Sustainability Assessment Indicators of Road Infrastructure Projects: A Systematic Literature Review

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Abstract

Purpose – Sustainability performance in road infrastructure projects is crucial for achieving the Sustainable Development Goals (SDGs). Despite being a persistent challenge, it is essential to determine how sustainability can be assessed in these projects. This necessitates a systematic review of sustainability assessment indicators of road infrastructure projects aiming to analyse and synthesize existing literature to identify these indicators.

Design/methodology/approach – Using PRISMA principles, 54 peer-reviewed papers from 2010 to 2022 were retrieved from three search databases (Scopus, Research for Life, and Google Scholar) as part of a systematic literature review. Data analysis techniques included both descriptive and content analysis.

Findings - The study identified 22 indicators. The results emphasized that the sustainability of road infrastructure projects should consider all three sustainability dimensions to provide development while meeting human needs, preserving the planet Earth, and enhancing economic growth. Similarly, indicators should be incorporated from the design phase to implement and attain sustainability successfully.

Originality/value – The study's findings provide the sustainability assessment indicators for roads, which serve as a foundation for developing a sustainability assessment indicator framework for road infrastructure projects. Future research can look at establishing the indicators for the end-of-life phase of the project lifecycle.

Practical Implications –The outcome of this study will serve as a guide to road infrastructure stakeholders to understand the relevant sustainability indicators to assess the sustainability performance of their projects.

Keywords: Sustainability, assessment, indicators, sustainability indicators, infrastructure projects, road construction.

1. Introduction

Sustainability phenomena began decades ago, intending to balance the 3-sustainability aspects; environmental, economic, and social in project delivery and minimize environmental impacts (Bueno *et al.,* 2015). Over the years, the sustainability concept has been established as a notion to be abided by for sustainable development (Suprayoga *et al.,* 2020). In support of this is the establishment of the Sustainable Development Goals (SDG) 2030 by the United Nations. The construction industry plays a significant role in sustainable development by providing the physical infrastructure necessary to meet societal needs. However, it also has negative effects on the environment and society (Srivastava *et al.*, 2022). Human life is significantly impacted by environmental and societal implications such as the use of non-renewable natural resources, excessive land consumption, and air pollution (Mansourianfar and Haghshenas, 2018).

According to Brundtland (1987) sustainable development entails meeting the needs and aspirations of the present generation without compromising the resources required by future generations to meet their requirements. It is an integration of three dimensions widely known as the Triple-Bottom-Line (TBL) which includes environmental, social, and economic aspects (Gillis *et al.,* 2016). The environmental dimension is the planet aspect of the TBL (Rajabi *et al.,* 2022). It deals with the protection and conservation of biodiversity and the environment by engaging in behavior that reduces ecological impact (Zavrl and Zeren, 2010). The economic dimension deals with the profit aspect, including financial affordability to beneficiaries and economic development which contributes to the National Gross Domestic Product (Pakzad *et al.,* 2017). Whereas the social dimension focuses on the 'people' component and measures how a project affects its stakeholders based on its community ties, employee development, and support for human rights (Rajabi *et al.*, 2022).

The idea of a bearable, equitable, and viable world is created by the intersection of the three dimensions, which together form sustainable development. Zavrl and Zeren (2010) state that different infrastructures may favor different aspects considering the purpose and priority of the projects. For instance, viability assumes a healthy economy and environment while ignoring its effects on society. The equitable domain exhibits strong results in both economic and social development but suggests that the environment is desecrated (Slocum, 2015). In the bearable aspect, the environment and society are both well-established, yet there is no distinct economic activity in the region (Liu *et al.,* 2019). According to Eugine *et al.* (2009), this is the most difficult domain to achieve. Nevertheless, Marsden *et al.* (2010) argues that all the dimensions should be incorporated to achieve sustainable development.

On the other hand, it is well known that infrastructure road projects are essential to economic development. However, they have negative repercussions on the environment. For instance, the traditional method of infrastructure project delivery is not sustainable due to its heavy reliance on natural resources, emissions, and waste generation (Simionescu and Silvius, 2016), despite the positive impacts on the economy and regional development (Zevallos *et al.*, 2017). According to the United Nations (2021), there hasn't been enough development in the area of sustainable transportation so far. The construction of road infrastructure consumes 60% of non-renewable materials (Alhjouj *et al.*, 2022). It has significant negative consequences on human social aspects, such as worker safety and relocation, as well as negative economic effects due to high production costs (Maelissa *et al.*, 2023). Yet, little attention has been paid to determining how sustainability can be assessed, hence difficult to judge whether infrastructure projects implemented are sustainable or not.

This indicates that to attain sustainability, assessment is required to establish its performance, which makes it necessary to apply sustainability assessment indicators on road infrastructure projects to ascertain their sustainability (Clevenger *et al.*, 2013). Consequently, to improve sustainability, Ugwu and Haupt (2007) asserted that it is essential to identify sustainability indicators. Many studies have been undertaken globally in response to this issue. For example, empirical studies by Shen *et al.* (2011), Krajangsri and Pongpeng (2019) and Okoro *et al.* (2020) have identified sustainability indicators for road infrastructure projects within a specific geographical context.

Accordingly, several review studies such as Gillis *et al.* (2016), Sdoukopoulos *et al.* (2019), Suprayoga *et al.* (2020) and Karjalainen and Juhola (2021) were carried out to identify sustainability indicators across various settings and provide an aggregate collection of these indicators. For instance, Gillis *et al.* (2016) focused on sustainability indicators for mobility consisting of different modes of transport (air, rail, and roads) at project, neighborhood, and city levels. Sdoukopoulos *et al.* (2019) looked at transport sustainability including walking, cycling, cars, and motorbikes. Karjalainen and Juhola (2021) focused on the methodological approaches for assessing the sustainability of urban transport (walking, cycling, and motorized vehicles). Whereas Suprayoga *et al.* (2020) studied the extent to which sustainability has been incorporated into assessments of road infrastructure projects.

Despite these studies, a gap remains in the literature. While Suprayoga *et al.* (2020) identified sustainability assessment indicators, they were based on existing sustainability criteria clusters. Furthermore, Suprayoga *et al.* (2020) highlighted that none of the previous studies considered all the criteria comprehensively. Therefore, they suggested that future studies should approach the identification of indicators holistically. Consequently, this study aims to critically review the indicators used to assess the sustainability of road infrastructure projects with the following identified objectives:

- Assess the annual publication trend on the sustainability indicators of road infrastructure projects from 2010 to 2022.
- Identify countries with the most publications on sustainability indicators of road infrastructure projects and assess the impact on the host country's sustainability development.
- Develop a list of sustainability indicators and further propose a conceptual framework to assess the sustainability of road infrastructure projects.

Therefore, the goal of this study is to analyze a range of sustainable road indicators from previous research to highlight commonalities and differences across contexts while providing an overview of the major indicators that have been identified.

The next section explains the methodology used to conduct the systematic literature review. In section 3, the findings of the study are presented and discussed. Finally, section 4 presents the major conclusions and recommendations for further investigation.

2. Methodology

According to Yi and Wang (2013), understanding and identifying a relevant topic matter for academics requires a rigorous review of previous studies. As such, the study used the systematic literature review approach, starting with a scoping evaluation of the literature on sustainability indicators of road infrastructure projects, to ascertain the subject matter. To evaluate and interpret the data, quantitative and qualitative analyses were applied. Because the method is suitable for presenting data with similarities or differences of certain topics from different contexts and relies on descriptive statistical presentation of data, the quantitative approach was suitable (Pickering *et al.*, 2014). On the other hand, the indicators needed to be categorized into themes, which demands the application of qualitative analysis. The thematic analysis approach was specifically employed since it helps locate patterns where multiple themes emerge (Castleberry and Nolen, 2018).

