less for dams.
- The application of different assessment approaches is specific and depends on many factors. The results of using "end point" methods are better understood as the consequences are visible but considered less certain, whereas the application of "midpoint" methods acts more for prevention, and parameters can be more accurately determined. For these reasons, the application of one of the combined approaches is preferred. The choice to apply one of them is determined on a case-by-case basis. Some of them have also been developed for particular regions, which limits their application.
- Noteworthy is the method BEES [36]. Unlike other approaches, this one combines the assessment of impacts and the life cycle costs of facilities;
- In Bulgaria, there are 216 large dams and the rest of all dams are small ones with a height of up to 15 m. Currently, it can be stated that all large dams in the country are in good operational condition. The companies that operate them have qualified and trained personnel. The main problem is with the small dams and the ones without cleared ownership, especially after the changes in 1989.
- Hydraulic structures are complex facilities that have a long service life. Depending on various factors, it is about 100 years and more. All the activities of material extraction, transportation, construction, repairs and maintenance as well as the possible removal of the dam are relevant to the determination of environmental impacts.
- More than 70 % of the dams in Bulgaria were built in the 1960s and 1970s, hence, two thirds of all dams in Bulgaria are currently more than 60 years old.
- Dams are hydraulic structures with a high secondary risk and even those classified as small can cause significant consequences (social, environmental and financial) in the event of accidents due to improper operation or lack thereof, endangering human life and certain material assets.

In the context of European policies on pollution reduction and sustainable development in recent years, increasing attention has been paid to the construction sector and the carbon footprint it leaves. The need to assess environmental impacts requires the application of different assessment methods and systems. Currently, systems such as LEED, BREAM, etc. are successfully used in the construction and maintenance of residential and non-residential buildings. All these approaches are based on LCA but unfortunately could hardly be applied to dams, moreover, for embankment ones. Considering the condition, age and large number of small dams especially of this type in the country, the need for the development and application of a LCA assessment model for small embankment dams is increasing.

A general conclusion from the above performed review can be drawn that the development of a LCA approach for hydraulic structures and small embankment dams in particular will help designers, builders, operators, governmental institutions, municipalities, etc. Based on the principles of sustainable construction, the development of a model based on modification of any of the above listed methods will enable the assessment of the specific impact of such dams and facilitate decision-making processes throughout all different stages of their operational life.

REFERENCES

1. FIEC Key Figures Edition report. European Construction Industry Federation, 2019.
2. Ikonomicheski otchet na stroitelnia sektor. Kamara na stroitelite v Bulgaria, 2021.
3. Construction Forecast Report. Eastern European Construction Forecasting Association, 2021.
4. Energiyna politika za Evropa. Komisia na evropeyskite obshtnosti, Bryuksel 2007.
5. Nov plan za deystvie otnosno kragovata ikonomika. Evropeyska komisia, 2020.
6. Zelena sdelka. Evropeyska komisia, 2020.
7. Our Common Future; World Commission on Environment and Development, 1987.
8. *Consoli, F.* et al. Guidelines for Life-Cycle Assessment: A “Code of Practice”. Society of Environmental Toxicology and Chemistry, 1993.
9. Life Cycle Assessment Society of Japan.
10. BDS EN ISO 14040:2006, Upravlenie po otnoshenie na okolnata sreda. Otsenka na zhiznenia tsikal. Printsipi i obshti iziskvania.
11. *Chunna, L.* et al. Life-Cycle Assessment of Concrete Dam Construction: Comparison of Environmental Impact of Rock-Filled and Conventional Concrete. // Construction Engineering and Management, 2013.
12. Godishen doklad. Darzhavna agentsia za metrologichen i tehnicheski nadzor, 2020.
13. Regulation 305/2011 of the EC on harmonized conditions for the marketing of construction products.
14. Zakon za ustroystvo na teritoriyata, 2021.
15. BDS EN 15643:2021, Ustoychivo stroitelstvo. Obshta ramka za otsenyavane na sgradi i stroitelni saorazhenia.
16. BDS EN 15804:2012+A2:2020, Ustoychivo stroitelstvo. Deklaratsii za produkt po otnoshenie na okolnata sreda. Osnovni pravila za kategoriyata na stroitelni produkti.
17. ISO 15392:2019, Sustainability in Buildings – General Principles.
18. ISO 21929-1:2011, Sustainability in Building Construction. Sustainability Indicators. Part 1: Framework for developing indicators and core set of indicators for buildings.
19. ISO 21931-1:2010, Sustainability in the construction of buildings – Framework for methods to assess the environmental performance of construction works – Part 1: Buildings.
20. ISO 15686-1:2011, Buildings and existing structures. Service life planning, Part 1: General principles and framework.
21. ISO 21930:2017, Sustainability in buildings and construction works – Basic rules for environmental product declarations for construction products and services.
22. BDS EN ISO 14040:2006, Upravlenie po otnoshenie na okolnata sreda. Otsenka na zhiznenia tsikal. Printsipi i obshti iziskvania.
23. TK101 “Ustoychivo stroitelstvo”, Balgarski institut za standartizatsia.
24. *Consoli, F.* et al. Guidelines for Life-Cycle Assessment: A “Code of Practice”. Society of Environmental Toxicology and Chemistry, 1993.

25. Life Cycle Assessment. A product-oriented method for sustainability analysis, Training Manual, Life Cycle Initiative Hosted by UN Environment, 2008.
26. *Collins, F.* Ageing of Infrastructure. Taylor & Francis Group, LLC, 2019.
27. *Chunna, L. et al.* Life-Cycle Assessment of Concrete Dam Construction: Comparison of Environmental Impact of Rock-Filled and Conventional Concrete. // Construction Engineering and Management, 2013.
28. *Menoufi, K.* Life Cycle Analysis and Life Cycle Impact Assessment methodologies: A state of the art. Universitat de Lleida, 2011.
29. Key figures 2019. Construction activity in Europe Edition 2020. European Construction Industry Federation, 2019.
30. Ikonomicheski otchet na stroitelnia sektor. Kamara na stroitelite v Bulgaria, 2021.
31. Construction Forecast Report. Eastern European Construction Forecasting Association, 2021.
32. LEED, https://www.usgbc.org/leed, (19.12.2022).
33. BREEAM, https://bregroup.com/products/breeam/, (19.12.2022).
34. DGNB, https://www.dgnb.de/de/index.php, (19.12.2022).
35. HQE, https://www.behqe.com/presentation-hqe/what-is-hqe, (19.12.2022).
36. *Lippiatt, B.* BEES 4.0 – Building for Environmental and Economic Sustainability. Technical Manual and User Guide. National Institute of Standards and Technology, 2007.

ЛИТЕРАТУРЕН АНАЛИЗ „ОЦЕНКА НА ЖИЗНЕНИЯ ЦИКЪЛ“

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Ключови думи: *жизнен цикъл, малки язовири, устойчивост, околна среда, въздействие, оценка*

РЕЗЮМЕ

Бурното развитие на строителството през последните години води до замърсяване на околната среда, растящо потребление на ресурси и отделяне на вредни емисии. Следваната политика на Европейския съюз за намаляването на въглеродния отпечатък и рационалното използване на изчерпаемите и неизчерпаемите природни ресурси е предпоставка за прилагането на методи, които да оптиимизират строителния процес. Настоящата статия има за цел да представи постиженията в областта на устойчивото строителство и да се запознае с разработените методи за оценка на жизнения цикъл на дадено съоръжение. В резултат от извършения анализ е оценена възможността за прилагане на някои от познатите методи за оценка при хидротехническите съоръжения.

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