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Type of the Paper (Review)

Life Cycle Assessment and Life Cycle Cost Analysis in Infrastructure Projects: A Systematic Review

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Abstract: The comfort of human life depends on the quality, size, and reliability of the infrastructure projects. In the infrastructure systems, rapid growth is found, where the economic and sustainable impact has become a topic of significant concern for policies and government officials. To achieve constraints of sustainable development, all the policies and actions over the infrastructure project's life cycle must be assessed. Decision-makers have adopted approaches for economic, social, and environmental initiatives through Life Cycle Assessment (LCA) and Life Cycle Cost Analyses (LCCA) of infrastructure projects. The purpose of this review is to highlight the impact of performing LCA and LCCA in infrastructure projects. To achieve this goal, a systematic literature review methodology is adopted in which renowned databases, i.e., Web of Science, Science Direct, Emerald and Scopus were selected to extract the relevant literature. Using the PRISMA approach, 1251 publications were identified which were then filtered and 55 documents were included in the final review. In the extracted publications most, researchers were biased toward LCA and LCA individually, whereas few focused on integrated LCA and LCCA. The researchers assessed the costs and impact associated with the infrastructure project while there were less focused on the environmental cost. Besides this, techniques of economic, social, and environmental growth of infrastructure projects have been emphasized during the design phase because of substantial relations between infrastructure design and operation management. Moreover, a conceptual framework has been developed that will assist the decision-makers to consider the effects of LCA and LCCA on various aspects of the infrastructure project and how it impacts sustainability. In the last, a case study was performed to assess the developed framework with the incorporation of environmental impact cost.

Keywords: Infrastructure projects, LCA, LCCA, Systematic Review, PRISMA statement, Sustainability.

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1. Introduction

The speedy development is noticed in the infrastructure projects, where the impact on the economy and sustainability has become a major concern for the policymakers and government officials. Besides the major attention of infrastructure projects and economic growth, many other aspects such as the impact should consider maintaining sustainability. Currently, the value of infrastructure projects is very immense, where not only the capital cost, but the operation, maintenance, and disposal cost also need consideration [1]. Likewise, with the immense growth of the infrastructure projects, the environment faces

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sustainability issue with toxic gaseous emissions, pollutant emissions, added fuel consumption, and noise pollution. Significant monetary procedures are required to overcome the issues of sustainability throughout the project life from the initial construction phase to the rehabilitation phase or end life to enhance serviceability. To maintain the proper functionality of the project, the user phase of the infrastructure project needs timely upgrading, as it has the longest duration in the life cycle [2-4].

In the long run, the infrastructure projects have been enhanced because of the dynamic relationship between economic and socio-environmental stressors with the decision-making processes of organizations [5]. Evaluating the expense of the life cycle and environmental effect, essential measures have been taken to integrate environmental goals into infrastructure projects [6, 7]. The Life Cycle Assessment (LCA) is a process that provides the ability to thoroughly identify and evaluate the environmental and social consequences of infrastructure paving systems across their lifetime. The LCA approach was first defined by the International Organization for Standardization (ISO) [8]. The LCA assessment is referred to as the "cradle-to-grave" approach consists of four main steps which are goal and scope, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and interpretation. The goal and scope of the analysis may determine the life cycle of the project [9]. The project life cycle involves the extraction of raw materials to disposal or recycling. However, there is no fixed life cycle for infrastructure systems [10], as all the properties of an infrastructure system cannot provide a definite time [11, 12], which need a scheduled rehabilitation to maintain the infrastructure over the life span. Besides this, the goal and scope also determine the functional unit of the project to reference for the whole project. The second stage of infrastructure LCA consists of inventory evaluations that accumulate and compile input and output data of a project under investigation. The inventory data provide possible resources, material and waste list or discharge material during the life cycle of a product [13]. The third step of the infrastructure LCA is an impact assessment where the inventory data collected for the various phases of the life cycle are classified into their categories of impact [14]. This means that the life-cycle inventories of each alternative decision are aggregated into a single file against every impact group. Interpretation is the final step of infrastructure LCA at which decisions are taken based on the outcome of the inventory and impact evaluation [15]. LCA will have the most significant if the evaluation analyses are used for policy review and management. However, the understanding of the LCA conclusions puts a serious restraint on policy analysis and infrastructure performance measures.

LCA evaluate the environmental impact of a project and the consequences generated throughout life from different aspect such as materials acquisition, its construction, operation and maintenance, disposal and finally the end life treatment [16-18]. The assessment of material acquisition and transportation impact is the primary step of infrastructure projects, for which LCA was carried out by practitioners. Many of these assessments include comparative LCAs performed for comparisons of various construction material forms such as bitumen and cement pavement or virgin materials with recycled or secondary materials [19-21]. Many LCAs are carried out on the pavement alone, whereas some studies also examined the complete infrastructure, including the preparation of the site and the construction of road [22-24]. Besides, attempts were made to define usual energy consumption and Carbon Dioxide (CO_2) emissions of various types of regular roads [20, 25, 26]. Although, the environmental impact in infrastructure projects is assessed, though the alarming increase in the impact [27], as shown in Figure 1, need policies to overcome the increasing environmental impact or compensate for the harmful consequences. With the growth of the infrastructure system and the increasing number of automobiles, carbon emissions from the transport industry have risen. Gross vehicle emissions on world roads increased by about half a gigaton between 2010 and 2020.

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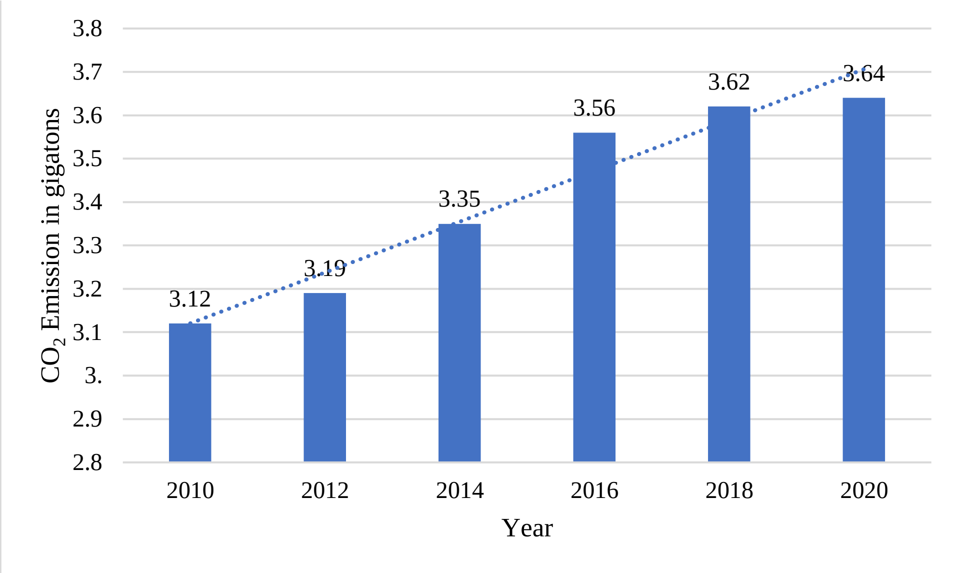

Figure. 1. Global vehicle CO_2 emission

In 1920, Arthur Pigou proposed that the emission of CO_2 should be charged to monitor the damages caused by the emission to the society and environment [28]. Later on, the proposal of considering charges for CO_2 was agreed with the implementation of the carbon price by most of the nation to overcome the Global Warming Potential (GWP) [29]. To implement the idea of the carbon price, a cap-and-trade system and carbon taxes was introduced. The cap-and-trade is a general concept by a government regulatory scheme intended to regulate activities of total emissions level. In the cap-and-trade system, the state grants restricted annual permits allowing businesses to release carbon dioxide in such levelled amount. Companies are fined if they generate emissions greater than their quotas permit. Unused permit allowances may be marketed or "trade," from businesses who reduce their emissions to other companies. Whereas the CO_2 tax is a consumption tax on transportation and energy fuels emissions. Carbon taxes aim to decrease emissions of carbon dioxide by rising prices which aims in reducing the demand for fossil fuels [30]. Incorporating the carbon cost in the LCA assessment of infrastructure projects could be a possible solution to minimize the harmful impact.

Likewise, LCA, the Life Cycle Cost Analysis (LCCA) is considered an appropriate methodology by decision-makers to evaluate the economical and socio-environmentally sustainable infrastructure project's consequences [31-35]. LCCA has many applications, among which it allows the decision-makers to compare and choose the best alternative to achieve sustainable development [36, 37]. LCCA is utilized in the decision-making process during the planning and design stage to evaluate all the constraints related to a project [38-40]. To meet sustainability goals, it is necessary to evaluate all economic practices and activities over the life cycle of a project. Planning at the early stage of the infrastructure projects may be more cost-effective with a resilient and productive construction over the life cycle with less environmental impact [41-44]. In recent decades, substantial attention was paid to the application of LCCA in infrastructure projects. Whereas the practical implementation of the process is observed considerably very low.

In the economies of many nations, infrastructure plays an important part. Economic development is related to the construction of infrastructure projects, that is why a huge investment has been made in this sector. Figure 2 highlights the contribution of infrastructure projects in the Gross Domestic Product (GDP) through investment in various countries. In 2018, the Chinese average capital investment as a proportion of the country's GDP was 10 times higher than the US. Chinese investments were considerably higher than in all other countries. Compared to its western European counterparts, investments in central and eastern Europe were larger [45].

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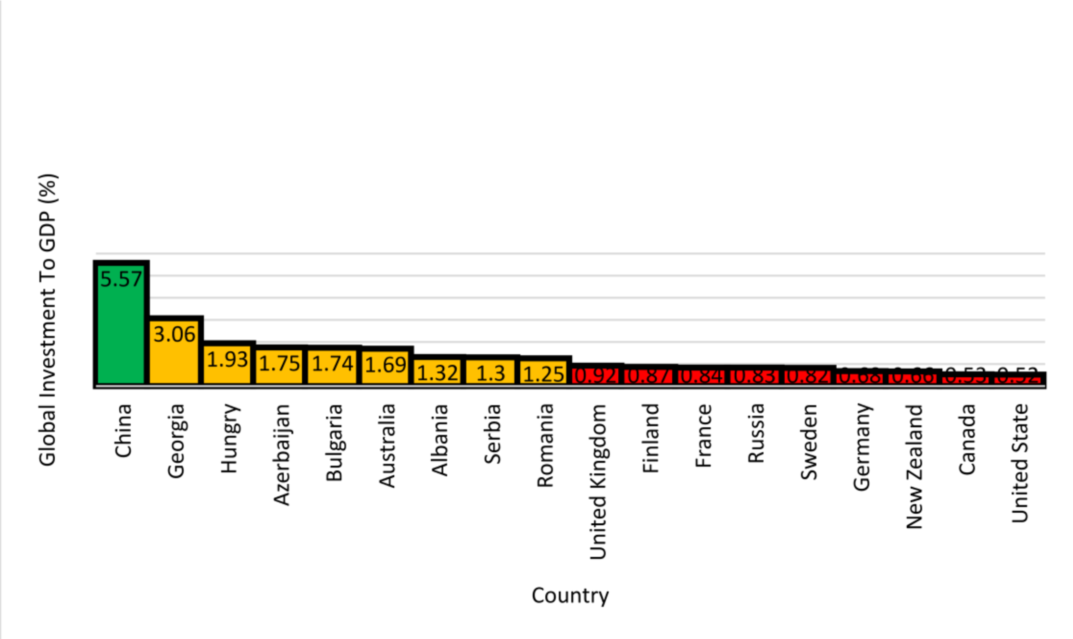

Figure 2. Countries Infrastructure Projects Investment Impact on GDP

Globally, new infrastructure projects face delays and cost overruns, which lead to the inefficient use of public resources [46, 47]. The root causes include the lack of transparency in project selection, the lack of project preparation, the silo approach by public entities in assessing feasibility studies, and the lack of public sector capacity to fully develop a bankable pipeline of projects [48, 49]. To tackle these issues, the government need a smarter investment approach and to do so critical policies sustainable are required. Given financial limitations, agencies need to utilize systematic decision-making methodologies that offer insight into long-term economic viability. One such approach is the LCCA, which measures the economic risk when considering the sustainability of infrastructure projects [50, 51]. However, the functional implementation of LCCA depends on a variety of factors such as the availability of supporting project documentation, the degradation insights into the state of the infrastructure, and the availability of guidance for calculating usage costs [40, 52].