To begin with, the literature search started with the database search using the title/abstract/keyword search protocol. Based on an eligibility criterion, document retrieval followed, after which, the retrieved papers were screened for suitability and relevance to the content required, which were later analyzed to identify the road sustainability indicators for consideration in this study. The systematic literature search process is further explained below.

2.1 Database Search

The search began in early August 2022. As referred in Karjalainen and Juhola (2021), distinct search engines should be utilized to ensure a representative and adequate sample of the literature. For this reason, three distinct scientific search engines including Scopus, Research 4 Life, and Google Scholar were used to locate relevant articles for this study. These search engines were opted for because of their large collection of papers on multidisciplinary research fields (Durach *et al.*, 2015). Moreover using separate databases enables the elimination of biases in the search (Ali *et al.*, 2017). Scopus is one of the most comprehensive databases of scholarly articles in the fields of social sciences (Karjalainen and Juhola, 2021) and Google Scholar is acknowledged as a highly diverse database for scholarly literature and is easily accessible at academic institutions (Ali *et al.*, 2017). Moreover, similar studies such as Siew *et al.* (2016) and Karjalainen and Juhola (2021) used these search engines to retrieve papers for their studies. Web of Science was not used in the search because it was not accessible from the authors' research library, as it is a paid access database and was not subscribed to. Moreover, Meho and Rogers's (2008) highlighted that two-thirds of the documents indexed in either Scopus or Web of Science databases may be found in both databases while a third or less are only referenced in one or the other. Likewise, a recent study by Zhao *et al.* (2019) reported that Scopus has a wider coverage compared to other databases thus enhancing the retrieval of recent papers due to its high indexing nature. Therefore, the use of Scopus and the other databases was considered sufficient.

As referred in Wijewickeama *et al.* (2021) the search was restricted to peer-reviewed papers for quality control and scholarly journals' importance to the advancement of knowledge (Tsai and Wen, 2005). Consequently, book chapters and eBooks were excluded. The relevant sources are presented in Table 1. The largest source was The Sustainability Journal with 10 articles published. This was followed by the International Journal of Construction Management (IJCM) (3), Procedia Engineering (2), Smart and Sustainable Built Environment

(2), Environmental Impact Assessment Review (2) and International Journal of Sustainable Transportation (2).

Table I: Results of relevant journals

Source	No. of Articles	Percentage
Journal Articles	**51**	**94**
Sustainability	10	
Organization, Technology and Management in Construction	1	
Infrastructure Asset Management	1	
Land use Policy	1	
Journal of Environmental Planning and Management	1	
Advances in Transport Policy and Planning	1	
Procedia Engineering	2	
Journal of Infrastructure Development	1	
Ecological Indicators	1	
International Journal of Construction Management (IJCM)	3	
Transportation research part D	1	
journal of Construction Engineering and Management (JCEM)	1	
Cities	1	
Journal of Sustainable Development	1	
European Transport Research Review	1	
Smart Sustainable Built Environment	2	
Procedia – Social and Behavioral Sciences (Transport Research Arena)	1	
Transport Reviews	2	
Environmental Impact Assessment Review	2	
Journal of Cleaner Production	1	
Sustainable Cities and Society	1	
International Journal of Sustainable Transportation	2	
International Journal of Sustainable Engineering	1	
International Journal of Sustainable Development and World Energy	1	
Journal of Industrial Engineering and Management	1	
International Journal of Sustainable built Environment	1	
Journal of Civil Engineering	1	
HBRC Journal	1	
ICSDEC 2012	1	
Clean Technologies and Environmental Policy	1	
Environmental Science and Policy	1	
Transportation Research Procedia	1	
Transport Policy	1	
Advance Materials Research	1	
IFAC Papers Online	1	
Conference Papers	**3**	**6**
IOP Conference Series: Earth and Environmental Science	1	
IOP Conference Series: Materials Science and Engineering	1	
49th ASC Annual International Conference Proceedings	1	

Source: Authors' own work

Additionally, irrelevant subject disciplines were excluded, including Agriculture, Biology, Law, Economics, Medicine, Arts, Drama, and Chemistry. Moreover, according to Hiebl (2023), justification for time covered in a systematic review paper can be justified through research or practical developments in the field of study. The World Bank's World

Development Report 2010 and the Dunkerque 2010 local sustainability agenda advocated for the pursuit of sustainable cities and infrastructure to improve the environmental, social, and economic dynamics. Hence 2010 was opted for as a starting point for the data search. Therefore, only articles published between 2010 and 2022 were used in this study to determine the sustainability indicators. Comparable to Le *et al.* (2022), the title/abstract/keyword search protocol was used to conduct an extensive search. The key search terms utilized were “sustainability” AND “assessment indicators” OR “criteria” OR “framework” AND “road projects” OR “infrastructure projects” OR “transportation projects”. Overall, the preliminary search produced 329 articles, 152 from Scopus, 115 from Research for Life, and 62 from Google Scholar. Details regarding the article search and refinement are discussed below.

2.2 Documents retrieval

The selection of papers was done by considering an eligibility criterion regarding the study's relevance as well as the diversity and representativeness of the literature considered throughout the review. The selection criteria were as follows: (1) Infrastructure projects (2) Sustainability assessment, (3) Sustainability indicators or criteria, (4) Peer-reviewed articles from 2010 to 2022 to include recent data, and (5) Articles in English. Out of the 329 papers produced from the three databases, some identified indicators from different infrastructure projects including water, energy, tunnels, sewage, and railway. However, because the study was limited to road infrastructure projects, these other papers were excluded from the study. Furthermore, duplicate papers from the different databases were excluded, thus, 116 papers qualified for further screening.

2.3 Screening of Relevant Papers

The screening process was specifically utilized to filter the documents found through search engines by considering the eligible material that was appropriate for the study to obtain relevant information. Firstly, titles were screened, followed by abstracts. If either did not demonstrate relevance to the research topic, the paper was eliminated. In total 36 papers were excluded leaving 80 articles for further screening. Furthermore, to assess whether the papers were appropriate for the context of the research, all materials were read and reviewed in their entirety. Based on the articles' justification for the association of topic, findings, and significance, the papers' quality was critically evaluated. Following this quality check, 30 articles were eliminated, leaving 50 articles for the review. Four additional papers were obtained through cross-referencing, leaving 54 papers for the final review. As supported by Le *et al.* (2022) the criteria for including these articles in the final list was that at least one sustainability indicator of roads should be mentioned. Figure 1 illustrates a summary of the method used.

