Life Cycle Assessment (LCA) on Road Infrastructure Projects: a Systematic Mapping Study

by Jati Utomo Dwi Hatmoko

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Abstract. LCA has been utilized over the past two decades to estimate the environmental impacts of pavement in infrastructures. The purpose of this study is to systematically map research on the use of LCA to calculate energy and emissions in road infrastructure projects. The research method is carried out by a literature review, in terms of systematic mapping study of a number of previous scientific publications, in the form of documents that have been published in international and national journals and proceedings, etc., in the last thirty years. The results show that: The topic of LCA is still an interesting area of research, and the trend from year to year shows an increase in the publication of articles in reputable journals. As much as 57.8% research, using the process based calculation method. Only 15.6% of research calculated energy and emissions in the four completed stages of the project life cycle. As much as 37.5% research compared the flexible and rigid pavement as research objects. There is a chance to research the development of the energy optimization model for road infrastructure projects using cradle to cradle system boundary, from initiation to the end of life as a whole project life cycle.

1. Introduction

Energy consumption is influenced by economic and technological growth, energy production leads to environmental emissions and consumption of non-renewable resources. Projections show a 50% rise in global energy demand relative to the current demand by the year 2030, which means that sustainability of energy must be accomplished [1]. Energy and associated problems are of global significance, as the IEAs say in 2011, linked to a historic amount of 13.113 million tons of coal equivalent (Mtce) in terms of total energy supply of primary energy (TPES) that is emission of 31.342 million tons of CO_2, considered to be the principal cause of global warming [2]. In the sustainability of urban environments, road infrastructure plays a significant role [3]. Two of the most widely used materials for pavement construction are asphalt and cement. Approximately 83% of all sidewalks and roads in the USA are made of asphalt, 7% of concrete road with or without asphalt, and almost 10% of composites such as asphalt surfaces on a concrete foundation [4].

The environmental impacts of asphalt mixtures used in paving construction must be adequately quantified, taking into account the entire product life cycle. The Life Cycle Assessment (LCA) offers the best approach to determine a product's environment, from the procurement of raw materials to its final disposal [5]. LCA is used since the 1980s to calculate the environmental effect of the paving on infrastructure and has been used for environmental purposes over the past two decades [3]. In recent years, green constructions have been one of the solutions in recent years to protect the environment and to reduce the energy use due to roads, with the rapid growth of road construction and environmental issues, to monitor or prevent a negative effect on the environment resulting from road construction [6].

Emission reduction strategies must be carried out in all sectors and all regions, where the Indonesian government has committed to reduce global warming by reducing emissions independently by 26% by 2020, and by 29% and by 41% in collaboration with international parties in 2030 [7].

With a lot of research on energy and emissions using LCA as a framework, it is necessary to make a mapping study that examines the use of LCA in road infrastructure projects. The purpose of this study is to map research systematically on the use of LCA to calculate energy and emissions in road infrastructure projects through literature studies for further research. These studies may also be a valuable preliminary phase in doctoral research, because a mapping analysis offers an objective and systematic method for identification of the type and scope of the empirical documents available to address some specific research questions [8]. This study provides the following contributions: first, provides a description of the research and development activities in this area, identification of active parties and entities; second, a summary of the processes and methods available on LCA in road infrastructure projects; and third, future research opportunities.

2. LCA and road construction

The first LCA study in the pavement infrastructure was held in the USA and conducted in 1996 by the Portland Cement Association on Environmental Value Engineering (EVE) LCA for concrete and asphalt toll road pavement systems [9] and in the same year a research by Häkkinen and Mäkelä, which carried out an environmental load assessment, namely energy and emissions from reinforced concrete and road asphalt on toll roads in Tampere, Finland [10]. Before LCA was widely used, research that analysed energy consumption in the road construction project was relatively few, such as, in 1984 at the United States of America an energy estimation procedure was developed in a project to find the energy content inherent in the final product and components in the process of the final construction product [11]. Then in 1993 in Singapore, a research was carried out for an evaluation the energy requirements at the production stage, namely the mixing process of asphalt in two different types of asphalt mixing plants, namely continuous drum mixing and batch-processing plant [12].