Over the last decade, numerous research on LCCA has been performed to determine the cost of infrastructure projects [19, 53-61]. Most of the studies have concentrated on comparing products used in rigid and compact infrastructure or have sought to reduce the cost and the environmental effect of infrastructure by utilizing advanced, bio-based, or recycled materials [19, 53-57]. In 1960, the American Association of State Highway and Transport Officials (AASHTO) released a detailed guide on project procedures. As per guidelines, AASHTO introduced LCC in its infrastructure Construction Guide in 1972 [62, 63]. Thus, according to AASHTO, LCC comprises all expenses and advantages connected with the provision of infrastructure during their whole life span [40, 64]. It covers costs due to the construction, repair, reconstruction, and disposal of the infrastructure facilities and costs related to travel time, vehicle service, injuries, and time delays during the initial development, maintenance, or rehabilitation of road users [65-67]. Because these costs do not appear at the execution stage, the interest rate or time value of capital has become significant, therefore, the terms net present value (NPV) and equal annual expense (EUAC) were added into the process of LCCA [68, 69].

The popular approach to LCCA is the NPV [40, 70-72], for which the cost is discounted. The discount rate is a significant factor in LCCA as it has a clear influence on the final costs [73, 74]. Discounting is a central methodology in LCCA which considers the time value of money as it is more in the present than in the future [75, 76]. All costs are attributed to their NPV after discounting them to find the complete LCC for each project [77-79]. This approach is often utilized where the expense of the item is to be compared over a different period. Furthermore, the value of cost comparisons focusing on the operating period, as maintenance in the operation period can have a serious effect on LCC. The US Department of Defense developed a framework to introduce LCCA for defense logistics in feasibility stage to increase its cost-effectiveness in the awarding of competitive bids, whereas, LCCA has acquired significance in other industries that aim to make sustainable development decisions [80-82].

To achieve the sustainability goal the integration of LCA and LCCA provides an efficient decision-making evaluation system. The LCA evaluation provides data required by quantifying environmental and social assessment for a comprehensive LCCA. LCCA assessment is responsible for the agency costs, i.e., the financing department expenditures. In addition to the agency costs, it also accounts for usage costs which are the expense of the vehicles induced by the design of the infrastructure. Moreover, the environmental costs such as the costs for emissions generated by construction and operating phases can also be considered for which LCA is the core assessment approach that generates useful data for LCCA. The data generated by the process of LCA can be utilized in the process of LCCA in which the indicators of LCA could be converted into the cost parameters.

While conducting the systematic literature review, a variety of publications related to LCA and LCCA have been identified. Historical evidence has been analyzed using the Scopus database [83] suggesting that reported publications in this field of study are changing significantly. Figure 3 indicates the number of publications from 1999 to 2020. From the 1999s to the 2007s, less work was performed on the implementation of LCA and LCCA in infrastructure projects, although, after 2007, sustainability was established as a moderate research priority in infrastructure projects and gained a foothold in research to add improvement to the field after 2012. To date, the usage of LCA and LCCA in sustainability, project management, construction productivity, and cost-effectiveness in infrastructure projects is of primary importance by the researchers. Although massive research has been carried on LCA and LCCA, there is still less interest among stakeholders in its application in construction projects [84-87].

The impact of life cycle evaluation research is evident in the field of engineering, as it acts as a significant measure that allows the engineering industry to determine efficiency based on sustainability, along with the serviceability and resilience of any project. In the process of life cycle evaluation, the costs and impact from cradle-to-grave of a project are included that delivers a momentous project. Besides the importance of LCA and LCCA, the impact of its implication in the infrastructure projects seems less. Thus, the purpose of this systematic review was to examine the existing literature conducted with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement on the implementation of LCA and LCCA in infrastructure projects and to highlight the influence of it on different aspects of infrastructure projects to ensures sustainability. Besides, the integrated LCA and LCCA approach was highlighted to quantify its impact on economic, social and environmental sustainability. Moreover, a conceptual framework was developed, which integrates the LCA and LCCA considering the cost and impact along with impact assessment cost to enhance sustainable decision making. The developed framework classifies the impact of different costs associated with infrastructure projects and their impact on sustainable constrains. Thus, it will help the decision-makers to enhance sustainable with the consideration of these costs in the planning and design phases. Additionally, to evaluate the framework, a case study was performed with an integrated LCA and LCCA approach to quantify the associated costs and impact. Besides, carbon prices were incorporated in the framework. In previous studies, the carbon price was not focused, whereas in this study the carbon price is incorporated in the developed model for integrated LCA and LCCA, which will assess the practitioners to consider the impact reduction cost to deliver a sustainable project.

2. Methodology

The methodology of this review consists of three stages to achieve the research aim which is to examine the existing literature conducted on LCA and LCCA for infrastructure projects and to illustrate how LCA and LCCA affect different aspects of infrastructure projects and ensures sustainability during decision making. In the first stage the problem was identified, the objective was established where an overall literature review was conducted. Then a methodological approach, i.e., Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [88-93] was selected to conduct the systematic literature review. The second stage of the research is focused on the suggested

PRISMA statement followed by several researchers. The motivation for selecting the PRISMA statement in this review paper is the systematic dissemination after the screening of the collected documents, which would make it simpler for researchers to carry out a thorough review. The flowchart for the PRISMA statement is shown in Figure 3. The PRISMA methodology adopted for this analysis consists of four steps. In the first step, data search policy and databases have been developed, also the keywords and search limitations have been defined. The PRISMA statement for the recognition of selection requirements has been introduced. In the second step, the data were screened and filtered by evaluating the titles and abstracts of the selected documents. In the third stage, the determination of eligibility was carried out in full text and the documents which did not fall into the scope were omitted. Data were retrieved from the selected datasets in the fourth step of PRISMA to conduct further interpretation. In the third stage, the results were identified, and a review was interpreted in the extracted publications followed by a detailed discussion. Moreover, based on the literature a framework was developed to integrate the LCA and LCCA with the incorporation of emission cost. Moreover, to evaluate the framework, a case study was conducted on a road project that justifies the impact of integrated LCA and LCCA on an infrastructure project.

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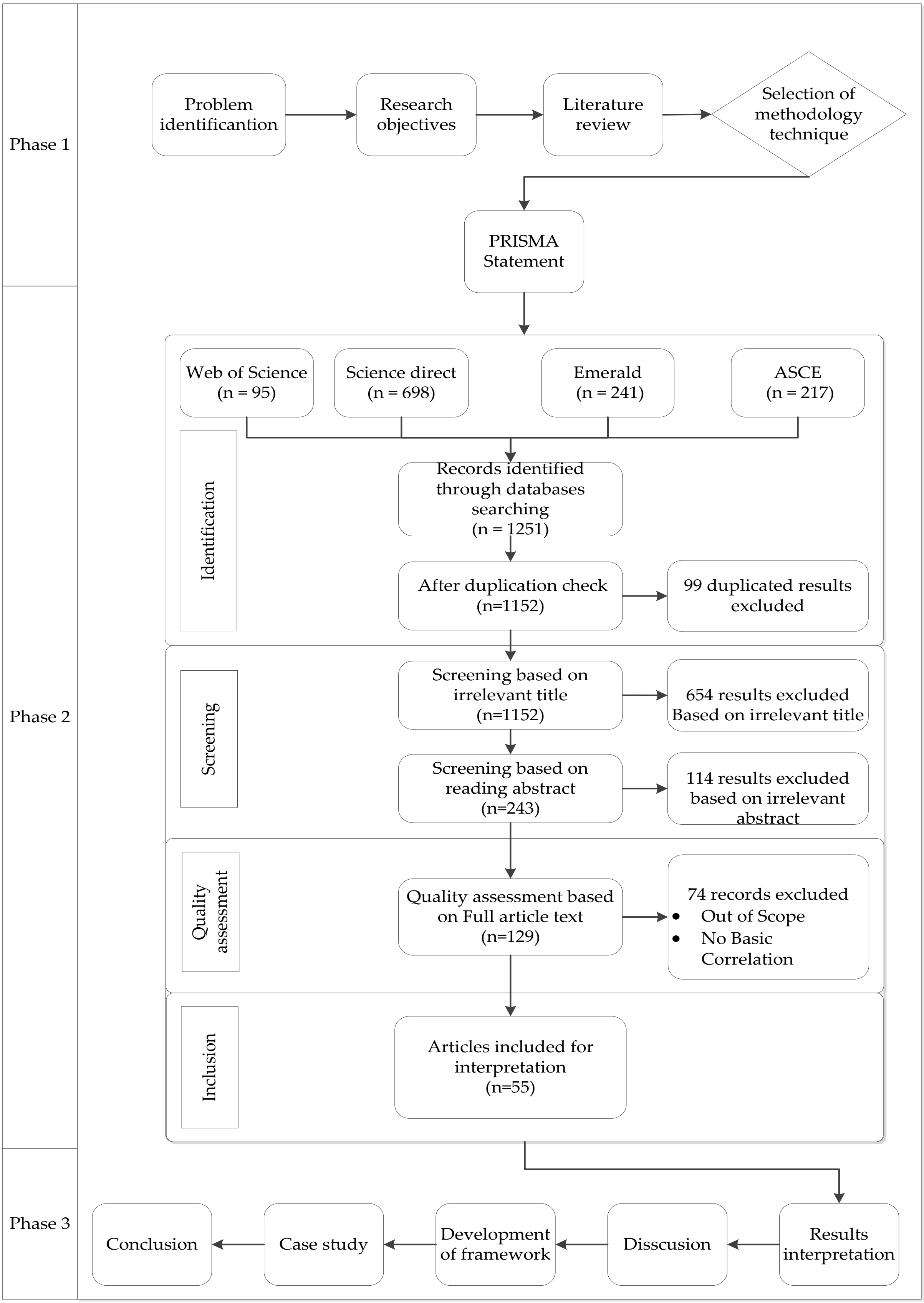

Figure 3. Methodology flowchart.

2.1. Research Strategy

A technique for this systematic review was designed to collect data from different sources for the related literature depending on the nature of this research. Four databases have been selected, i.e., Web of Science, Science Direct, Emerald, and Scopus which are known to be the top databases that include all indexed publications. The scope of this study focuses on "Life Cycle assessment", "Life Cycle Cost Analysis," and integration of both LCA and LCCA in the "infrastructure projects". Data was checked in these databases using the search string ((("life cycle assessment analysis" OR "LCA") AND (Life cycle cost analysis)) AND (pavement)). The corresponding keyword phrase is described based on the search algorithm of the selected databases, which contains the main keywords related to the scope of the research. Besides, the limitation for the type of publication i.e., research articles, review articles and conference papers were also applied. The scope of the research was then narrowed down to the construction industry and eventually to the infrastructure projects. Moreover, the publication in English was chosen only.

2.2. *Selection Criteria*

The selection parameters used for this systematic review are focused on the PRISMA statement established by Moher, et al. [94]. The primary objective was to perform a state-of-the-art study of integrated "Life Cycle Analysis" and "Life Cycle Cost Analysis" in infrastructure projects and its role in "sustainability" and "project management" at various stages of the project. A total of 1251 publications have been identified by applying the constraint of type, area, and language.

2.3. *Quality Assessment*

The data obtained from the four databases have been combined into a single file getting 1251 results which were reviewed for duplication. The duplication often exists because some of the publication exists in multiple databases. In the analysis total of 99 publications were noticed as duplication and were omitted from the list and 1152 results remained for further screening. Subsequently,1152 results were reviewed by deleting publications with irrelevant titles and 243 publications were left for further screening. In the next stage, the abstracts were reviewed to include only those publications which fulfil the purpose of this review. After reviewing publications based on titles and abstracts, 129 publications were chosen for quality assessment. A full-text study of the 129 publications was completed and only 55 related publications were left and used for a thorough review and analysis.