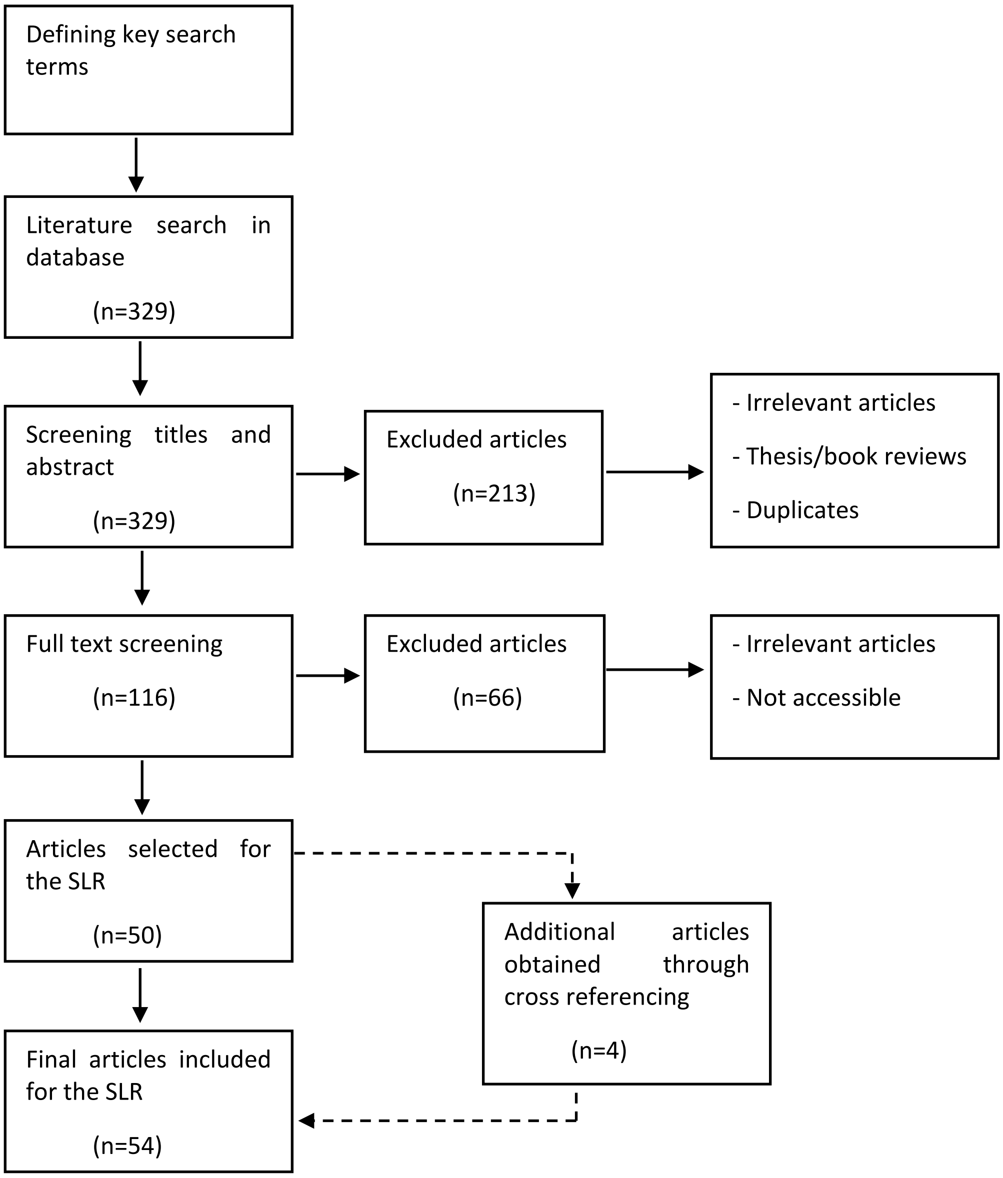

Figure 1: Systematic literature review search process

2.4 Analysis and Synthesis

A descriptive analysis of the papers was conducted at this stage to offer information on publications by year, and geographic focus. Moreover, descriptive analysis is crucial for a systematic review since it provides a solid framework for the subsequent content analysis

(Prajapati *et al.,* 2019). Furthermore, content analysis was adopted to synthesize results on the indicators extracted from the literature, which is appropriate for both qualitative and quantitative data (Elo and Kyngas, 2008). Moreover, similar studies, including Rostamnezhad and Thaheem (2022) and Akomea-frimpong and Osei-Kyei (2022) used the same approach. Comparable to Karjalainen and Juhola (2021) this synthesis was done using MS Excel to record the frequencies of the indicators from the papers, from which 22 indicators emerged. Synthesis was conducted to prevent redundancy. For example, the terms 'resilience to climate' by Gillis *et al.* (2016) and 'durability' as mentioned by Liu *et al.* (2019) have the same meaning and are used interchangeably. Additionally, certain indicators have been combined, for instance, energy conservation as mentioned by Pakzad *et al.* (2017), and energy efficiency by Patil *et al.* (2016) were merged to form a single indicator: energy efficiency.

3. Systematic Literature Review Results

3.1 Descriptive Analysis

3.1.1 Distribution of Publications by Year

Since the introduction of the sustainability concept, it has gained momentum over the years (Suprayoga *et al.,* 2020). In the past decade, the concept has been well known in the construction industry, as evidenced by the different publications illustrated in Figure 2. Over the previous 12 years, the average trend indicates a consistent rise in publications. The numbers reveal a dramatic increase starting from 2015, with an average increase of 3 articles before 2015 to an average of 5 articles from year 2015. The year 2017 and 2020 saw the most articles produced, with 7 each, making them the most prolific years. As supported by Karjalainen and Juhola (2021), the fact that 63% of all papers were published between 2016 and 2022 is remarkable. This increase is possibly attributed to the introduction of the sustainable development goals (SDGs) by the United Nations in the year 2015, which aims at achieving sustainability by the year 2030. The increase in articles shows a rise in scholars' awareness and interest in the field, which is expected to continue, to attain the SDGs.

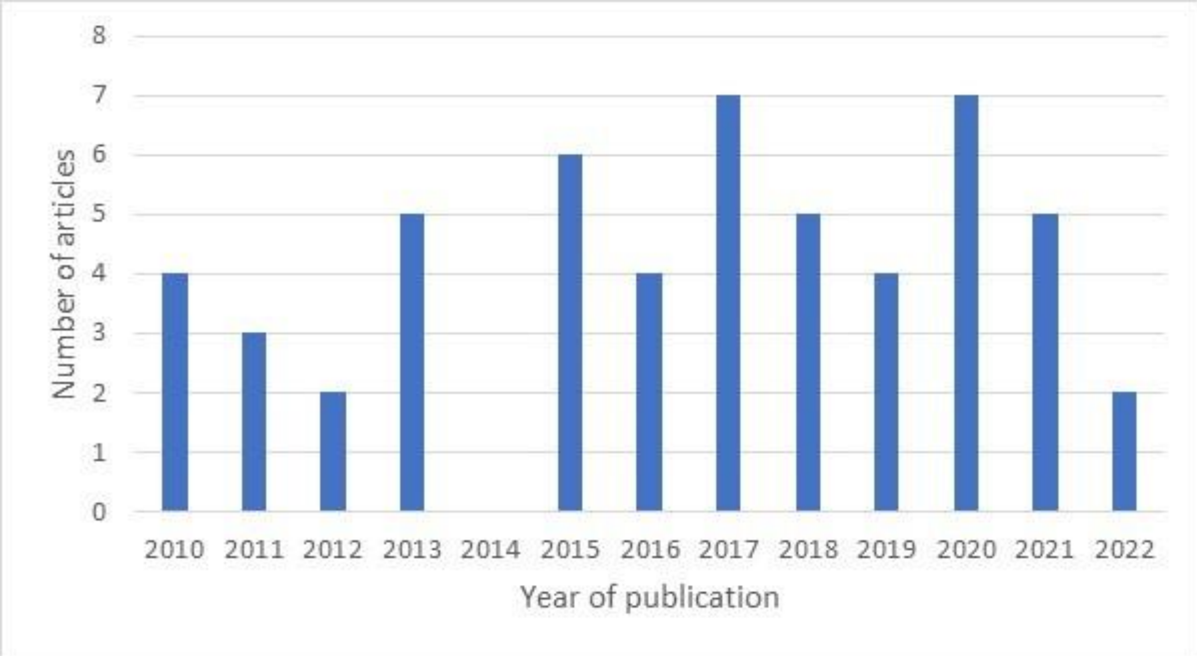

Figure 2: Publications by year

Source: Authors' own work

3.1.2 Distribution of Publications by Country

The demographic distribution of the articles was then the subject of bibliometric analysis, as depicted in Figure 3. The analysis revealed that the studies covered at least 28 countries, both developed and developing. This highlights the important contributions that various nations contributed to the identification and development of sustainability indicators for infrastructure projects. Australia had the most articles (n=8), followed by Spain (n=6) and China with (n=5), and then Taiwan with (n=4). Greece and Canada had 3 each, while Chile, USA, and Brazil had 2 papers each. Whereas the rest had 1 paper each. It is clear that most publications come from European nations and the least from African nations with only two publications, similar to Thounaojam and Laishram (2021), which calls for more research to be done in these nations. Furthermore, the results show that developed countries (n=15) and developing countries (n=13) contributed almost equally to the field of study and the identification of sustainability indicators is widespread worldwide. This is corroborated by UNESCO (2016), which asserts that both developed and developing nations are attempting to move toward sustainability due to the difficulties in the built environment, including scarcity of natural resources, unemployment, and pollution. Moreover, With the adoption of the SDGs by all 193 member states and the UN 2030 Agenda, governments, and researchers are attempting to track sustainability performance more (Li *et al.*, 2021).