The growth of the road construction sector defines the implications for the use of non-renewable resources, energy expenditure and environmental emissions. Latest environmental issues have emphasized the importance of effective construction and quality strategies in this field due to the huge quantity of construction and maintenance materials [5]. The impacts of pavements have also been identified well beyond the extraction and processing of pavement materials [13]. The LCA approach method is best used to assess the environmental impact of pavement. It is a recognized technique for measuring environmental effects related to energy use, greenhouse gas emissions and emissions of operations and goods, and it provides a systematic method for the analysis of the net environmental output of goods and services across a variety of environmental indicators, covering all significant experiences with human and natural systems [14].

Many recent studies has used Systematic Literature Review (SLR) research methods on the use of LCA to assess the environmental impacts of roads that have been carried out include: identified and mapped the use of Life Cycle Sustainable Assessment (LCSA) in the major research libraries, through a process of bibliometric and systematic literature review [15]. Undertake critical analysis to explore the development and application of the LCA method in road projects and presenting future directions [16]. Conduct a critical analysis and methodological problems in the interconnected LCA on road networks [17]. Evaluation of rubberized asphalt pavement's energy use and environmental effects during the life cycle [18]. Quantify possible impacts derived from the use of unconventional and alternative materials in road construction [19]. Highlight the issues of a critical review and study gaps investigation on modelling pavement life cycle environmental impacts [20]. Undertake systematic and critical analysis of the studies performed and published over the past twenty years that are specifically linked to pavement LCA has been carried out to verify that the knowledge in the literature is adequate to assess the type of road with the least environmental impact [3]. There are seven differences between the SLR and Systematic Mapping Study (SMS) methods, one of them is the element results. Where in SMS, a series of papers relating to a subject area are grouped into a variety of dimensions and the number of papers in different categories is counted. While in SLR, primary study's findings are aggregated with qualifier possible to respond to relevant study questions [21].This study uses SMS method which is quite

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popular among researchers, and was chosen because it is still rarely used for literature review on LCA in road infrastructure projects. Some examples of research using SMS include: conduct research on Building Information Modelling (BIM) and the Internet-of-Things (IoT), to analyse the overall productivity of study, demographics, and patterns affecting the area of research [22]. Investigate case studies in the Social-LCA and carried out which one was applied in order to analyse the implementation of the phases of research methods [23]. Conduct research to systematically map the published papers on natural, social and economic sustainability at the farm level in dairy-farming, with a regional emphasis on Europe, North America, Australia, and New Zealand [24]. Perform an overview of the interoperability and integration research approaches for IoT systems [25]. Explore the intersection of the computing industry and software engineering education to figure out developments in software engineering [26]. Perform an analysis to systematically define, describe taxonomically and map the status of adaptive security or self-protection for mobile computing [27].

3. Research method

The research method is carried out by a literature review in the terms of systematic mapping study of a number of previous scientific publications in the form of documents that have been published in international and national journals and proceedings, dissertations, theses, book chapters, and research reports, in the last thirty years. A systematic mapping is a method used to identify, categorize and analysed a number of previous literature relevant to the current research topic being researched. The product of a systematic mapping would be a formal report focused on the classification system of current literature, often capable of presenting a visual summary of the analysis of the connection across literature and categories [28]. In other literatures, SMS is intended to map the related research carried out instead of to analyse and view RQs in depth [8, 29]. In this study, the data obtained came from the search results for documents from 1996 to 2020. A systematic mapping study begins by establishing the review protocol describing the research strategy and, in particular, the research plan. The review protocol includes , in particular, research issues, the search process, the selection criterion for the study, the classification scheme and the data extraction and analysis procedure [30]. The core stages of this systematic mapping method included: formulation of the study protocol and research questions; exploratory search and data collection; and analysis of the data collected and reporting. Figure 1 show the procedure followed in this systematic mapping analysis and descriptions of each phase are listed in the following explanation.