3. Results and Interpretation

The overview of the number of publications over the years is outlined in this portion. Besides, a keyword review conducted with VOSviewer software is provided. Subsequently, the interpretation of the included papers, along with a philosophical framework, which indicates the impact of LCA and LCCA on the infrastructure projects was proposed. To assess the proposed framework a case study was conducted that enhance the adaptability of the framework.

3.1. *Summary of extracted articles*

For this systematic literature review, four databases were chosen i.e., Scopus, Web of Science (WOS), ASCE Library and Emerald. In the data assessment 44 publication from Scopus, 33 from WOS, and 4 from ASCE and Emerald each was considered for the interpretation. These databases provide information from the largest research, publishing and patent library in the world, offering access to the most reputable material. These databases frequently classify, interpret, and exchange the most significant data, uncover new developments in the research field, and identify influential collaborators. Moreover, out of 55 publications, 20 were research articles, 4 were conference papers and 2 weres review papers.

3.2. *Keywords analysis*

A systematic analysis of the keywords in specific fields of science helps to clarify the dynamics of development and inequalities in the research sector. By examining the keyword co-occurrence relationships, the role and purpose of internal components can be better understood in a certain academic area and the limits of the discipline can be revealed. In the current systematic analysis, with the benefit of VOSviewer software, a keyword-based data connection was created, as shown in Figure 5 for the data searched by the keywords ((("life cycle assessment analysis" OR "LCA") AND (Life cycle cost analysis)) AND (pavement)).

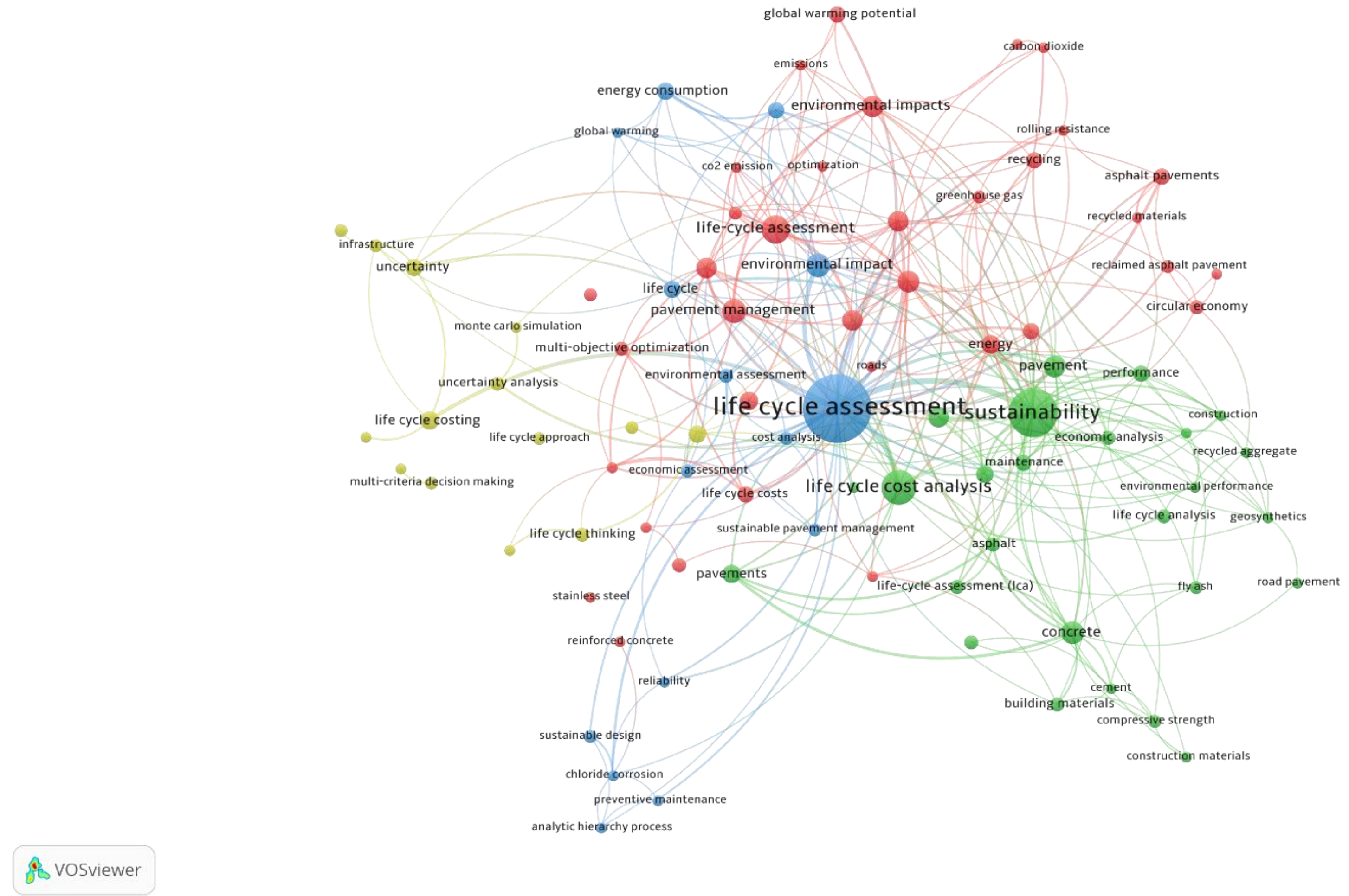

Figure 5. Mapping of Co-occurrence Keywords

The frequency of keywords was evaluated using the "complete count" methodology available in the VOSviewer. The minimum occurrence of keywords was set as 3 such that the VOSviewer can consider a keyword having an occurrence of more than 3 times. With 6 keyword occurrences, a total of 77 eligible words have been found by the program that reaches the threshold. A mapping network of 77 linked recurrent keywords with four fuzzy clusters was created. The cluster nodes are a keyword that connects to other nodes indicating the connection between them and the keywords used in these publications frequently.

The first cluster of Blue nodes was assembled around the term "life cycle assessment" with a maximum occurrence of 61 and a term "life cycle cost" having occurrence 43. Inside the same cluster, the terms "environmental impact" and "energy consumption" with occurrence 12 and 7 demonstrate the assessment of the environmental impact of infrastructure projects and the associated cost were focused on by the researchers. Construction projects have a significant influence on the environment and the economy, which is often assisted by decision-making strategies such as life cycle assessment and LCCA to ensure sustainability.

The second cluster of green nodes reflects the second large cluster assembled around the most used word "sustainability" with the occurrence of 57 and "life cycle cost analysis" with the occurrence of 23. This cluster comprises several primary terms such as: "concrete," having 11 occurrences, "pavement" with 9 occurrences, "performance" with 7 occurrences, "economic analysis" with 5 occurrences and other related words. This cluster demonstrates the researchers focus on the identification of economically sustainable pavement. Optimizing the environmental effects and expense of the project may be accomplished by implementing special approaches such as recyclable materials and ensuring sustainability by decision-making tools such as LCCA, as after assessment of the sustainable socio-environmentally sustainable options the final decision only based on the available economic resources.

The third cluster with red nodes was assembled around "pavement management" with 16 occurrences near "life cycle assessment" with 12 occurrences. The surrounding words within this cluster are "asphalt pavement,9", "greenhouse gas emissions,9", "sustainable development,8" and "energy,8". This cluster describes the focus of researchers in optimizing environmental indicators by adopting recycled or reclaimed material in infrastructure projects which reduces harmful emissions. Whereas the keyword analysis shows that the main concern was to optimize the consequences of an infrastructure project with management strategies. Proper management strategies enhance the project efficiency during the Operating and maintenance phases which are the most impact causing stages of a project. Infrastructure management and pavement management has a significant combination with LCA and LCCA which shows the contribution of LCA and LCCA decision-making techniques to the management of infrastructure projects.

The fourth influential cluster has yellow nodes around the word "life cycle costing" with 8 occurrences, along with "life cycle assessment" and "environmental impact" with 7 occurrences both. LCA justifies the environmental impact and provides the required data for LCCA. In the various publication, the integrated LCA and LCCA approaches are adopted to evaluate the economic, environmental, and socially sustainable project with the inclusion of environmental and social costs. Besides, a significant term "uncertainty analysis" of 5 occurrences has been used since the data required for processing LCA and LCCA is expected to face data uncertainty. The term uncertainty has close connections to the term "sensitivity analysis" of 3 occurrences which is used to resolve uncertainty. Table 1 indicted the summary of the keywords, their occurrences and link with other keywords derived from VOSviewer.

Table 1. VOSviewer keywords occurrence summary

. No	Keywords	cluster	Links	Total link strength	Occurrences
1	analytic hierarchy process	1	4	4	3
2	carbon footprint	1	10	12	6
3	chloride corrosion	1	7	10	3
4	cost analysis	1	5	5	4
5	economic assessment	1	6	7	4
6	energy consumption	1	8	11	7
7	environmental assessment	1	9	10	5
8	environmental impact	1	15	26	12
9	global warming	1	8	8	3
10	life cycle	1	10	12	7
11	life cycle assessment	1	53	128	73
12	preventive maintenance	1	7	8	3
13	reliability	1	5	7	3
14	sustainable design	1	9	11	4
15	sustainable pavement management	1	8	8	4
16	asphalt	2	8	15	5
17	cement	2	6	7	3
18	co2 emissions	2	8	9	3
19	compressive strength	2	6	6	4
20	concrete	2	14	25	11
21	construction	2	8	9	3
22	construction materials	2	3	3	3

23	economic analysis	2	10	14	5
24	environmental performance	2	7	7	3
25	fly ash	2	6	6	4
26	geosynthetics	2	8	8	3
27	life cycle analysis	2	4	5	5
28	life cycle cost analysis	2	23	38	23
29	life-cycle assessment (lca)	2	9	14	5
30	maintenance	2	15	17	6
31	net present value	2	12	12	3
32	pavement	2	18	27	10
33	performance	2	17	20	6
34	recycled aggregate	2	7	7	3
35	road pavement	2	4	4	3
36	sustainability	2	47	77	41
37	asphalt pavement	3	17	21	9
38	assessment	3	6	6	3
39	carbon dioxide	3	5	6	3
40	circular economy	3	6	6	5
41	climate change	3	24	32	10
42	co2 emission	3	6	6	3
43	emissions	3	8	8	3
44	energy	3	14	20	8
45	environmental impacts	3	12	16	10
46	global warming potential	3	4	6	6
47	greenhouse gas	3	8	10	4
48	greenhouse gas emissions	3	13	20	9
49	life cycle cost analysis (lcca)	3	2	2	4
50	life-cycle assessment	3	21	32	12
51	optimization	3	7	8	3
52	pavement management	3	20	29	16
53	pavement rehabilitation	3	6	7	4
54	reclaimed asphalt pavement	3	8	9	4
55	recycled concrete aggregate	3	4	4	3
56	recycled materials	3	7	8	3
57	recycling	3	9	11	6
58	rehabilitation	3	13	16	6
59	reinforced concrete	3	6	6	3
60	road construction	3	4	4	3
61	rolling resistance	3	9	11	3
62	stainless steel	3	5	5	3
63	sustainable development	3	13	15	8
64	infrastructure	4	6	7	4
65	life cycle approach	4	4	4	4
66	life cycle costing	4	8	15	8
67	life cycle costing (lcc)	4	2	2	4
68	life cycle thinking	4	13	15	5
69	life-cycle sustainability assessment	4	4	5	3
70	monte carlo simulation	4	3	4	3
71	multi-criteria decision making	4	5	6	4
72	pavement sustainability	4	5	6	4
73	sensitivity analysis	4	4	5	3
74	life cycle assessment	4	15	16	7
75	sustainable pavements	4	6	7	3
76	environmental impact	4	10	14	7
77	uncertainty analysis	4	6	9	5

4. Analysis of The Extracted Publication

In this section, the chosen publications were analysed and the results are interpreted. First, the publication targeting the LCA is stated following by the publication focusing on the LCCA in the infrastructure projects. The last publication which focuses on the integration of LCA and LCCA to achieve economic, social, and environmental sustainability are interpreted.