The many publications from Australia are not surprising, considering it is ranked highly as one of the most sustainable countries in the world, which entails that it has several sustainability initiatives put in place, including the Sydney green grid (Siew *et al.*, 2016) and the 2018 Australian Sustainability Development Goals (SDGs) Summit which brought much-needed national attention to environmental goals and targets (Alam *et al.*, 2017). Therefore, the Australian dominance of sustainability assessment research is plausible.

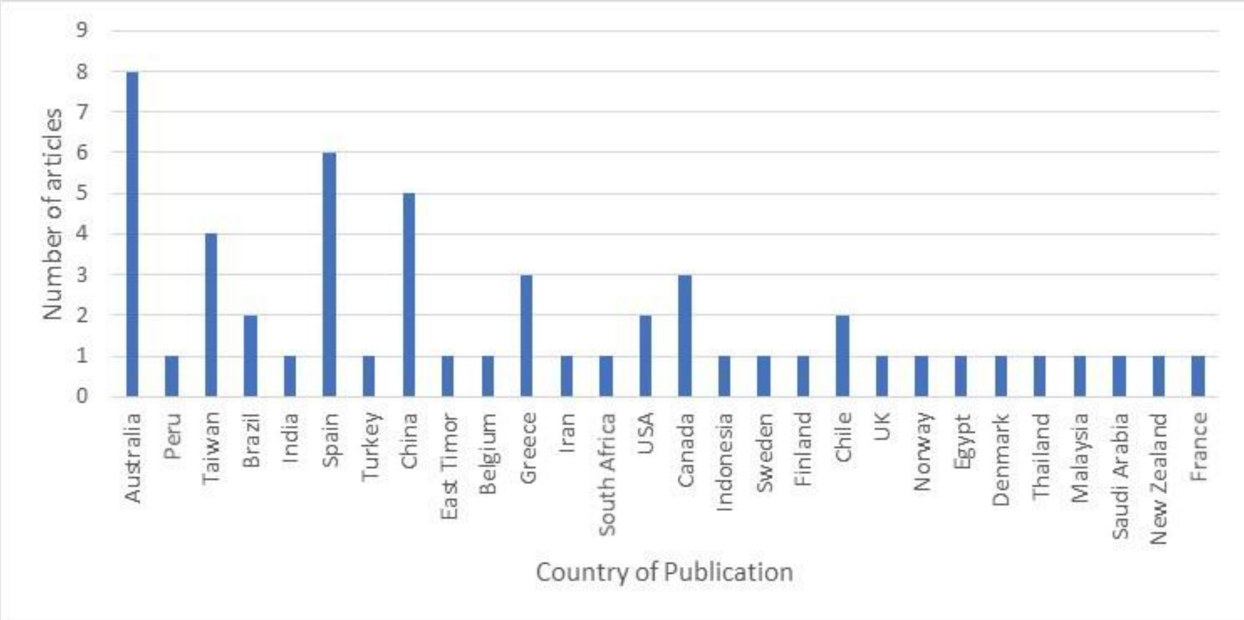

Figure 3: Publications by Country

Source: Authors' own work

3.1.3 Sustainability Indicators According to Project Lifecycle

From the reviewed papers, most authors did not group the indicators according to the project phases, instead, they were generally acknowledged. Studies like Huang and Hsu (2011) and Pakzad *et al.* (2017) contend that the indicators cut across all project phases, but should be considered from the design phase to other project phases. Nevertheless, other authors such as Umer *et al.* (2016), Sierra-Varela *et al.* (2018), and Arshad *et al.* (2021) have identified and categorized the indicators according to the project lifecycle, which includes design and planning, implementation, operational, and end of life. This approach is commendable because it serves as a guide throughout various project phases. For instance, indicators such as travel time savings, accessibility, community development, profits, and revenues as well as affordability of transport are mainly associated with the operational phase. In contrast, stakeholder participation, innovation and technologies, waste management, and materials and resources are mostly related to the implementation phase.

Nonetheless, these considerations should begin in the design and planning stages. On the other hand, other indicators like health, safety, and security appear to span all phases. However, the review reveals that indicators specific to the end-of-life phase are missing from the literature. This observation is supported by Rostamnezhad and Thaheem (2022) who assert that this gap is due to a lack of clarity regarding this phase. Therefore, more studies are needed to properly identify and define indicators relevant to the end-of-life phase.

3.1.4 Trend of Sustainability Indicators over the years

Figure 4 illustrates the historical trends of indicators over time. Overall, since 2010, the indicators have evolved and improved, albeit with an inconsistent pattern. There was a decline after 2010, followed by an increase in 2015, possibly influenced by the development of the SDGs. Surprisingly, there was another decline in 2018 followed by an increase from 2019 to 2020, and then a drop again in 2021. The study also noted that certain indicators, such as health, safety and security, energy efficiency, and ecological protection have remained consistent over time. This suggests that these indicators have been stable since 2010 and should be prioritized in projects. For example, public safety and well-being are most significant in road infrastructure projects (Sierra-Varela *et al.,* 2018). However, other indicators such as profits and revenues and affordability of transport have shown inconsistent over the years. On the other hand, indicators like durability, equity, and human rights as well as cultural heritage, have gained popularity recently, particularly since 2015. This trend indicates that these indicators are becoming more prominent because of recent sustainability developments. For instance, given the damage caused by extreme weather and climate change to infrastructure, durability is increasingly important (Gillis *et al.*, 2016). From this evolving pattern, similar to findings by Castanheira and Bragança (2014), it can be inferred that indicators will continue to evolve to reflect current events. Demands are constantly changing, and cities are continually adapting to achieve sustainability. This evolution has led to the development of new generations of sustainability evaluation tools and indicators that will guide and facilitate the implementation of more sustainable projects.