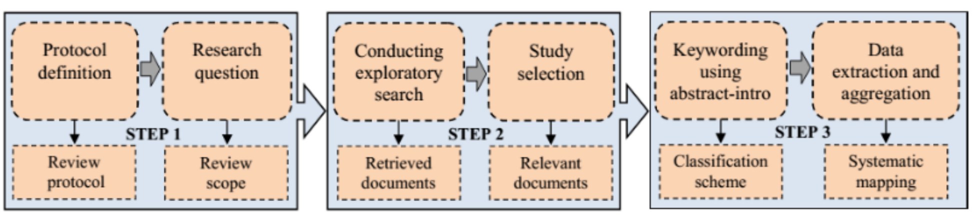

Figure 1. The steps of systematic mapping study.

This systematic mapping analysis is based on the methodology guidelines given by Kitchenham and Charters [31]. The method for gathering and reviewing the related studies is split into the following six stages:

a. Determination of the research scope and definition of the RQs to be addressed in the analysis.
b. Search for potentially significant documents, including the implementation of the strategy for searching and the acquisition of known documents.
c. Identification of genuinely applicable documents from initial collection on the basis of title, abstract, full text and content evaluations, including the purposeful sampling of other relevant research taken from the references in the paper.

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d. Data extraction from the residual documents to provide more thorough analysis.
e. Document classification and analysis of extracted data in order to respond to specified RQs.
f. Validity assessment and discussion of the potential shortcomings of the analysis.

To get an overview of the recent studies in this research scope, LCA to calculate energy and emissions in road infrastructure projects, this study define ten RQs for analysing, there are list in Table 1 below.

Table 1. Research question and objective.

No.	Research question (RQ)	Objective
1	What's the intensity of publications over the years?	To highlight the development of science in terms of publications and progress of research in recent years.
2	What are the type of documents typically published?	To identify the most type of documents that substantially indicates the existence of researches activity.
3	What documents source have published the most works in this research?	To identify the most source of documents and frequency of distribution over the years.
4	Which country publish most coverage in this research?	To identify the country most coverage in this research.
5	What is the subject area of the existing research?	To identify the major research subject area and key issues in this research.
6	Who is the most author in this research?	To identify the most productive researchers in this research.
7	What is the most affiliation on this research?	To identify the most productive institution in this research.
8	What methods are used to calculate energy and emissions in road infrastructure projects using LCA?	To identify the methods are used to calculate energy and emissions in road infrastructure projects using LCA.
9	What system boundaries are applied to calculate energy and emissions in road infrastructure projects using LCA?	To identify the system boundary are applied to calculate energy and emissions in road infrastructure projects using LCA.
10	What type of pavements are used to calculate energy and emissions in road infrastructure projects using LCA as the object of the research?	To identify the type of pavement as the object of this research.

The search strategy to search for relevant documents in the field of LCA to calculate energy and emissions in road infrastructure projects terms, was used the Scopus publication database. The search strings in our mapping study were developed using the criteria defined by Dieste et al. [32], in these five basic sequence:
a. Deriving significant words by disintegrating the research questions;
b. Identification of alternate spellings and synonyms for key terms;
c. Verification of keywords in any relevant documents that have already been retrieved;
d. The use of alternate spellings and synonyms using the "OR" logical operator; and
e. Use the "AND" logical operator to connect the key terms.

In order to verify the accuracy of the search strings, some of relevant documents as check samples selected randomly, which discussed relevant to this research scope, these check documents had to be present in the number of documents found using the search strings. To conduct an automated scan of the chosen publication database, the search string was the following. ((life AND cycle AND assessment) AND (road) OR (highway) AND (energy) AND (emissions)), the result is 299 documents, which is then used to answer the RQ-1 to RQ-7. Then these documents are selected based on the title, abstract, full text, and quality assessments to get articles that are relevant to the research objectives, the results are 64 documents to be analysed, and answer the RQ-8 to RQ-10. The collection processes of the sample was carried out on the basis of careful reading of the collected documents to identify the most important papers answering the research questions, specifying the following inclusion and exclusion criteria for the review of collected articles, inclusion criteria: documents focused on different aspects of LCA to calculate energy and emissions in road infrastructure projects. Exclusion criteria: documents not written in English; published on non-peer reviewed type, such as working papers and magazines; and not related to the research scope. Data extraction was designed to gather the