4.1. Assessment of Infrastructure Performance with LCA

In this section, the publication focused on the LCA were interpreted. LCA was adopted to assess the material selection and impact of materials and infrastructure at various phase of the life cycle.

4.1.1 Phases of LCA

The first phase in the construction process is to extract raw materials used to manufacture the product linked with GHS emissions. The second phase is the transportation of the extracted materials and machines to the building site and then transported to waste disposal from where the construction activities of the project, such as the construction of new infrastructures, maintenance, reconstruction, and renovations, progress. On the construction site, utilization of equipment may account for GHG pollution. In the maintenance and rehabilitation phase of LCA, emissions of GHGs are to be considered because of traffic delays caused by construction and maintenance. Then comes the use phase, where the fuel consumption and emission of GHG due to deteriorating pavements are calculated. In the end, life stage pavement materials demolished and then deposits or recycle, where the demolition and recycling or transporting of the demolished materials causes harmful emission. GHG emission analysis is highly important for stage and is considered by many researchers in all extraction, manufacturing, transport, production, use and end-of-life activities [12]. The construction phase has the highest (62.0 %) impact on the environment, followed by the end life phase (35.8 %) and then the M&R phase (1.7 %) [95]. This impact only considers the construction, maintenance and demolition activities, whereas the user's activities are omitted which changes the results drastically. Liu, et al. [96] considered the material production, transportation, construction and use phase of a permeable pavement compared to dense asphalt, whereas the research has some limitation that did not consider some environmental factors for a permeable pavement which needs to be focused on future. Most approaches overlook Maintenance and Rehabilitation (M&R) phase assessments, which may be very useful in maximizing the effects of the M&R phase. However, the service and performance level of infrastructure changes dynamically where the environmental impact depends on it. Batouli and Mostafavi [97] analyzed the scenario and adopted service and performance adjusted LCA (SPA-LCA) where it was concluded that the increasing demand of infrastructure leads to increase environmental impact which could be overcome with the improvement of current management practices in the use phase. Moreover, it was also suggested increasing the investment for M&R could significantly improve the network performance and sustainability.

Similarly, the use phase of a project has more impact on the environment as the traffic and vehicle-related emissions covers use phase consequences [98]. In the LCA usage period, Haslett, et al. [99] observed a 6.4 % rise in energy demand and GWP when incorporation the realistic traffic conditions. whereas in some practices the impact of the usage periods is ignored while some did not mention clearly.

4.1.2. Pavement Materials Assessment with LCA

The material endorsement evaluation in the infrastructure project is one of the key parameters to consider for a sustainable environment. Different considerations such as cost and environmental effects should be examined in the estimation of material selection. Besides, its impact on survivability and performance on a project should be taken into consideration when making decisions on the materials. LCA is a standard approach that promotes the overall use of products for an infrastructure project. Various research undertaken LCA in the materials assessment in the infrastructure project, where some researchers focused on virgin materials, some focused on recycled while some assessed the combination of both. Although some researchers did not clarify the nature of the material. In a case study, Heidari, et al. [100] analyzed the effect of concrete and asphalt on a project and discovered that the concrete pavement would increase the cost of the projects by about 35 %, although eliminating pollution by around 2000,000 tons per year and reducing the use of energy by 700,000 GJ. Similarly, a 26 % reduction was measured for Hot Mixed Asphalt (HMA) pavement compared to the plain concrete pavement. It identifies that the smart selection of materials should be assessed with LCA to measure sustainable measures.

LCA is the methodology for measuring the environmental effects of a given infrastructure project during its life cycle, from the processing of raw materials to the final recycling. The environmental effects of infrastructure projects were measured through analyses of environmentally sustainable materials and recycled materials. The relative energy, Global Warming Potential (GWP) and cost decreased with increased recycled content, as observed by Yang, et al. [21] by comparing 10 blends with 25–60 % ABR to a virgin dense-graded mixture. Similarly, Araújo, et al. [23] analyzed the different type of recycled materials and With 50.0% Recycled Asphalt pavement (RAP), energy consumption was reduced by 3% and gaseous emissions were reduced by 14 % for CO_2, 23% for SO_2 and by 15% for CH_4, N_2O and NO.

In many countries, the recycling of concrete paving has been a common practice. While the material properties and structural efficiency of floors substituted by recycled concrete aggregates with virgin concrete have been extensively identified. However, relatively little focus been done to determine the possible advantages of sustainability with LCA. Some of the researchers focused on the recycled materials, where the impact of recycled materials is found minimum as compared to the virgin materials such as hot mix asphalt with reclaimed asphalt (HMAP) achieve best social and economic performance compared to hot mix asphalt with an additive warm mix which achieve more environmental performance [101]. Similarly, 25 % clinker hydraulic road binders minimize GHG emissions by more than 50 % while fly ash also decreases GHG emissions with 50 % cement material [22].

The infrastructure project requires a huge number of materials as the development is growing at a high rate. Assessment of recycled material is an important alternative for sustainable construction the relative energy, GWP and cost were decreased with the increased recycled content by comparing recycled materials with virgin materials. Recycled materials such as recycled asphalt pavement (RAP) and recycled asphalt shingle(RAS), which can partly replace virgin asphalt binding and aggregate mixtures are widely identified as one of the most frequently used sustainable techniques for asphalt pavement (AC) [21]. The trend of recycled concrete is becoming very common where material performance and properties are emphasized very largely although little consideration is given to the sustainability perspective. Keeping in view, Shi, et al. [20] conducted an LCA comparison of Recycled Plain Cement Concrete (PCC) pavement with Concrete Aggregate mixed with Plain Cement Concrete (RCA-PCC) pavement where it was observed that RCA-PCC saves 35 % of the cost, utilizes 18 % less of energy, generates 23 % fewer air emissions and 17 % fewer gas emissions, uses 25 % reduced ground, releases 26 % fewer pollutants and is 15 % less mobility, while saves 34 % in water runoff. A detailed summary of publication about adaptation of materials and impact of infrastructure during life cycle phases are demonstrated in Table 2.

Table 2. Publication summary of LCA of pavement materials

S.	Article	Material	Phases	Remarks

S. No		Recycled Materials	Virgin materials	Material Production	Transportation	Construction	Use	M&R	End life	
1	Li, et al. [95]	✓	-	-	-	✓	-	✓	✓	• The construction phase has the highest environmental impact (62.7 %), followed by the demolition (35.8 %) and maintenance phases (1.7 %). • Steel has the highest proportion of environmental impact in the construction phase (55.5 %).
2	Liu, et al. [96]	-	-	✓	✓	✓	✓	-	-	• life cycle economic cost of Permeable Asphalt (PA) is 26–27 % higher than that of Dense Asphalt (DA) • The environmental impact under each impact categories is about 20–65 % lower than that of DA
3	Heidari, et al. [100]	-	-	✓	-	✓	-	✓	✓	Compared to asphalt pavement concrete pavements increase 35 % costs, 2,000,000 tons of carbon emissions reduction and 700,000 GJ reduction in energy consumption annually.
4	Shi, et al. [20]	✓	✓	✓	✓	✓	✓	-	✓	RCA-PCC pavement saves 35 % of the cost, utilizes 18 % less energy, generates 23 % fewer air emissions and 17 % fewer gas emissions, uses 25 % reduced ground, releases 26 % fewer pollutants and is 15 % less mobility, while saves 34 % in water runoff.
5	Haslett, et al. [99]	-	-	-	✓	-	-	✓	-	In the LCA usage period, a 6.4 % rise in energy demand and GWP has resulted in the incorporation of realistic traffic conditions.
6	Liu, et al. [24]	-	✓	✓	✓	✓	✓	✓	✓	The RCA-PCC pavement is slightly less sustainable compared to the plain PCC pavement during the use phase.
7	Batouli and Mostafavi [97]	-	-	-	-	-	-	✓	-	Rise in M&R expenditure ensure the network’s efficiency and environmental impacts significantly.
8	Zheng, et al. [101]	-	-	✓	✓	✓	✓	✓	-	The best economic and social performance was achieved by hot mix asphalt with reclaimed asphalt (HMAR) and the best environment performance was achieved with hot mix asphalt with warm mix additive (HMAW)
9	Anastasiou, et al. [22]	-	✓	✓✓	✓	✓	✓	✓	✓	The 25 % clinker hydraulic road binders minimize GHG emissions by more than 50 % while fly ash also decreases GHG emissions with 50 % cement material.
10	Yang, et al. [21]	✓	✓	✓	✓	✓	✓	✓	✓	The relative energy, GWP and cost decreased with an increased recycled content were observed in comparing 10 blends with 25–60 % ABR to a virgin dense-graded mixture.
11	Yu, et al. [25]	✓	-	-	-	-	-	-	✓	8.2-12.3 %, 5.9-10.2 % in energy and GHGs and a reduction in overall costs
12	Araújo, et al. [23]	✓	✓	✓	✓	✓	✓	✓	✓	• With 50.0 % Recycled Asphalt pavement (RAP), energy consumption was reduced by 3 % and gaseous emissions were reduced by 14 % for CO_2, 23 % for SO_2 and 15 % for CH_4, N_2O and NO.

13	Batouli, et al. [19]	✔	✔	✔	✔	✔	✔	✔	-	• Compared to the FDOT design and the ACPA rigid floor design, the HMA flexible pavement created 13.2 times and 14.1 times higher GWP.

4.2. Assessment of Infrastructure Performance with LCCA

The quality and luxurious life of humans depends upon the infrastructure quality, quantity, and efficiency. To maintain the quality and efficiency of the infrastructure project it should be maintained properly throughout its life. The proper functionality and safety of infrastructure require routine M&R intervention. LCCA is an approach that identifies the M&R intervention of infrastructures including direct and indirect costs. LCCA approach assists to evaluate optimal M&R approaches for deteriorating structures over a specific time. After reviewing the included articles, a detailed summary of the articles was demonstrated in Table 3 which were then interpreted.

Table 3. Publication summary of LCCA

S. No	**Author**	**Purpose**	**Methodology**	**Type of Projects**	**LCCA dependencies**						
					Time	**Inspect Cost**	**User Cost**	**Environmental Hazards**	**Safety performance**	**Agency cost**	**Cost function**
1	Kong and Frangopol [105]	Deterioration analysis	Reliability-based structure management systems	-	✔	-	✔	-	✔	✔	✔
2	Saad and Hegazy [106]	Deteriorating infrastructure	Microeconomic	Pavements	-	-	-	-	✔	✔	✔
3	Sajedi and Huang [107]	Analyzing Corrosion associated cost	Reliability-based life-cycle-cost comparison	Bridges	✔	-	-	-	✔	✔	✔
4	Akadiri and Olomolaiye [108]	Material selection	Questionnaire	Infrastructure	✔	-	✔	-	-	✔	✔
5	Gao, et al. [36]	New construction materials	Stochastic Multi-Objective Optimization	Bridge deck	✔	-	-	-	-	✔	✔
6	Salinas, et al. [109]	Interface bonding	Comparative analysis	Tack Coat	-	-	-	-	-	-	✔
7	Li, et al. [110]	Highway decision making	multi-commodity minimum cost network (MMCN)	Tollway project	✔	-	-	-	-	-	✔
8	Li, et al. [111]	Safety risk	Fault tree analysis (FTA) is	Highway	-	-	-	-	✔	✔	✔
9	Jha, et al. [112]	Maintenance time management	Optimization model	Highway	✔	-	-	-	-	✔	✔
10	Huang and	Maintenance time management	Concurrent maintenance	Bridges	✔	-	-	-	-	✔	✔