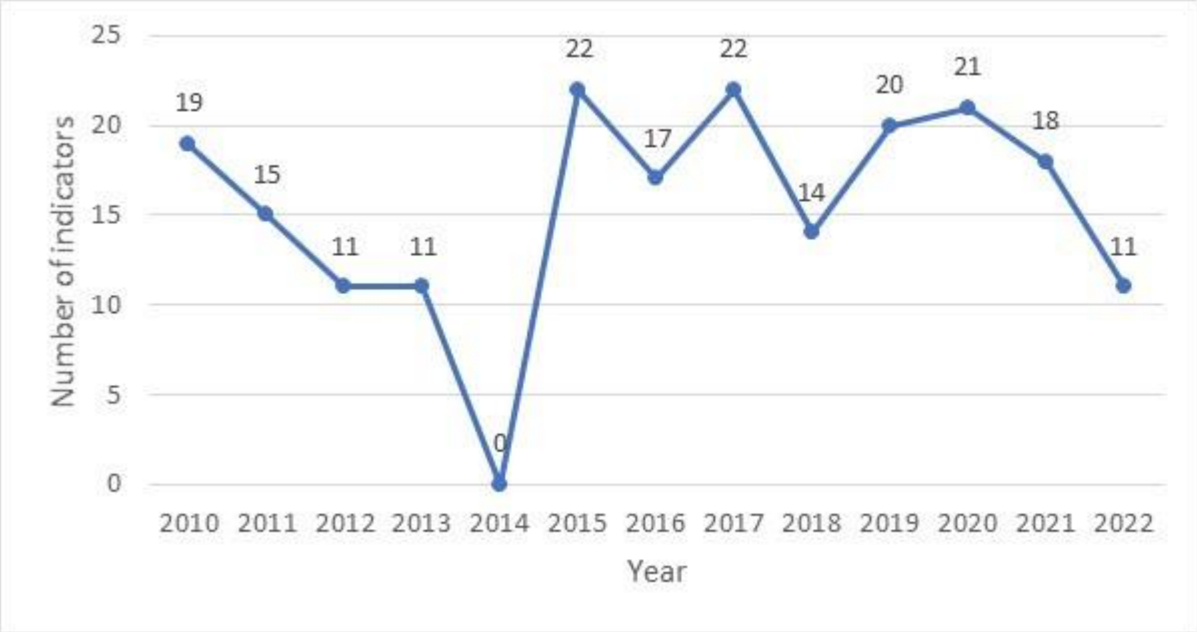

Figure 4: Indicators per year

Source: Authors' own work

3.1.5 Indicators in Various Countries

As shown in Table 2, there are disparities in the indicators identified across countries, consistent with Huang and Hsu's (2011) assertion that country-specific priorities, policies, and needs influence variations in indicators between countries. The reviewed articles reveal both similarities and differences among these indicators. Certain indicators, such as health, safety and security, energy efficiency, and pollution, are common across many countries, highlighting their global significance. For example, public safety is of the utmost concern universally, necessitating global attention to issues such as accidents, injuries, and fatalities as emphasized by Alsulami and Mohamed (2013), who stressed the importance of road infrastructure ensuring user safety. Conversely, some indicators appear to be prevalent only in selected nations, for instance, indicators such as travel time saving and profits and revenues, are more commonly addressed in developed countries. Travel time saving, in particular, is valued in developed countries where traffic congestion prolongs travel times, making speed and traffic flow crucial factors as noted by (Karjalainen and Juhola, 2021).

Furthermore, the cultural heritage indicator appears to be predominant in Asian nations such as China and Taiwan as well as Spain in Europe. This aligns with cultural preservation values in these regions, where reflecting the community's features in infrastructure is highly valued

(Suprayoga *et al.*, 2020). Unfortunately, similar to the findings of Karjalainen and Juhola (2021) there is limited number of publications from North American, South American, and African countries. This scarcity hinders the determination of prominent indicators in those regions, underscoring the need for further studies.

3.2 Content Analysis

3.2.1 Selection of Indicators

Indicators were primarily sourced from 54 peer-reviewed papers, as previously reported. Content analysis was conducted to evaluate these papers and identify and analyze road sustainability indicators. Some studies such as those by Sierra-varela *et al.* (2018), Tran *et al.* (2020) and Montalbán-Domingo *et al.* (2021) addressed one aspect of sustainability, while others including Salling and Pryn (2015) and Akomea-frimpong *et al.* (2022) addressed two, three, or more aspects. Consequently, as suggested by Bueno *et al.* (2015), the indicators identified in these publications were combined to create a comprehensive list that considers all three dimensions (environmental, social, and economic).

Regrouping and synthesis were required because the overall number of indicators was relatively high (79), and indicators frequently overlapped. Therefore, a reduction process was necessary. A similar methodology to that employed by Karjalainen and Juhola (2021) was applied, and the most popular indicators, like those cited in more than 10 publications were considered in this study. This reduction process led to 22 final indicators as illustrated in Figure 5, from which a framework was developed as depicted in Figure 6. The 22 indicators were categorized according to the three sustainability dimensions. The findings illustrate that the environmental dimension dominates with ten indicators including energy efficiency, reduction of emissions, noise pollution, innovations and new technologies, water efficiency, efficient land use, sustainable materials and sources, waste management, air pollution, and ecosystem protection. The social dimension has eight indicators, including travel time reduction, accessibility, health, safety and security, culture and heritage preservation, durability, employment, stakeholder participation, and equity. With four indicators, the economic dimension contains the least indicators, comprising infrastructure project cost, profits and revenues, affordability, and community development. The following section discusses these indicators.

Table II: Summary of indicators per country

No	Indicator	Australia	Taiwan	Brazil	India	Spain	Turkey	China	East Timor	Belgium	Greece	Iran	South Africa	USA	Canada	Indonesia	Sweden	Finland	Chile	UK	Norway	Egypt	Denmark	Thailand	Malaysia	Saudi Arabia	New Zealand	Peru	France	Countries
1	Travel time saving	√		√		√				√		√			√	√	√					√								**9**
2	Accessibility	√	√	√	√	√		√		√	√		√		√	√	√			√		√	√	√					√	**17**
3	Health, safety and security	√	√	√	√	√	√	√		√	√	√	√	√	√	√	√	√		√	√		√	√		√	√			**22**
4	Durability	√	√	√		√		√		√			√		√		√				√	√				√				**12**
5	Employment	√	√	√		√		√		√	√		√		√		√		√	√		√		√				√	√	**16**
6	Stakeholder participation	√	√	√	√	√	√		√				√	√				√		√						√	√			**13**
7	Equity and human rights	√	√	√	√	√	√	√			√							√			√									**10**
8	Cultural heritage	√	√	√	√	√		√			√			√						√			√		√					**11**
9	Energy efficiency	√	√		√	√		√	√	√	√	√	√	√	√	√		√		√	√		√	√					√	**19**
10	Reduction of emissions	√	√		√	√	√			√	√		√		√			√		√	√	√			√	√	√			**16**
11	Noise reduction	√	√		√	√		√			√	√						√		√		√	√	√						**12**
12	Innovation and new technologies	√	√	√	√	√		√	√		√			√		√						√							√	**12**
13	Water efficiency	√	√		√	√	√	√			√	√		√	√						√			√						**12**
14	Materials and sources	√	√	√		√	√	√	√		√	√		√	√		√			√	√		√	√						**16**
15	Waste	√	√		√	√		√			√	√			√								√	√					√	**11**
16	Pollution	√	√	√	√	√		√	√		√	√	√		√	√		√	√	√				√		√			√	**18**
17	Ecology	√	√	√		√		√			√		√	√	√			√		√			√	√	√	√			√	**16**
18	Efficient land use		√			√		√			√	√			√	√		√		√			√							**10**
19	Community development	√	√	√	√	√		√			√		√		√	√				√			√	√				√		**14**
20	Infrastructure project cost	√			√	√	√	√			√	√	√	√						√	√									**11**
21	Profits and revenues	√		√	√		√	√			√		√					√			√									**9**
22	Affordability	√			√		√			√	√		√					√		√			√			√				**10**
	Total indicators	**21**	**18**	**14**	**16**	**20**	**9**	**18**	**5**	**8**	**19**	**10**	**13**	**9**	**14**	**8**	**6**	**11**	**2**	**15**	**9**	**7**	**11**	**11**	**3**	**7**	**3**	**2**	**7**	