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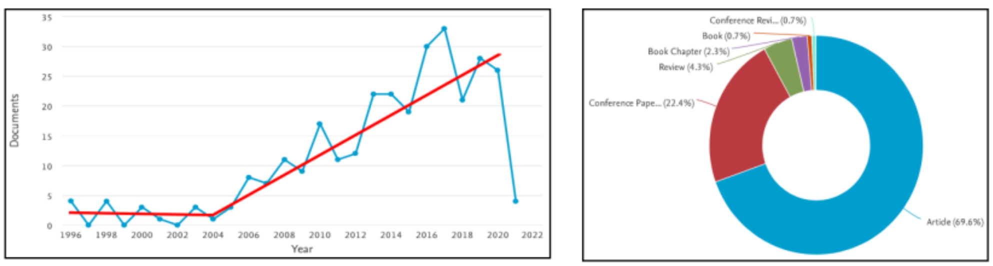
necessary information, such as: title and authors; source and type (journal, proceeding or book chapter); date of publication; and gathered information based on the classification scheme. The classification scheme was prepared by adopting the keyword method guidelines by Petersen et al., [28]. The classification scheme is generated and developed by key wording the abstract, introduction and conclusion and or reading the full-text of documents to classify and cluster various aspects and their contributions.

4. Results and discussion

The findings of the systematic mapping analysis were obtained by following the procedure mentioned in the previous part, starting from the RQ-1 to the RQ-10 as follows.

4.1. RQ-1

Based on the trend every year, the number of documents shows an increasing trend of research each year on this topic, and still suitable to be used as a topic for further research, as can be seen in Figure 2(A). This outcome is in line with the literature review research by Azarijafari et al., from 2010 to 2015 the number of publications in those years has increased [20], it means that there is increased consideration in using LCA to assess the environmental loads of road pavement [16]. Previous research by Visentin et al., used systematic and bibliometric methods of scientific publications in the period 2008 to 2019 about Life Cycle Sustainability Assessment, where the number of documents released has grown steadily and rapidly since 2015, with a peak in 2019 [15].

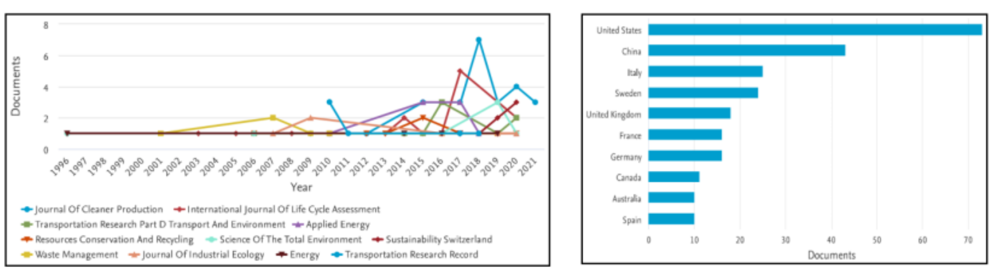


(A) Document by year. (B). Document by type.

Figure 2. Document released based on year and type.

4.2. RQ-2

Based on document types, the three most types are articles 69.6%, conference papers 22.4% and review papers 4.3% as can be seen in Figure 2(B). This shows that most of these documents have been published in reputable journals and have passed the peer review process, which improves the quality of the article [15].



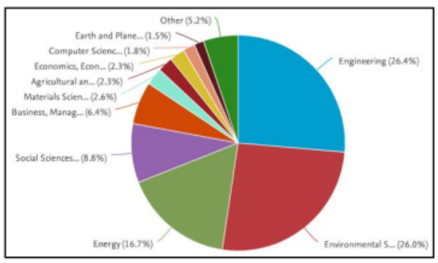
(A). Document per year by source. (B). Document by country.

Figure 3. Document released based on source and country.