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	Huang [113]										
11	Macek and Snížek [114]	Maintenance and renovation	Bridge pass application	Bridge	✓	-	-	-	-	✓	✓
12	Farran and Zayed [115]	Infrastructure rehabilitation	Genetic Algorithm and Markov chains.	Infrastructure	-	-	-	-	-	-	-
13	Shahtaheri, et al. [116]	Infrastructure sustainability	SIMPLE-Design	Infrastructure	-	-	-	-	-	-	✓
14	Hasan, et al. [6]	Integrated LCCA	Review Analysis	Road network	✓	-	✓	-	✓	✓	✓
15	Al-Chalabi [117]	Total Ownership Cost (TOC)	MATLAB	Road tunnel	-	-	-	-	-	-	-
16	Babashamsi, et al. [118]	Pavement LCCAs	Critical Review	Pavements	✓	-	-	-	-	✓	✓
17	Heidari, et al. [60]	Pavements Alternatives	DP, MCS and TOPSIS	Pavements	-	-	✓	✓	-	✓	✓
18	Senaratne, et al. [119]	Maintenance and renovation	Net Present Value (NPV)	Harbour bridge	✓	✓	-	✓	-	✓	✓
19	Okte, et al. [120]	Incorporating user cost	International roughness index (IRI) progression model	Tollway road	-	-	✓	-	-	-	✓
20	Praticò, et al. [121]	Risk level of the highway design	Fault tree analysis (FTA)	Highway	-	-	-	✓	-	✓	-
21	Hameed and Hancock [122]	Integration of environmental and economic factors	Integrated life-cycle analysis approach (ILCA2)	Infrastructure	-	-	✓	✓	✓	✓	✓
22	Salem, et al. [123]	Pavement rehabilitation alternatives	survey of the US and Canadian state transportation agencies	highway	-	-	✓	-	-	✓	-
23	Wang, et al. [124]	Integration of environmental and economic factors	Environmental incorporated-LCCA model	Bridge	-	-	-	✓	-	✓	✓
24	Janbaz, et al. [125]	Estimate the capital and annual costs of a UFT system	Regression model	Underground Freight Transportation (UFT)	-	✓	✓	-	-	✓	✓

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25	He, et al. [126]	Integration of environmental and economic factors	Athena Pavement LCA and MOtor Vehicle Emission Simulator	highway	✔	✔	✔	✔	✔	✔	✔
26	Hasan, et al. [127]	LCC-based identification of geographical locations	Probabilistic Hazard Analysis	Reinforced concrete girder bridges	✔	✔	-	✔	✔	✔	-

4.2.1. Cost Function

Construction analysis provides a face value mostly case studies, i.e., the discussion of conscience, comprehensive illustration of the implementation of a modern model or process. The life cycle of the infrastructure project is fully case-based, where the outcomes of the trials are compared in percentage form to determine the better alternatives. In a case study of an infrastructure project, Kong and Frangopol [105] incorporated cost function with the time variable. Incorporation of time with cost function evaluate the impact of time travel or delays due to pavement performance and serviceability on the user cost. Although incorporating cost function with other variables such as the effect of project inspection and scheduled or routine M&R will improve the maintenance efficiency of infrastructure deterioration. Introducing cost function in the infrastructure intervention and reliability enhances the reliability-based structure management system. A reliability-based management model can be used for various analyses. A safe and operable approach is required to sustain the deteriorating infrastructure assets. Mostly infrastructure management possesses detailed LCCA to allocate the funds for M&R optimally. Saad and Hegazy [106] identify the lack of a mechanism to justify the allocation of LCCA details in M&R and incorporated microeconomics theories to justify the decision made based on the LCCA. The concept of marginal utility is used by economists to determine the number of items, the consumers are willing to invest. The microeconomics approach justifies the fund allocation based on consumer behaviours and proved the marginal utility per dollar is equalised.

4.2.2. Agency Cost and Users Cost

The LCC of infrastructure consists of Agency and User Costs over an appropriate period of analysis. The Agency's costs include the initial construction costs and the M&R costs incurred during the analysis period. User costs occur during the serviceability phase and M&R phase when the working zone is present. Normally in LCCA of traditional practice, the agency costs are considered whereas the users operating cost is ignored, which is more important for accurate calculation of LCC. Okte, et al. [120] investigated the resurfacing Illinois Tollway project to evaluate the vehicle operating cost (VOC) as user cost and found that the VOC should be considered in LCCA as it is reliable for the International Roughness Index (IRI) progression model. IRI is the strategy used in the pavement design which impacts the VOC directly. The integration of user costs into design and decision-making systems immediately from the planning phase of the project would enable transport departments to remain customer-oriented and minimize the total impact of the project [123].

4.2.3. Operation and maintenance Management Cost

For infrastructure design, cost-optimal solutions are required that not only affect the Life cycle cost but also enhance the management strategies to ensure safety performance [111]. Infrastructure or pavement design and maintenance management have considerable interaction among them such as good designed and properly maintained pavement minimize the life cycle cost of the whole project. Whereas, there is a lack of consideration of maintenance management costs noticed in the design phase thus increasing the life cycle cost of the project [112]. The M&R tasks on operation infrastructure are very important, whereas M&R activities increase the users' cost by causing traffic jams and detours. A concurrent M&R methodology has been introduced into the maintenance management of existing bridges infrastructure which helps in integrating the maintenance timing of the bridge elements hence reducing the user cost and total life cycle cost [113]. The same methodology can be adopted for on land pavements to optimize the users' cost. The model optimizes the life cycle cost of the bridge by incorporating the user cost as well as the agency cost, but the deterioration cost is not considered which needs to be incorporated further. Moreover, an economical construction strategy for bridges has been highlighted and it is evident that the bridges project management consist of investment cost as well as appropriate operating cost because of extended service life. An innovating computational model is presented, which links the pricing databases into two sets such as the operational and maintenance cost calculations are based on the expert database whereas the replacement cost of the components linked to the designer price database [114]. Mostly the M&R methods for infrastructure projects were reported for a specific type of project such as pavements, bridges, etc. Farran and Zayed [115] developed a generic model for maintenance and rehabilitation planning of public infrastructure that helps in determining the optimal M&R decision-making analysis by using the genetic algorithm and Markov chains. The model helps in overcoming the computational calculation whereas the model is only valid for four alternative decisions. Similarly, in railway infrastructure, the operational cost equates to 25-30 % per annum. The railway track needs to be inspected and maintained annually. Senaratne, et al. [119] selected Sydney Harbour Bridge (SHB) as a case study to evaluate the maintenance and ongoing operation of railway infrastructure considering timber transoms. The transoms used has shorted life span and height chances of degradation, therefore the issue was analysed by exploring sustainable alternative such as fiber composite with the implication of LCCA and found it more financially stable. Thus, the M&R during the operational phase affect the project significantly which needs to be assessed during decision making where LCCA is found considerable approach for best decision making.

4.2.4. Material Selection With LCCA

In complex infrastructure projects, the materials need routine maintenance, repair, and rehabilitation to ensure safety and maintaining the interconnected structure to overwhelm the corrosion associated cost. Corrosion management strategies should be the selection of suitable materials during repair or utilizing materials having corrosion-resistant properties that help to optimize the LCC. Long-term cost-effectiveness has been analysed for various groups of materials in the design and repairing phase and a time-dependent reliability LCC model has developed [107]. Moreover, Hasan, et al. [127] introduced a new method that incorporates the hazard correlated with airborne chloride with the Carbon Steel and Stainless Steel reinforcements into the probabilistic LCC estimate of the RC bridge to manage the corrosion hazards. The model asses the practitioners to assign an appropriate geographical location for the girder bridge to optimize the maintenance cost. While to improve the performance and productivity for sustainable infrastructure, usually, new materials are adopted at the project level and network level. LCCA plays a significant role in material selection [108]. Though, because of the limited implementation data of newly adopted materials, the reliable estimate of the life cycle cost becomes a challenge. A bottom up LCCA framework has been presented which analyses conventional as well as new construction materials at the project level and network level.

Efforts presented to incorporate various cost factors such as years, users, and social cost, as well as a stochastic tackling of uncertainties, has been included. The purpose was to approach the reasonable estimate of the future performance of the newly adopted materials or techniques [36]. Similarly, A convenient method to analyses the optimized tack coat for the pavement layer is LCCA, which will help to ensure cost-effective optimum tack coat application in the field [109]. Moreover, project selection has a significant impact

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on fulfilling the scope of a project. A multi-commodity cost network (MMCN) model has been introduced to assist project selection and evaluation by estimating the LCCA. Although the model plays a significant role in the selection of an optimal solution a huge amount of data is required which makes the use of the MMCN model limited [110].

4.3. Integrated LCA and LCCA

The environmental efficiency of the infrastructure system is based on complex transitions in service level and infrastructure performance. LCA describes environmental effects for the lifetime of a material or project and, by quantifying environmental and social responsibilities, provides the required data for LCCA. Some studies argued that the agency cost, user costs and the environmental cost for preventing environmental damage should be allocated to a project. Adopting an LCA and LCCA approach in the design and decision-making phases will help and identify the most economical and environmental options, that can be utilized by all the parties involved in the planning to analyze sustainable alternatives [99]. Implementing an integrated LCA and LCCA methodology in the infrastructure approach could enhance road infrastructure management which will consider all the associated cost along with environmental protection cost. A detailed summary of the articles is shown in Table 4, where it is shown some publication adopted LCA and LCCA individually and some of the publications are focused on integrated LCA and LCCA. Besides this, the sustainability indicators highlighted by the publications are also indicated.

Table 4. Publication summary of Integrated LCA and LCCA

S. No	Authors	LCA	LCCA	Environmental Indicators									
				Energy Emission	SO	Particulate matter	SO2	CO	Pb	VOC	CO2	N2O	Ch4
1	Kendall, et al. [128],	✔	✔	-	-	✔	✔	✔	✔	✔	✔	✔	✔
2	Zhang, et al. [129]	✔	✔	-	✔	✔	✔	✔	✔	✔	✔	✔	✔
3	Liljenström, et al. [130]	✔	-	-	-	-	-	-	-	-	✔	-	-
4	Tokede, et al. [131]	✔	-	-	-	-	-	-	-	-	✔	-	-
5	Liu, et al. [96]	✔	✔	-	✔	✔	✔	-	-	-	✔	-	✔
6	Heidari, et al. [60]	✔	✔	✔	-	-	-	-	-	-	✔	-	-
7	Shi, et al. [20]	✔	-	-	✔	-	-	-	-	-	✔	✔	✔
8	Haslett, et al. [99]	✔	-	✔	-	-	-	-	-	-		-	-
9	Liu, et al. [24]	✔	✔	-	✔	-	✔	-	-	-	✔	✔	✔
10	Yang, et al. [21]	✔	✔	✔	-	-	-	-	-	-		-	-
11	Yu, et al. [25]	✔	✔	✔	✔	✔	✔	✔	-	✔	✔	✔	✔
12	Araújo, et al. [23]	✔	-	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
13	Batouli, et al. [19]	✔	✔	-	✔	-	-	-	-	✔		-	-
14	Giustozzi, et al. [132]	✔	-	✔	-	-	-	-	-	-	✔	-	-
15	He, et al. [126]	✔	✔	✔	-	-	-	-	-	-	✔	-	-
16	Nascimento, et al. [133]	✔	-	-	-	-	-	-	-	-	✔	✔	✔
17	Li, et al. [134]	✔	-	-	-	-	-	-	-	-	✔	-	-
18	Park and Kim [103]	✔	-	-	✔	-	✔	-	-	-	✔	-	✔
19	Zheng, et al. [101]	✔	✔	✔	-	-	-	-	-	-	✔	-	✔
20	Umer, et al. [135]	✔	✔	-	✔	✔	-	-	-	✔	✔	✔	✔
21	Santos, et al. [104]	✔	✔	-	-	-	-	-	-	-	-	-	-

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22	Batouli and Mostafavi [97]	✔	-	-	-	-	-	-	-	-	✔	-	-
23	Inti, et al. [136]	✔	✔	-	-	-	-	-	-	-	✔	-	✔
24	Gschosser and Wallbaum [137]	✔	✔	✔	-	-	-	-	-	-	✔	-	-
25	Santhanam and Gopalakrishnan [26]	✔	-	-	✔	-	✔	-	-	✔	✔	✔	✔

Mostly in the life cycle evaluation, the environmental damage costs are ignored. An extensive LCA technique in the field of pavements is used in the analysis to estimate the marginal cost of damage to different emissions and an algorithm was developed to align the LCA with the LCCA model. In comparison with usual traffic activities, the congestive module accounts for extra fuel usage and air pollution during construction and M&R cycles. Analysing the results of the LCA implementations, streamlined maintenance schemes costs are decreased by 5.9–10.2 % and by holistic costs relative to previous optimization schemes by 8.2–12.3 %, compared with the influence of energy/GHG assessments [25].