Source: Authors own work

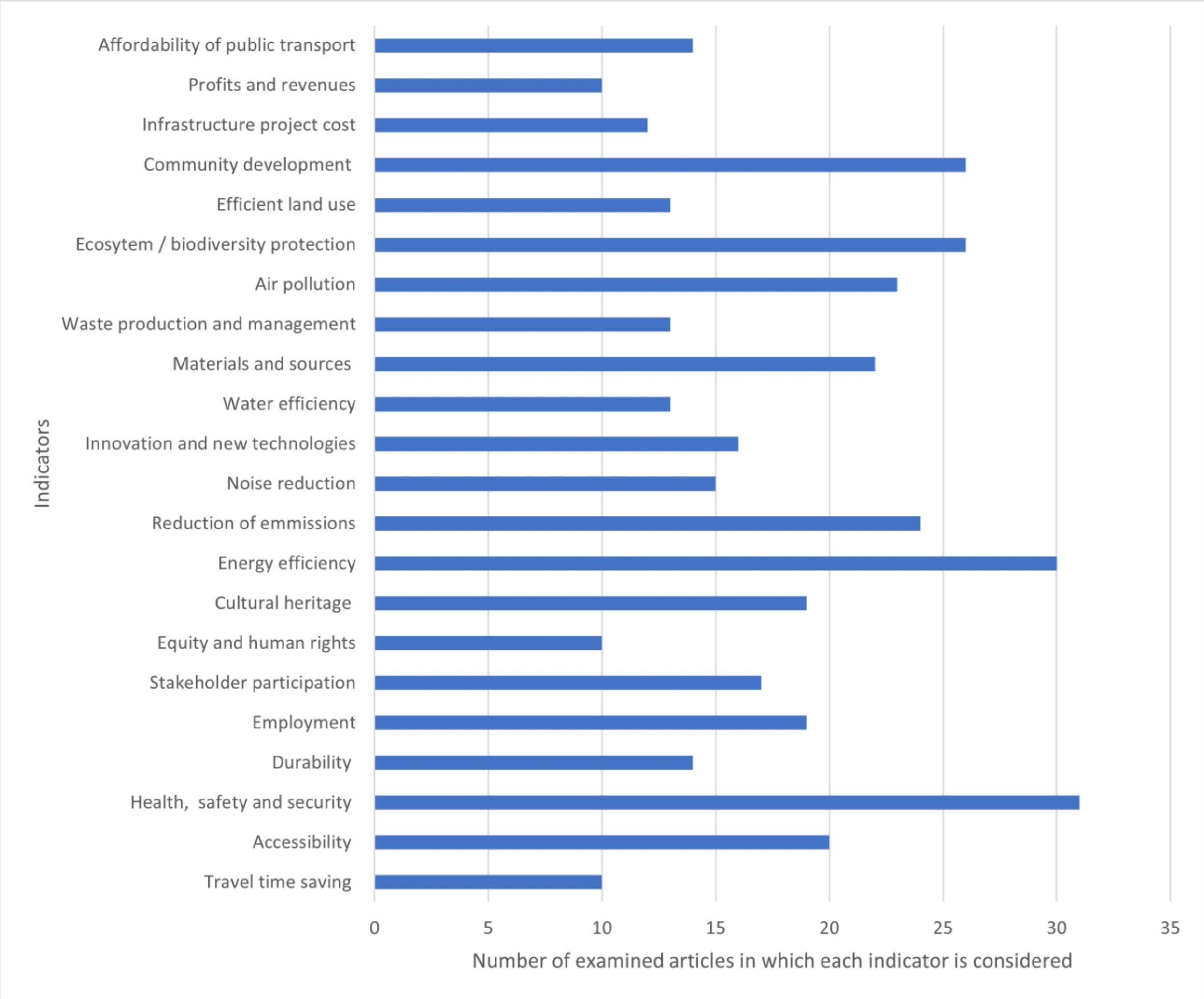

Figure 5: Frequency of Indicators in Publications

Source: Authors own work

Source: Authors' own work

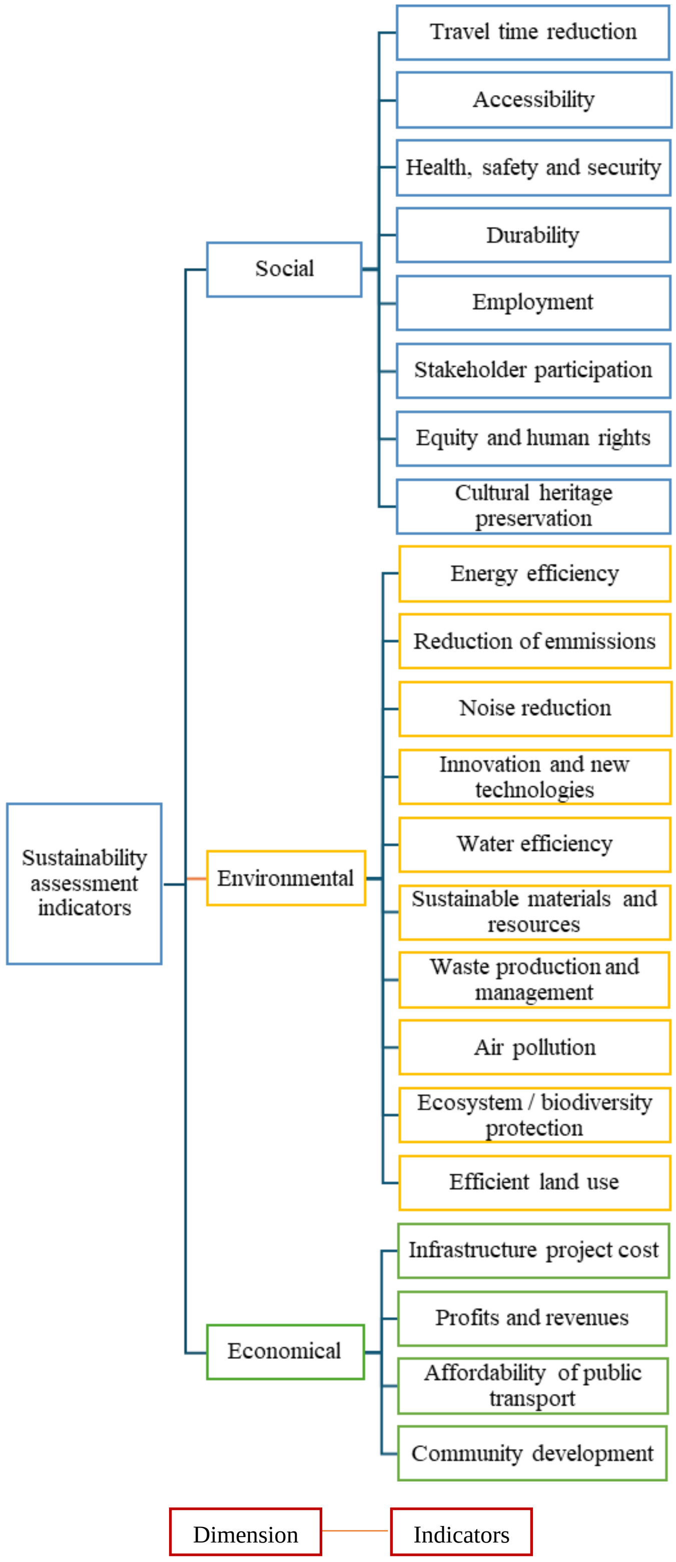

Figure 6: Sustainability assessment indicator framework

Source: Authors' own work

4. Discussion

As depicted in Figure 6, the findings illustrate that all 3 dimensions are used to assess the sustainability of roads, which demonstrates the importance of the integration of all 3 aspects to achieve sustainable goals (Suprayoga, *et al.,* 2020). However, the environmental dimension dominates with 10 indicators, followed by social with 8, then economic with 4. According to Reza *et al.* (2013) and Adzar *et al.* (2019), this confirms that environmental aspects are given more priority, moreover, in conjunction with Alam *et al.* (2017), the economic dimension is the least considered.

Likewise, Figure 5 depicts the frequency of the various indicators in the publications, indicating those that are utilized more frequently and those that receive less consideration. Health, safety, and security was the most cited indicator with 31 citations, indicating that the well-being of the community, users, and workers on site has the highest priority in the sustainability of roads, according to the literature. This is followed by energy efficiency (30), community development (26), and ecological protection (26). Conversely, indicators such as profits and revenues, equity and human rights, travel time reduction, and infrastructure project cost, are the least frequently used, covered in fewer than 12 publications. This suggests that the initial and operation costs of the project and the revenues generated are not highly regarded. Moreover, equity which addresses minority concerns such as accessibility for the disabled, is not well-regarded. This is unfortunate as Karhalainen and Juhola (2021) state that disadvantaged groups should have access to infrastructure facilities. The following paragraphs elaborate on these indicators in more detail.