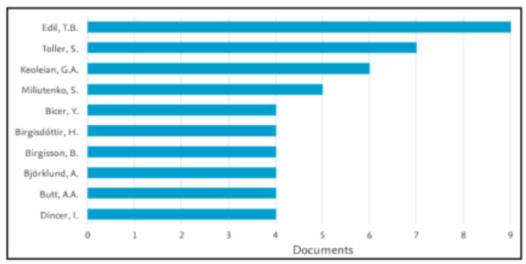
4.3. RQ-3
Based on document sources, in the last ten years there has been a significant increase in the number of documents published in several reputable journals such as the Journal of Cleaner Production, International Journal of Life Cycle Assessment, etc., as can be seen in Figure 3(A). Several research results with systematic literature reviews place these journals in the top ranking as the main source of reference as in the article [15,16].

4.4. RQ-4
The number of documents based on country of origin, then there are five countries that conducted the highest research, namely the United States followed by China, Italy, Sweden and the United Kingdom, as can be seen in Figure 3(B). The results of the research by Visentin et al., there are eight of the top ten researchers relate to the top five countries of the publications, namely: Germany, the United States of America, the United Kingdom, China, and Italy [15].

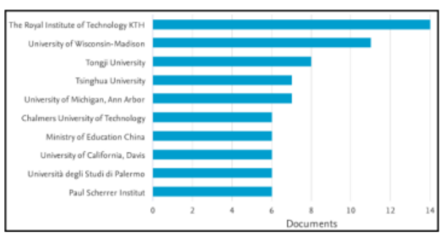
4.5. RQ-5
Based on the document subject area, the top three are research in the fields of Engineering 26.4%, Environmental 26.0% and Energy 16.7% as can be seen in Figure 4(A). This area is also ranked in the top three in the research of Visentin et al., with the order of Environmental Science 37%, Energy 22% and Energy Engineering 14% [15].



(A). Document by subject area



(B). Document by author



(C). Document by affiliation

Figure 4. Document released based on subject area, author and affiliation.

4.6. RQ-6
From Figure 4(B) it can be seen that the document is based on the author, so there are 4 authors who are the most productive, namely first, Edil, T.B., followed by Toller, S., Keoleian, G.A. and Miliutenko, S.As an information, Tuncer B. Edil has done a lot of research industrial products such as shredded automotive tires, by-products of foundries, coal combustion fly ash, recycled concrete aggregate, and recycled asphalt pavement [33, 34].

4.7. RQ-7
From Figure 4(C) it can be seen that the documents based on affiliation, there are three of them, namely The Royal Institute of Technology KTH, followed by the University of Wisconsin-Madison and Tongji University. The three highest universities according to research by Visentinet. al., in the Life Cycle Sustainability Assessment: A systematic literature review, namely: Arizona State University, University of Central Florida and Istanbul Sehir University [15]. This difference may be due to differences in the keywords used in the study and the database resource.

4.8. RQ-8
Based on the calculation method, there are four calculation methods used, namely Process-based 57.8%, Hybrid 17.2%, Input-Output 12.5% and other such as ANN method, regression, etc 12.5% as can be seen in Table 2 as follows. In line with the results of the systematic literature review, where the most widely used method order is Process-based 71.3%, Hybrid 11.7% and Input-Output 6.4%. [16]. Several studies have used software such as: NONROAD, Athena, PaLATE, LICCER, SimaPro, e-CALC, GaBi, DuboCalc, VTTI/UC Pavement LCA Tool, eco-indicator 95 method, etc. [3].

4.9. RQ-9
From the 64 documents can be seen in Table 3 as follows, there is only 15.6% researches calculated energy and emissions in the four completed stages of project life cycle, starting from raw material processing, construction, operation, maintenance and rehabilitation (M&R) to the end of life. Then 12.5% researches from the stage of raw material processing, construction, operation, to maintenance and rehabilitation (M&R), the remaining 71.9% studied only at one and or several stages. According to Jiang and Wu's study, with 96.8%, 62.8%, and 86.2%, respectively, the materials extraction, transportation, and construction phases were the most frequently included life cycle phases. In the meanwhile, with 29.8%, 58.5%and 34.0%studies, the consideration of usage, M&R and EOL phases was less common [16].