Zhang, et al. [129] studied the pavement system with an LCA and LCCA integrated Life Cycle Optimization (LCO) model, where an energy savings of 5-30 %, Reduction of 4-40 % GHS pollution, while concrete costs decreased by 0.4-12 %, was reported. With 50.0 % Recycled Asphalt pavement (RAP), energy consumption was reduced by 3 % and gaseous emissions were reduced by 14 % for CO_2, 23 % for SO_2 and 15 % for CH_4, N_2O and NO [19]. In many of the studies, LCA and LCCA are adopted where user cost, agency cost and environmental impact are considered whereas very few studies incorporated the environmental cost [19, 25, 101, 128, 129] as well, which is the cost utilized for the depletion of the harmful impact of the environment.

Infrastructure projects affect the economic, environmental, and social system directly or indirectly, whereas it is recommended that the infrastructure agencies must review these parameters in the planning stage of a project [125]. A decision-making system introduced by integrating sustainability criteria and economic criteria, developing a model which utilizes LCA and LCCA for pavement management and selection of best alternatives between Asphalt Concrete Pavement (ACP) and Plain Cement Concrete Pavement (PCCP). The results evaluated from the analysis demonstrated that ACP is more economical than PCCP although its carbon emission is highest. Thus LCCA implementation in pavement selection is very important, as a case study, indicates that choosing concrete pavement increases the construction cost by 35 % whereas, it will reduce 2 million tons of carbon emission and 0.7 million GJ energy consumption annually [60]. Moreover, Hameed and Hancock [122] developed an integrated life cycle approach (IILCA2) that unite the LCA and LCCA by incorporating materials quantities, the environmental impact of materials in term of cost such as carbon footprint and cost of waste materials. Similarly, Wang, et al. [124] incorporated the environmental costs such as structure emissions to air, water and land and developed an environmental incorporated-LCCA model. The model was applied on a bridge to select structural material for bridge girders, taking into consideration direct, environmental, and overall initial costs. Whereas steel girders are found to have lower direct costs and environmental costs due to lower pollution, easier building practices and the higher content recycling rate in the construction phase, demonstrating greater economic and environmental efficiency in the initial level. Further, He, et al. [126] proposed a decision-making framework to integrate the LCA and LCCA to assess highway treatment events which allow to implementation of the most suitable alternative for a project. Project solutions were evaluated utilizing different environmental methods, including asphalt overlay of the warm mix, cold in-place recycling, maximum depth reclamation, intelligent compaction, and precast concrete pavement systems. Using the outcomes of life cycle evaluation with the implemented proposed framework, the professionals may help grasp the ramifications of project-level actions, conduct what-if analysis to analyses exchange between options and achieve sustainability-related organization priorities and goals. Additionally, the back-and-forth relation among the economic, environmental, and social features of infrastructure seems very tough for the decision-makers in the design phase. As a result, reducing the initial construction cost, the decision-makers

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compromise the environmental and social entities. A sustainable infrastructure multi-criteria preference assessment of Alternative for early design (SIMPLE-Design) strategy is formulated which incorporates the indifference curve to assess the decision-makers in dealing with the back-and-forth relationship between different alternatives [116]. Whereas, further the indifference curve needs to be extended with the inclusion of more trade-off entities to improve the decision-making in diverse scope. The LCCA, future cash flows, feedback, and incorporating the project performance with sustainability can assess the process of decision making towards the selection of sustainable options for a construction project. Interpreting the principal of LCA with LCCA to demonstrate the sustainability that asses the quality, time and cost of a project [6], which is very useful for new and repairable systems because, at some point in their life span, their operating and maintenance costs and impact will exceed their acquisition costs [117].

4.3.1. Life Cycle Model Development

In many studies, the researchers developed some models or frameworks that try to minimize the limitation of the existing methodologies for specific parameter or areas. He, et al. [102] developed a Decision support system with the integration of LCA and LCCA which allows the practitioners to evaluate a sustainable project alternative by identifying economic, social, and environmental impact. Similarly, Li, et al. [95] defined the Environmental Impact Evaluation (EIE) Model to analysis each of the processes that contribute to the transport life cycle of projects in which the development stage has the highest environmental impact 62.7 %, followed by the demolition 35.8 % and restoration stages 1.7 %.

Data availability is one of the critical aspects in the process of LCA to evaluate a successful analysis although the acquisition of the data in the assessment is found very confusing and sometimes improper data leads to faulty computations. Park and Kim [103] built an LCA-based Environmental impact Estimate Framework that incorporates existing data during its design process to estimate the environmental impact of an earthwork type road project, however, the established model uses only limited data available in the design stage. Santos, et al. [104] He has evolved the LCC-LCA model that depends on a hybrid inventory system that enables sub-models to link each other across data sources. This provides for the monetary flows linked to the pavement life cycle structure exchanges that are specifically protected by the LCC model for which data is not accessible.

5. Discussion

The construction industry is one of the most important industries, which has a huge impact on the economy, environmental as well as social life [138-141]. To meet sustainability objectives, it is necessary to evaluate the activities over the life cycle of the project. LCA an LCCA are the assessment tools the evaluate the project performance in terms of environmental, social, and economical impact. Implementation of Life cycle techniques for decision-making during the planning and design stage to evaluate all the constraints related to the infrastructure project may be more cost-effective with a resilient and productive construction over the life cycle of the project.

With the increasing interest in sustainability, LCA adaptation in the infrastructure projects gained significant momentum in the field of research. LCA deal with the impact of a project on the environment and social life of human being. Whereas adopting sustainability strategies, the project faces a cost issue increasing the budget of the project. To consider the economic perspectives of a project along with sustainability, the LCCA methodology got the attention of the practitioners and researchers. Likewise, LCA, the LCCA is perceived by decisionmakers to be an effective solution for assessing the economical project with improved sustainability. LCCA has a wide range of application, which allow decision-makers to compare and choose a sustainable option in terms of cost.

In the process of LCA, the impact of an infrastructure project is calculated from the materials extraction to the end life of the project where a detailed inventory is generated and integrated with impact values. The inventory generated a detailed of a project which can be further used for cost assessment. In some researches, the infrastructure project life cycle is an asset with virgin material whereas in some places recycled materials are used and compared [95]. Likewise, using RCA in the pavement could save 18 % of energy, reduce 23 % gaseous emissions, reduce 25 % pollutants whereas 35 % overall cost of the project. However, in the assessment of materials for an infrastructure project, the environmental impact is considered whereas the environmental costs are ignored. Since the environmental impact could only reduce and cannot be eliminated, which need potential attention to treat, thus consideration of environmental cost is very important in the LCCA stage. The environmental cost is the cost that could use for the treatment of the damage or reduce the impact. Besides, in several research and case studies, the LCA and LCCA are adopted individually while some focused on the integrated results of LCA and LCCA.

Economic and environmental development techniques for road projects have been emphasized with proper management. Efficient management approaches enhance infrastructure performance during planning, construction, operation, and maintenance. The LCA and LCCA have a significant relation with management strategies in the decision-making stages. Whereas there is a lack of consideration of the maintenance management costs during the design process, thereby raising the environmental impact, social stresses and life-cycle cost of the project. [112]. Similarly, maintenance of operating projects is very significant, where the maintenance activities increase the cost of travellers by creating traffic delays and detours that also become a great cause of energy consumption and environmental stresses.

LCA and LCCA have been described as the most developed methodology that affects different facets of infrastructure projects to optimize the cost and environmental impact ensuring a sustainable project. Besides, LCA and LCCA are known to be important approach used in the planning and design phase by decision-makers to assess the economic, environmental, and social sustainability [142-144].

6. Conceptual Framework

Based on the literature, a conceptual framework, as seen in Figure 6 has been developed to consider the impact of life cycle evaluation on various aspects of the infrastructure project and how it impacts the economy, environment, and social life.

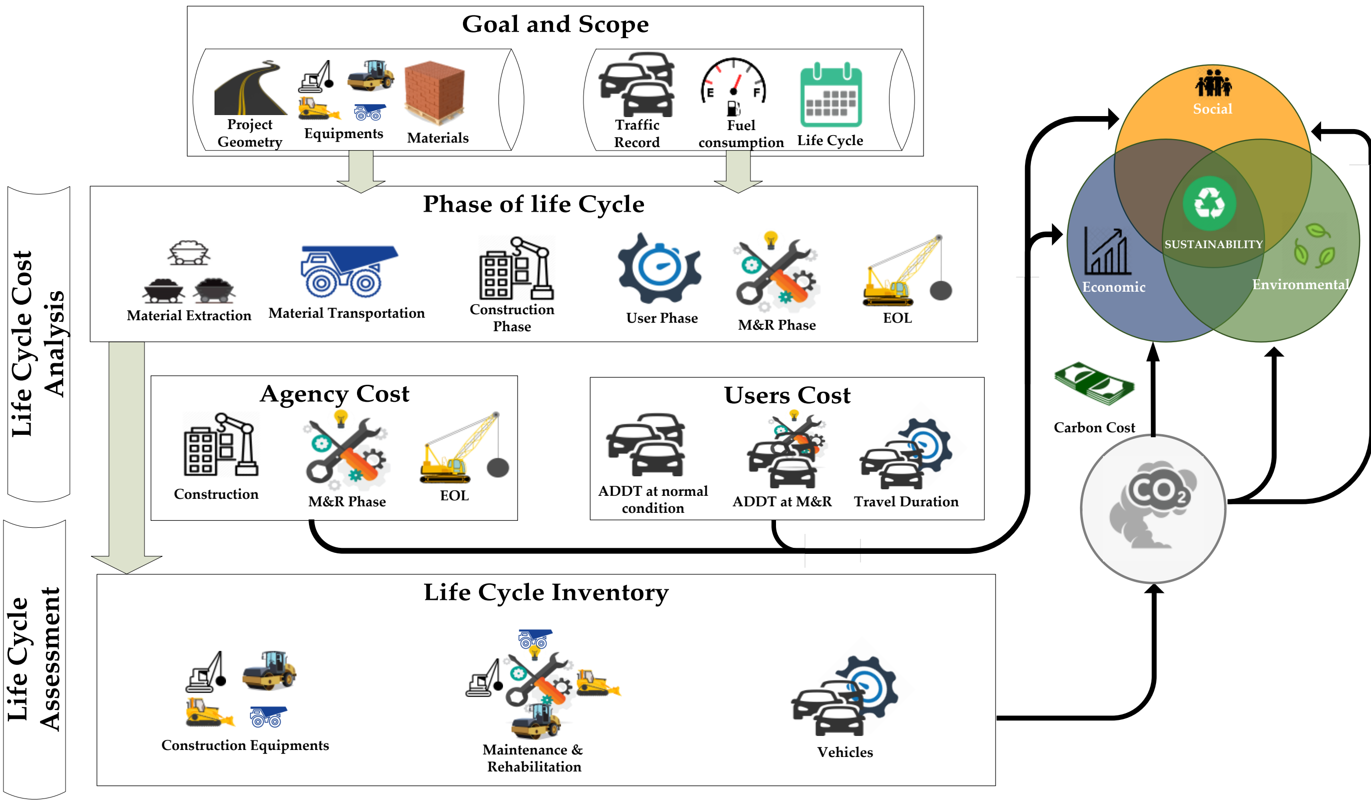

Figure 6. Integrated LCA and LCCA framework and its impact on sustainability

The use of integrated LCA and LCCA is an obligatory prerequisite to efficiency regarded in infrastructure planning and management. Initially, LCA and LCCA identify appropriate solutions to the design or M&R approach. The LCA and LCCA describe initial construction and operation, the M&R activities needed for the future and the coordination of those activities. The life cycle evaluation approach can develop solutions to identify environmentally, economically, and socially sustainable technology, products, and services. The economic effects of capital expenditure are assessed by LCCA. Whereas the LCA assess the impact and potential risks associated with the project. The cost of the overall life cycle, including planning and design, development, service and repair, and disposal, should be included in assessing the agency cost and users' costs, whereas the impact of agency activities and user activities are also the key concern to identify. The embodied impact of materials, transportation of materials, the onsite machinery utilization in the construction and rehabilitation phase as well as the vehicle in the use phase impact the environment adversely. Comparably, the use phase of infrastructure project is the main part of the project which impacts the economy and environment. Consequently, for a sustainable project, their impact, and the cost to reduce the impact must be considered in the decision making of life cycle evaluation.