4.1 Environmental Sustainability Indicators

This group of indicators addresses the extent to which the project impacts the planet and its surroundings (Paredes and Herrera, 2020). The following are the parameters used to evaluate a project's environmental impact.

4.1.1 Energy Efficiency

The findings of this study reveal that high energy consumption is a core sustainability issue that affects both developed and developing countries. It is imperative to control and reduce energy consumption, using renewable energy sources such as solar, biogas, and wind. Additionally, employing energy-efficient plants and machinery in construction activities

(Umer *et al.*, 2016), recycling and reuse of energy, and selecting sustainable materials and techniques during construction (Bueno *et al.,* 2015) are crucial steps.

4.1.2 Water Efficiency

According to literature, inefficient water usage and water scarcity are becoming significant issues. The construction industry consumes substantial amounts of water in its operations, making water efficiency paramount (Krajangsri and Pongpeng, 2019). However, water conservation is often overlooked (Zavrl and Zeren, 2010). This indicator is primarily associated with the implementation phase, with strategies such as greywater reuse, rainwater harvesting (Fernández-sánchez and Rodríguez-lópez, 2010) and the development of water reduction and monitoring plans (Krajangsri and Pongpeng, 2019) emerging as crucial measures.

4.1.3 Sustainable Materials and Resources

The construction industry heavily relies on natural resources, leading to a significant risk of resource depletion. Siew *et al.* (2013) assert that smart and sustainable building practices should include the use of sustainable materials and the efficient use of resources. Therefore, the emphasis should be on using sustainable materials. Additionally, strategies such as the reuse and recycling of materials, effective resource management techniques, as well as sustainable material selection, should be prioritized in road infrastructure project delivery (Suprayoga *et al.,* 2020). Although the design and implementation phases are highlighted in this context, the operation phase should also be considered.

4.1.4 Waste Production and Management

The study findings demonstrate that construction operations produce in large quantities waste from demolition, broken materials, and other sources, significantly contributing to environmental pollution. Therefore, it is crucial to reduce or eliminate waste from construction activities wherever feasible (Patil *et al.,* 2016). From the literature, associate this indicator primarily with the implementation phase. Consequently, waste management practices including on-site recycling, waste collection, efficient waste disposal, and use of waste reduction techniques have emerged as essential strategies (Liu *et al.,* 2021).

4.1.5 Greenhouse Gas Emissions

About 10% of all emissions globally come from the construction industry's operations, primarily due to the use of heavy machinery, the manufacture and supply of building materials, and the disposal of construction waste (Arioglu *et al.*, 2017). Henning *et al.* (2011) state that reducing energy demand, ensuring the efficient use of energy, and employing renewable energy sources are critical aspects of reducing emissions. Mansourianfar and Haghshenas (2018) contend that understanding the construction sector's actions that contribute to emissions is essential for establishing mitigation strategies and advancing sustainable development.

4.1.6 Air Pollution

The pattern indicates that environmental issues related to pollution have existed for a long period, and construction activities exacerbate the decline in air quality. According to Umer *et al.* (2016), to reduce pollution, it is essential to take the necessary precautions during construction and use appropriate materials. Studies such as Zhou and Liu (2015) and Balaras *et al.* (2020) have argued for increased focus on this aspect and emphasized implementing strategies such as vegetation planting, air dust reduction measures, and the use of energy-efficient plants and equipment during construction operations.

4.1.7 Ecosystem/Biodiversity Protection

Ecosystem protection is a global concern, and the building sector has a significant influence on the environment in this regard. Simionescu and Silvius (2016) and Ngossaha *et al.* (2017) highlight the significance of biodiversity protection through a harmonious interaction system between the construction sector and its surroundings, including living and non-living surroundings. Correspondingly, features such as species reallocation, compensation, and substitution of flora and wildlife are essential to biodiversity protection (Vassallo and Bueno, 2020).

4.1.8 Noise Reduction

Noise from construction activities and traffic affects people's health and the community (Gillis *et al.*, 2016). According to Alam *et al.* (2017), strategies for noise abatement should be implemented to mitigate its effects and improve the acoustic quality of the environment. Mansourianfar and Haghshenas (2018) suggested that strategies should be put in place to minimize noise complaints. However, Gillis *et al.* (2016) highlighted that noise pollution remains prevalent in residential areas, with some projects failing to adequately consider this factor.

4.1.9 Innovation

This indicator is particularly prevalent in developed countries, where efforts are focused on enhancing the delivery of road infrastructure projects through advanced and innovative technologies to foster sustainable growth. Moreover, this indicator is also gaining momentum in developing countries where new methods and technologies are being adopted such as intelligent transportation systems on the highways for lane control, dynamic message signs, traveler information, and revenue management systems (Cavalcanti *et al.*, 2017; Tran *et al.*, 2020).

4.1.10 Efficient Land Use

This indicator is important because road infrastructure occupies land space (Mansourianfar and Haghshenas, 2018). Hence Sdoukopoulos *et al.* (2019) emphasize efficient land use. Sierra-Varela *et al.* (2018) further argue that effective land design can facilitate the efficient use of available land by integrating all infrastructural elements, such as walkways, parking areas, and road furniture.

4.2 Social Sustainability Indicators

This dimension seeks to meet people's requirements throughout the project life cycle (Hussin *et al.* 2013). Factors considered in this category include health, safety, and security; employment; stakeholder involvement; culture and heritage preservation; accessibility; equity; travel time reduction; and durability.

4.2.1 Health, Safety and Security

Findings confirmed that this indicator is given the most attention and is considered with high regard because the safety of workers on site is significant (Rostamnezhad and Thaheem, 2022). Several authors, including Yu *et al.* (2018), Okoro *et al.* (2020) and Karjalainen and Juhola (2021), supported the idea that it is important to consider the safety of site workers and third parties (communities and users) during construction activities. Umer *et al.* (2016) emphasize that the road user’s safety should be guaranteed through road safety signs, markings, and signaling as well as safety audits to verify continuity and determine whether the set safety precautions are effective. Therefore, this indicator remains relevant throughout the project lifecycle.

4.2.2 Employment

This indicator plays a crucial role in enhancing both the economy and the well-being of people. According to Sierra-Varela *et al.* (2018), infrastructure projects should aim to create employment opportunities for local inhabitants thereby improving their livelihoods and fostering internal economic circulation within the region. Additionally, Rostamnezhad and Thaheem (2022) argue that considerations should include employee working conditions, well-being, job security, and equality, with attention to minority group concerns (Haavaldsen *et al.*, 2014). Despite the construction industry being male dominated, gender equality is increasingly gaining prominence. Therefore, incorporating local employment opportunities in the delivery of road infrastructure projects is crucial (Toth-Szabo and Varhelyi, 2012). This indicator is predominant in the implementation phase; however, it should also be considered in the operation phase.

4.2.3 Stakeholder Involvement

Studies from both developed and developing countries identified this indicator (see Table 2). According to Poveda and Lipsett (2011), involving stakeholders in road projects by bringing their opinions into the decision-making process improves project success. Besides, Rostamnezhad and Thaheem (2022) assert that it enhances transparency and ensures all stakeholders are informed on project issues. Therefore, the right stakeholder management methods should be incorporated into a project (Patil *et al.* 2016). It is evident that this aspect is crucial to project success and its inclusion throughout the project cycle is valuable for the successful delivery of road infrastructure projects.

4.2.4 Culture and Heritage Preservation

Various countries have different cultures that are reflected in the architecture of the cities (Cavalcanti *et al.* 2017). According to the findings, in Asian and European countries this indicator seems to be prevalent. Accordingly, Yu *et al.* (2018) contend that projects should be designed and carried out in harmony with the community culture, and the projects should reflect the community's particular characteristics and personality to maintain the ethnic identity of the community and increase the value of neighborhoods (Suprayoga *et al.*, 2020). Moreover, findings revealed that the project's activities should not cause harm to the cultural traditions and artifacts in the area and should be protected (Shen *et al.*, 2011). However, in African regions this indicator seems dormant, which calls for further investigation.