Table 2. Methods of LCA approach used to calculate energy and emissions

Calculation method	Number of documents (%)		References
Process-based	37	(57.8%)	[10], [9], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58],[59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69]
Input-output	8	(12.5%)	[70], [71], [33], [72], [73], [18], [34], [74]
Hybrid	11	(17.2%)	[75], [76], [77], [78], [79], [80], [81], [82], [83], [84], [85]
Others (ANN, regression, etc.)	8	(12.5%)	[86], [87], [88], [89], [90], [91], [1], [92]
Total	64	(100%)	

Table 3. System boundary of LCA approach used to calculate energy and emissions

System boundary/Phase					Number of documents (%)		References
Material	Construction	Operation	M&R	End of life			
√	√	√	√	√	10	(15.6%)	[37], [77], [78], [79], [80], [47], [56], [57], [73], [74]
√	√	√	√	-	8	(12.5%)	[10], [35], [76], [38], [82], [83], [52], [85]
√	√	√	-	√	1	(1.6%)	[48]
√	√	-	√	√	5	(7.8%)	[9], [36], [75], [42], [69],
√	√	√	-	-	1	(1.6%)	[62]
√	√	-	√	-	6	(9.4%)	[71], [40], [41], [43], [46], [18]
√	√	-	-	√	1	(1.6%)	[70]
√	√	-	-	-	10	(15.6%)	[39], [45], [33], [81], [49], [84], [72], [86], [61], [34]
√	-	-	√		1	(1.6%)	[44]
-	√	√	-	-	1	(1.6%)	[67]
-	-	√	√	-	1	(1.6%)	[55]
√	-	-	-	-	6	(9.4%)	[88], [91], [59], [64], [66], [1]
-	√	-	-	-	12	(18.8%)	[50], [51], [53], [54], [58], [87], [89], [60], [63], [65], [68], [92]
-	-	√	-	-	1	(1.6%)	[90]
				Total	64	(100%)	

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4.10. RQ-9

There are 4 types of pavement that are the object of research on this topic, namely 26.6% Flexible pavement, 12.5% rigid pavement, 37.5% flexible and rigid pavement and 23.4% Others part of road pavement (earthwork), polyurethane, etc.), as can be seen in Table 4 as follows. The comparisons between asphalt and concrete paving materials have attracted significant research over the years, but there has been no general conclusion [16].

Table 4. Type of pavements of LCA approach used to calculate energy and emissions

Type of pavement	Number of documents (%)		References
Flexible pavement (asphalt)	17	(26.6%)	[71], [75], [42], [44], [45],[33],[55], [72], [88], [85],[91], [64],[34],[66], [67], [1], [74]
Rigid pavement (concrete)	8	(12.5%)	[43], [46], [37], [81], [90], [59], [61], [18]
Flexible and rigid pavement (both asphalt and concrete)	24	(37.5%)	[10], [9], [70], [35], [36], [76], [39], [40], [41], [78], [79], [80], [82], [83], [47], [48], [49], [50], [84], [52], [56], [57],[73], [62]
Others part of road pavement (earthwork, polyurethane, etc.)	15	(23.4%)	[38], [77], [51], [53], [54], [86], [58], [87], [89], [60], [63], [65], [68], [69], [92]
Total	64	(100%)	

5. Conclusion and future work

There is an increasing trend in the number of studies from year to year, which is also shown from the increase in based on document types, based on document sources, based on the country of origin, and based on the document subject area so that suggests this topic is still interesting to research but with a different focus, which has never been done, such as discussing software to conduct LCA. There are four methods of LCA approach used to calculate energy and emissions, namely process-based, input-output hybrid and others such as ANN, regression, etc. Most of the research, namely 57.8%, used process-based methods to calculate energy and emission. There are only 15.6% research that apply the cradle to cradle system boundary (material – construction – operation – M&R – end of life), and the differences in the system boundary can cause differences in research results. As much as 37.5% research compared the energy use on the flexible and rigid pavement (both asphalt and concrete) as research objects. Based on these results, there is a chance to research the development of the energy optimization model for road infrastructure projects using cradle to cradle system boundary, from initiation to the end of life as a whole project life cycle.

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