Furthermore, the new infrastructure projects are very costly to execute, thus it is recommended and practiced rehabilitating old and existing infrastructure or assessing recycled material in the construction. The rehabilitation process impacts the environment and economy comparatively low, while the inclusion of M&R costs and impact in life cycle evaluation will enhance sustainability. moreover, most infrastructure projects ignore user activities, consequently, adversely affects the user's life. The key parameter such as Vehicle expenditure, travelling time, and safety is the important aspects need to be considered in the life cycle of infrastructure projects. The vehicle utilizes fuel affecting the economy and emits harmful gasses affecting the environment, whereas the fuel consumption and emission of harmful gasses are proportional to the time of travel. Consequently, social sustainability is affected as the life of humans depends upon infrastructure quality, quantity, and efficiency. Thus, adopting an integrated LCA and LCCA approach to incorporate the impact and cost of agency activities and user activities will enhance the constraints of sustainability. Moreover, in the developed framework, carbon price is incorporated, which will assess the managerial activities to compensate the harmful impact due to infrastructure projects. The integration of the carbon price enhances the framework adoptability for delivering sustainable project.

7. Case Study

To evaluate the impact of an infrastructure project on sustainability, an integrated LCA and LCCA framework was developed. In the design and decision-making processes, the implementation of an LCA and LCCA approach is expected to define the most cost-effective and environmentally sustainable options. The introduction of an advanced infrastructure LCA and LCCA approach facilitates road infrastructure management, which considers all related costs and environmental mitigation costs. To assess the model, a case study was performed with the integrated approach of LCA and LCCA and LCA for a 1 km road construction consist of 2 lanes. The road was design based on the AASTHO standard for 20 years. The adaptation of integrated framework for the case study is shown in Figure 7.

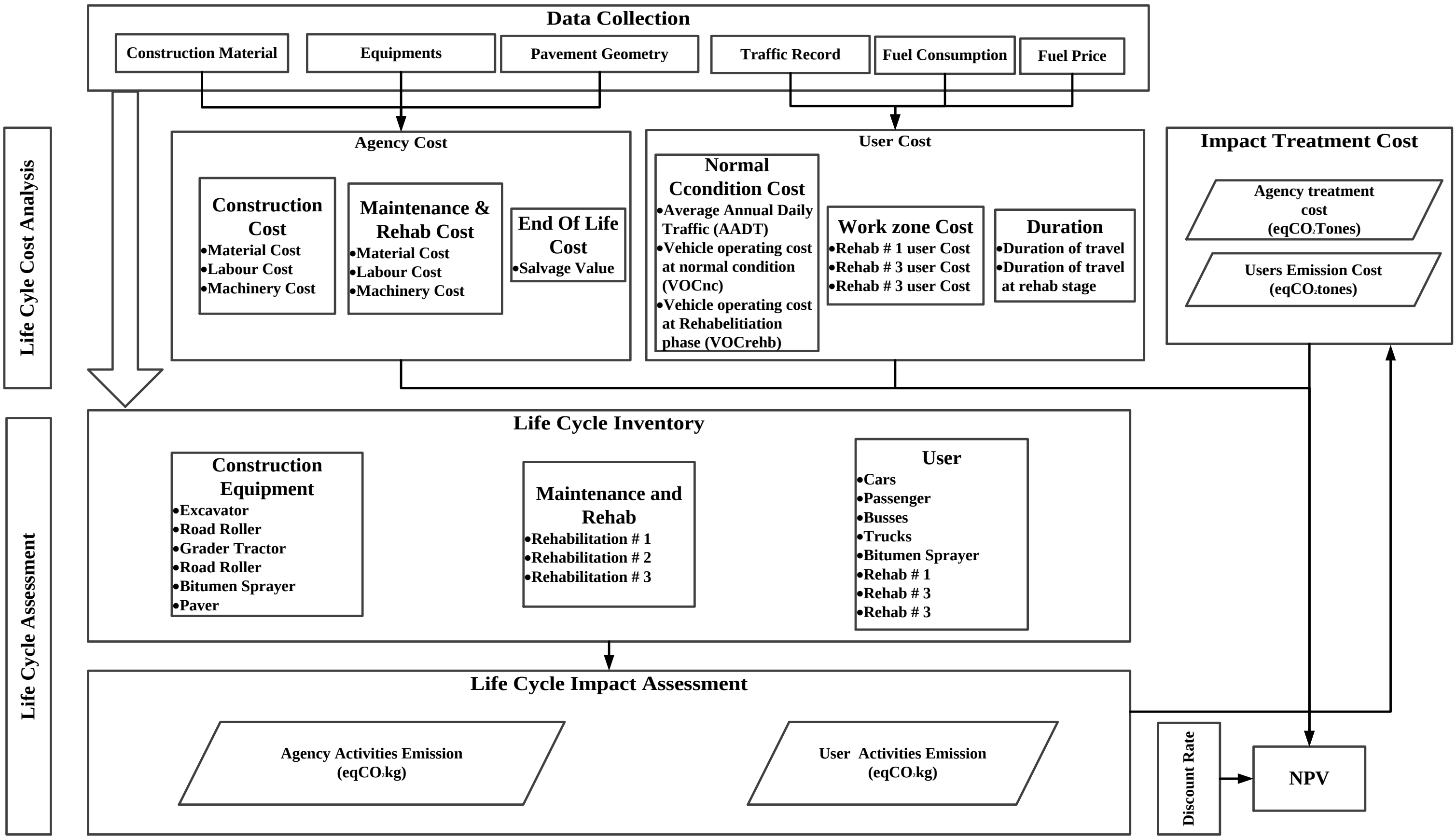

Figure 7. Case study adopting Integrated LCA and LCCA framework

7.1. Data COllection

7.1.1 Agency Data

The important data regarding the project such as pavement geometry, construction activities, construction materials, on-site equipment used for construction and related costs were collected from the resident engineer, contractor, and Communication & Work (C&W) department of Khyber Pakhtunkhwa, Pakistan [145]. The cost breakdown structure of the construction phase is shown in Table 5.

Table 5. Construction phase cost breakdown

	Component Activities	Qty	Unit	Total Cost (USD)
1	Clearing and Grubbing by mechanical means	1829.00	m2	185
2	Compaction of Natural Ground	1829.00	m2	229
3	Formation of Embankment from Borrow Excavation in Common Material including compaction Modified AASHTO 90 % by power roller.	1114.38	m3	5,505
4	Grooving in existing BT road of size 4x4 cm @ 2-meter c/c.	3657.99	m2	1,167
5	Granular Subbase Course using Pit Run Gravel	278.60	m3	2,508
6	Water Bound Macadam Base Course	746.64	m3	11,760
7	Bituminous Prime Coat	3657.99	m2	4,350
8	Asphaltic Wearing Course (Asphalt Batch Plant Hot Mixed)	186.10	m3	21,871

9	Pavement marking in reflective thermoplastic paint with glass beads for line 15 cm width.	1999.39	m	1,288
	Total			48,863

The M&R cost was assumed and estimated by the reference project in the same area with the help of contractors and project engineers. The pavement life is considered 20 years and having a schedule M&R cycle after every 5 years for which a fixed price was allocated in the planning phase. The details about the maintenance and rehabilitation are shown in Table 6.

Table 6. Maintenance and Rehabilitation cost breakdown

Component Activity	Year	Cost (USD)
M&R # 1	5	10,000
M&R # 2	10	10,000
M&R # 3	15	10,000
Total M&R Cost		**30,000**

The estimation of salvage value or End of Life Value (EOLV) of the project in Pakistan is frequently ignored. In the current case, the EOLV of the asset was calculated -5864 USD based on the ratio of end condition of the pavement multiplied by the initial construction cost using equation 1.

$$EOLVi = \left(\frac{PSIni-2}{4.5-2}\right) * Ci \qquad (1)$$

Where EOLVi represents the end-of-life value of alternative i, PSI_{ni} is the pavement serviceability index of alternative i at the end of life and Ci is the initial construction cost of alternative i.

7.1.2. Users Data

The cost of the users is the assessment and integration of daily user vehicle cost in normal condition along with the cost of M&R activities. Due to the M&R activities, different levels of traffic jams are likely to occur in the upstream work area based on traffic volume. To take account of transport delays, speeds of vehicles must be estimated and compared against normal traffic conditions.

To evaluate the users' cost during normal operation the Annual Average daily traffic (AADT) recorded 2500 with an 8.4 % growth rate annually, was obtained by the project engineers measured during the feasibility stage. The Vehicle Operating Cost (VOC) was determined by the distance travelled by the ADDT in the total days of the year multiplied by the unit rate of daily vehicle operating cost as shown in Table 7, using equation 2. The VOC was obtained by NTRC report Pakistan [146] and fuel consumption from daily fuel rates of Pakistan.

$$VOC = TD * AADT * Time * OC \qquad (2)$$

Where TD is the distances travelled by the vehicle, AADT is the daily traffic, Time is the number of days for which the cost to be calculated and OC is the per vehicle operating cost.

Table 7. Vehicle Operating Cost during normal condition

Vehicle Type	USD/ 1000km	USD/1km	AADT	Duration	VOC (USD) (1st Year)	AADT Growth Rate	AADT (20th Year)	VOC (USDD) (20th Year)

Car	317	0.317	800	365	92,629	8.4 %	4,015	464,869
Passenger	392	0.392	600	365	85,849	8.4 %	3,011	430,843
Busses	963	0.963	500	365	175,789	8.4 %	2,509	882,219
Trucks	654	0.654	600	365	143,218	8.4%	3,011	718,760
Total		**2**	**2,500**		**497,484**		**12,547**	**2,496,690**

Compared to the pavement normal condition, the VOC deviates from the normal condition during the M&R activities. The work zone under the maintenance activities affects the users' cost, travelling time and increases the environmental impact. Due to the insufficient data, the user cost is assumed to increase by 20 % in the normal condition. The M&R activities are scheduled after every 5 years with a maximum duration of 30 days. The users cost during the M&R phase are mentioned in Table 8.

Table 8. Vehicle Operating Cost during Maintenance and Rehabilitation

Component Activity	Year	Activity Duration (days)	VOC_{nc} (USD)	VOC Increase (%)	VOC_{Rehb} (USD)
M&R # 1 Work zone user cost	5	30	174,481	20 %	209,377
M&R # 2 Work zone user cost	10	30	174,481	20 %	209,377
M&R # 3 Work zone user cost	15	30	174,481	20 %	209,377
		Total			**628,132**

7.2. Life Cycle Assessment

The first phase of LCA is the identification of the Goal and scope of the project. In the current LCA of pavement only the construction phase, maintenance and rehabilitation phase, and use phase are considered for assessment. The assessment of raw material acquisition and end life are omitted due to the unavailability of appropriate data provided. In the construction phase, the impact of the pavement due to the construction activities and on-site machinery are measured. Similarly, the M&R phase is similar to the construction phase where the impact of maintenance activities and the machines used are measured. Moreover, the use phase of LCA measures the potential impact of the usage activities such as vehicle fuel consumption and emission. In the following case study user impact such as energy depletion and CO_2 emissions due to on-site machinery used for construction and the vehicle and transportation are taken under consideration.