4.2.5 Accessibility

One of the objectives for the provision of road infrastructure is to enhance mobility and accessibility to amenities and cuts across various regions. According to Okba *et al.* (2021), the roadway infrastructure should provide users adequate access to other transportation networks and important services like hospitals, schools, and workplaces. Sierra-Varela *et al.* (2018) argued for the availability of public transportation as a way of enhancing accessibility. On the other hand, studies such as Salling and Pryn (2015) and Umer *et al.* (2016) argued for more private motorized and non-motorized transportation such as cycling and walking in order to provide access to services in the absence of public transportation.

4.2.6 Equity

Issues of equality such as equal rights of access to several services and other important aspects of human life have been of particular concern, especially in recent times (Karjalainen and Juhola, 2021). In this regard, Haavaldsen *et al.* (2014) observed that income, health, working conditions, geographical distribution, generational issues, and gender concerns are typical aspects of equality and should be incorporated into road infrastructure projects. Although this indicator is not given much attention in the literature, Yu *et al.* (2018) highlights its significance, and emphasize the inclusive designing and building of transportation facilities to cater to everyone including the disabled and the elderly.

4.2.7 Travel Time Reduction

The findings demonstrate how pertinent this indicator is, considering that traffic flow and congestion are global issues. Toth-Szabo and Varhelyi (2012) contend that the constructed road infrastructure projects should be able to reduce travel time not just for motors but non-motorized modes as well, including pedestrians and cyclists (Bueno *et al.*, 2015). The literature makes it clear that this indicator mainly comes into play in the operational phase and both motorized and non-motorized forms of transportation should be considered.

4.2.8 Durability

This indicator has become popular in recent times, especially from 2015, and cuts across different areas. According to Newman (2015), current events, particularly climate change and severe weather, have made this indicator crucial in recent years, considering the detrimental effects of severe weather on road infrastructure. In this regard, the strength and resilience of the roads is vital. Yang *et al.* (2018) emphasizes that strategies such as use of robust building techniques, long-lasting materials, and top-notch operating and maintenance systems are crucial and it ought to be included throughout the whole project lifecycle, starting from the design phase.

4.3 Economic Sustainability Indicators

The economic indicators deal with the profit generation aspect of a project (Pakzad *et al.,* 2017). Indicators considered in this dimension include community development; affordability; profits and revenues; and infrastructure project cost.

4.3.1 Community Development

This indicator encompasses the impact of roadway projects on the community, including enhancing the local economy by increasing property values and fostering residential growth (Patil *et al.,* 2016). According to the literature, community development is prioritized in various locations globally. Zhou and Liu (2015) and Rao *et al.* (2018), emphasized the importance of utilizing local labor, resources, and suppliers to ensure money circulates within the community, thereby stimulating economic activity. Similarly, Liu *et al.* (2019), highlight benefits such as property value appreciation resulting from road infrastructure projects in this context.

4.3.2 Affordability

This indicator evaluates the users' ability to afford transportation facilities (Akomea-frimpong *et al.* 2022). Despite its importance, it receives less attention in literature. Gillis *et al.* (2016) argued that the costs associated with private and public transportation on roadway infrastructure should be reasonable. Likewise, Sdoukopoulos *et al.* (2019) assert that the percentage of household income spent on transportation should be a critical evaluation factor. Surprisingly, based on literature from 10 countries examining this indicator, 7 developed countries prioritized it more compared to only 3 developing countries. Therefore, there is a clear need for further investigation and increased consideration of this indicator in developing nations.

4.3.3 Profits and Revenues

Profitability is an essential criterion for sustainability assessment, to ensure that investment capital is recovered. Literature suggests that this indicator is often not given significant emphasis. Nonetheless, studies by Haavaldsen *et al.* (2014), Okoro *et al.* (2020), and Akomea-Frimpong *et al.* (2022) argue that investors should be satisfied with revenue generation, aiming to optimize profits. Based on the review, this indicator is primarily considered during the operational stage of the project lifecycle.

4.3.4 Infrastructure Project Cost

The findings indicate that this indicator receives the least attention despite its significance. According to Vassallo and Bueno (2020), factors including project investment expenses, which often include land acquisition, design, legal, administrative, and construction expenditures, are considered in this context. Additionally, Flores *et al.* (2016) and Umer *et al.* (2016) reported that whole life cycle costing is an important aspect as such maintenance and operation costs should be accounted for. It is evident that this indicator typically spans throughout the project lifecycle.

In summary, the findings of this study reveal that the environmental dimension remains dominant, consistent with trends observed in earlier research such as Poveda and Lipsett (2011) and Opoku *et al.* (2019), where the environmental dimension was prioritized. However, social issues and economic aspects are equally crucial and require attention. Moreover, the economic dimension deserves greater focus, highlighting the necessity for additional research to identify indicators within this dimension.

5. Conclusion

A specific set of indicators that highlight road infrastructure sustainability was lacking. To bridge the literature gap, a systematic literature review was carried out to establish sustainability indicators for road infrastructure projects, based on 54 peer-reviewed articles published between 2010 and 2022. This review aimed to establish sustainability indicators tailored to road infrastructure projects. The findings highlight 22 key indicators used for sustainability assessment of road infrastructure projects. Notably, indicators such as ‘health, safety and security’, ‘energy efficiency’, ‘community development’, ‘ecosystem protection’, and ‘reduction of emissions’ emerged most frequently in the literature. Hence, it can be concluded that these are the most widely used indicators for assessing the sustainability of road infrastructure projects.

The findings also suggest that achieving sustainability in road infrastructure projects necessitates consideration of all three dimensions: environmental, social, and economic. While the economic dimension is underscored with fewer indicators compared to the others, it remains pivotal for ensuring project sustainability. Additionally, integrating indicators across the project lifecycle, from the design through implementation is crucial for achieving sustainable outcomes. However, the absence of indicators specifically tailored for the end-of-life underscores the need for further research in this area. Thus, addressing end-of-life activities such as waste management, demolition, and sustainable material disposal, is essential to mitigate environmental and public health risks. Furthermore, the study highlights that indicators are context-driven, varying across regions to accommodate different needs and priorities. This context-driven variability emphasizes the importance of adapting sustainability strategies to local conditions to effectively support development while preserving environmental integrity and fostering economic growth.

It was also noted that there is a scarcity of literature from African countries, which poses challenges in identifying prominent sustainability indicators specific to the African context. Consequently, this study emphasizes the need for further research in Africa to bridge the knowledge gap and facilitate the development of tailored sustainability assessment tools for road infrastructure projects in the region. Comparative studies across continents or countries would also be valuable to discern each region's sustainability priorities. Furthermore, the study highlights that sustainability indicators are dynamic and continue to evolve to accommodate recent developments and emerging challenges. The findings affirm that a comprehensive, context-specific, and lifecycle-based assessment is essential for assessing the sustainability of road infrastructure effectively. This study addresses the central question of how road infrastructure projects are assessed for sustainability.

Finally, the study findings hold significant implications. Firstly, it consolidates a comprehensive set of indicators for sustainable road infrastructure in a single publication, providing stakeholders with a unified set of indicators for assessing road project sustainability. This set of indicators informs relevant stakeholders about key indicators crucial for evidence-based decision-making and policy formulation, essential for achieving the sustainability development goals in road infrastructure projects and contributing to the SDGs by 2030.

Furthermore, the study's insights will guide future researchers in exploring underexplored areas within the field. Additionally, the identified indicators can serve as foundational elements for developing sustainability assessment frameworks or models specific to road infrastructure projects.

Despite the study's contribution, it has limitations. Primarily, its focus on peer-reviewed papers restricts its breadth of publications reviewed. Future research could broaden this scope to include books, conference proceedings, and grey literature potentially offering deeper insight into sustainability assessment indicators for road infrastructure projects.

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