The second phase of LCA is the development of Life LCI which consists of a detailed list of input and out data flow of variables for and asset or a product. The LCI for the case study is developed from the data collection stage. The inventory list contains the potential aspect of a project as shown in Table 9, that impact the environment. The equipment utilized for the construction phase is also expected the same for the rehabilitation phase activities. Similarly, the potential sources of impact in the use phase are different type of vehicles and their emissions.

Table 9. Life-Cycle Inventory

Construction Equipment	Fuel Type	Unit
Construction and Rehabilitation phase		
Excavator	Diesel	L/hr
Road Roller	Diesel	L/hr
Road Roller	Diesel	L/hr
Grader tractor	Diesel	L/hr
Road roller	Diesel	L/hr
Bitumen Sprayer	Diesel	L/hr

Paver	Diesel	L/hr
Use Phase		
Car	Petrol	L/hr
Passenger	Petrol	L/hr
Busses	Petrol	L/hr
Trucks	Petrol	L/hr

The third phase of LCA is the LCIA which aims to evaluate the potential impact on the surrounding resulting from the variables determined in the LCI. In the case study, only the fuel depletion and CO_2 emissions by the equipment in the construction, M&R phase and the vehicles in the use phase are under consideration. During the construction phase, the daily activity and duration of activity details are provided by the project engineer. The total consumption of fuel is measured as shown in Table 10, by multiplying the hours of activities, the duration in days and the unit consumption by the machinery. During each activity, the machinery burns the fuel in the result of which the CO_2 is emitted that are harmful to the environment and human health. The burning of 1-litre diesel of fuel per hours is equivalent to 2.62 kg of CO_2 [147]. The total consumption of diesel fuel is converted to the equivalent of CO_2 kg.

Table 10. Construction phase fuel consumption and CO_2 emission

Construction Equipement	**Daily Activity (Hr)**	**Duration (days)**	**Total hours**	**Unit Consumption (l/hr)**	**Total Consumtion (l/hr)**	**Eq CO_2 kg**	**Eq CO_2 Tons**	**CO_2 Cost (USD/Ton)**
Excavator	8.00	5	40	8	320	838	1	29
Road Roller	8.00	12	96	10	960	2,515	3	88
Road Roller	8.00	10	80	10	800	2,096	2	73
Grader tractor	8.00	12	96	6	576	1,509	2	53
Road roller	8.00	15	120	10	1,200	3,144	3	110
Bitumen Sprayer	8.00	10	80	9	720	1,886	2	66
Paver	8.00	8	64	12	768	2,012	2	70
		Total			**5,344**	**14,001**	**14**	**490**

Similarly, The LCIA for the use phase is measured in which the input from the LCI generated was evaluated with impact output. In the use phase, the vehicle and the rehabilitation phase are the potential sources of fuel consumption and CO_2 emissions. The unit price of the 1-litre petrol in Pakistan was taken 0.69 USD. The total fuel consumption of the vehicles is measured by the VOC during the design period, whereas the VOC due to the work zone in rehabilitation is also highlighted being as the VOC and impact of the vehicle increase with the time delays. Then, the total amount of fuel consumption is converted to Kg where 1 litre of petrol is equal to 2.19 eq CO_2 Kg as shown in Table 11.

Table 11. Maintenance and Rehabilitation phase fuel consumption and CO_2 emission

Component	Year	Energy Source	Total cost (USD)	USD/L	litre	Eq CO_2 kg	Eq CO_2 Tons	CO_2 Cost (USD/Ton)
Car	20	Petrol	464,869	0.69	673,723	1,610,198	1,610	56,357
Passenger	20	Petrol	430,843	0.69	624,410	1,492,339	1,492	52,232
Busses	20	Petrol	882,219	0.69	1,278,578	3,055,802	3,056	106,953
Trucks	20	Petrol	718,760	0.69	1,041,681	2,489,617	2,490	87,137

Rehabilitation # 1 Work zone user cost	5	Petrol	209,377	0.69	303,445	725,234	725	25,383
Rehabilitation # 2 Work zone user cost	10	Petrol	209,377	0.69	303,445	725,234	725	25,383
Rehabilitation # 3 Work zone user cost	15	Petrol	209,377	0.69	303,445	725,234	725	25,383
		Total			4,528,727	10,823,658	10,824	378,828

7.3. Life Cycle Cost Analysis of road project

The relative effect on the results of the study of specific LCCs variables differs between the major and the minor values. The level of detail in the LCCA relates to the level of evaluation on the investment. Little variations in potential expense impact the reduced present value slightly. Even such considerations complicate the study in no way without enhancing the outcome of the analysis tangibly. The difficulty in identifying certain costs makes it less wise, particularly if the impact on LCCA results is at best marginal, FHWA report [148]. Following the FHWA manual, certain variables are omitted to get the best marginal outcomes.

In the final stage, the Equivalent Uniform Annual Costs (EUAC) of the case study was performed as shown in Table 12, using the NPV approach using equation 3.

$$EUAC = NPV\left(\frac{1(1+i)^n}{(1+i)^n}\right) \quad (1)$$

where NPV: net present value, i= discount rate, and n= years of expenditure.

All the cost identified are single payment cost which is discounted to NPV. The discount rate for the uniform series cost is considered by the FWHA report [148] against each year of the payment occurring. In the process of LCCA, the agency cost and user cost are identified. Besides this, considering the carbon price to compensate for the environmental impact such as CO_2 emission cost was calculated. To implement the carbon price the "Cap-and-trade" system and carbon taxes phenomena were considered in LCCA. The carbon tax or the cap and trade are the amount implemented by the government the consumers which they must pay. The carbon price is then utilized to reduce the impact of harmful emissions.

The amount Eq CO2 kg were converted into tons for which an average cost of 35 USD per ton of emission was calculated as shown in Table 10 and Table 11.

Table 12. Life cycle cost analysis of road project

Cost Component Activity	Cost	Discount Rate	Years	P/F	NPV
	(USD)	i	n		
Initial construction Cost	48,863	1	1	0.5	24,432
Construction CO_2Cost	490	1	1	0.5	245
Rehab #1	10,000	0.7835	5	0.055416	554
Rehab #1 User Cost	209,377	0.7835	5	0.055416	11,603
Rehab #2	10,000	0.6139	10	0.008341	83
Rehab #2 User Cost	209,377	0.6139	10	0.008341	1,746
Rehab #3	10,000	0.481	15	0.002765	28
Rehab #2 User Cost	209,377	0.481	15	0.002765	579
User cost for normal years	1,868,559	0.3769	20	0.001667	3,115

doi:10.20944/preprints202103.0316.v1

User CO_2 Emission cost		378,828	0.3769	20	0.001667		632
Salvage Value	-	5,864	0.3769	20	0.001667	-	10
					NPV		43,007

After conducting integrated LCA and LCCA for the case study, the impact and cost are evaluated for construction, M&R and use phase as shown in Figure 9.

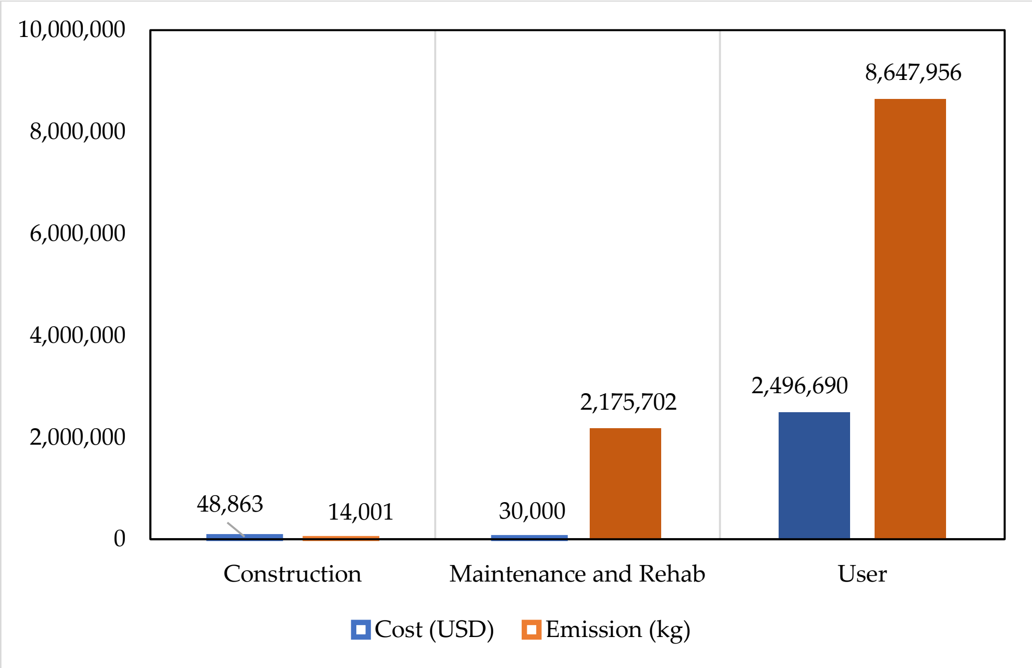

Figure 9. Associated costs and emission with different phases

The construction phase is the least costly and having the least impact comparatively to the maintenance and rehabilitation phase and user phase. In the construction phase, the on-site machinery is responsible for the emission which ends with the completion of the project. Besides this, the M&R phase of the project usually cost less because of routine maintenance or scheduled maintenance activities are performed to sustain the survivability of the infrastructure. Moreover, the M&R phase has a higher impact compared to the construction phase. The impact of maintenance and rehabilitation is higher due to the activities during the service phase, which increases the emission and other environmental impacts. In the M&R phase, emissions of CO_2 are summed up individually to indicate a clear impact during this phase. The user phase comparatively to the construction phase and rehabilitation phase is most costly and have a higher impact. During the user phase, the vehicles are responsible for the increases in the cost and emissions where the vehicle utilizes fossil fuel affecting the economy and discharges toxic emissions affecting the atmosphere. The use phase lasts longer than the construction phase and M&R phase, whereas the fuel consumption and emission of toxic gasses are proportional to the duration of the project. This will enhance the sustainability thresholds of an infrastructure project, the adoption of an integrated LCA and LCCA approach to include and forecasting the associated impact and costs could be during decision making could prove very effective. And enhance the project sustainability thresholds of the project.

8. Conclusions

A systematic literature review was performed on 55 articles consist of research papers, conference papers and review papers. PRISMA methodology was adopted for the evaluation of the extracted data from five databases namely: Scopus, Web of science, Emerald, and Science Direct. The study focuses on the influence of integrated LCA and LCCA in the enhancement of infrastructure designing and management strategies. Furthermore, environmental and economic developing strategies have been highlighted for infrastructure projects, with significant interconnections in infrastructure planning and maintenance, including well-designed and well-maintained strategies that reduce costs and impact for the entire life cycle of the project. In the extracted publication it was noticed that majority of the publication were centred to LCCA and LCA approach individually, while some of the publications were focused on the integrated LCA and LCCA. In the integrated approach, all the costs associated with a project and the impact were evaluated while the environmental cost has been ignored. It has been recommended that the cost of the impact associated with the life cycle of pavements to be included throughout the life of the project which should be used to overcome the negative consequences. To incorporate the environmental cost in the integrated LCA and LCCA approach a case study was conducted to evaluate the impact of the overall project. The results of the case study indicated that the different phases of the life cycle of a project affect the economy, social life, and environment at a different level. The user phase is the most critical phase which has high cost and impact compared to other phases followed by the M&R phase.

9. Future Direction

The conducted case study with integrated LCA and LCC involves costs and impact related to pavement construction, maintenance and rehabilitation and user phase. For the three phases, a detailed LCA and LCA is performed with the inclusion of environmental cost such as CO_2 price, whereas the materials extraction and end life of the project are omitted. In future, a study should be performed including Material extraction and end life of the project to assess the impact and related cost including environmental cost.

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