sustainability

Review

Assessing the Sustainability of Transport Systems through Indexes: A State-of-the-Art Review

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Abstract: The transportation sector significantly impacts economic development; however, its sustainability is challenged, particularly due to the increase in urban vehicle numbers and the associated negative consequences. In response, diverse evaluation methods have been introduced to assist decision-makers in assessing sustainability, accompanied by the development of numerous indicators to monitor the progress of sustainable transport systems. Consequently, the evaluation of the transport system has become crucial. This study conducts a comprehensive literature review on existing approaches used to assess transport sustainability through composite indicators. The analysis began by selecting articles using keywords like "sustainable transport", "sustainability indicators", "composite index", and "assessment". Subsequently, 61 relevant articles were identified, and only 47 studies from the period 2002–2022 were selected. The analysis was completed by synthesizing the literature and presenting the findings. The examination of literature trends revealed a limited focus on freight transport, with most studies concentrating solely on traditional sustainability dimensions. Additionally, the analysis highlighted the significant impact of various normalization, weighting, and aggregation methods on composite indicator results. Finally, recommendations for precise sustainability assessments are provided to guide future research endeavors.

Keywords: composite indicator; sustainability; assessment; freight transport; public transport; sustainability dimensions; literature review; index

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1. Introduction

An effectively managed transport system is vital for the seamless operation of diverse sectors, thus playing a pivotal role in fostering the economic development of the country. However, with the remarkable increase in the number of trips and heavy goods vehicles, the current transport system generates problems such as congestion, insecurity, pollution, etc. Indeed, it causes more greenhouse gas emissions and consumes great amounts of energy. In the last decade, local authorities and transport stakeholders have become aware of the importance of solving these issues [1,2]. Therefore, special attention has been paid to sustainable transport [3]. However, to attain this objective, the current transport system should be reconstructed by evaluating its present status using adequate tools to assess transport sustainability. Assessing sustainability across diverse domains is challenging and requires the formulation of specific indicators. Therefore, employing methods centered on composite indicators not only facilitates the assessment and monitoring of the transport system but also promotes the development of best practices. In recent years, a multitude of articles have introduced composite indicators to assess the sustainability of transportation systems. In this context, our goal is to examine the literature, clarify the methodologies involved, and help decision-makers in formulating an appropriate composite indicator. Specifically, this paper aims to achieve two objectives: (i) to identify trends and gaps in existing approaches for assessing sustainability in the transportation sector, and (ii) to propose future research directions. The following questions are answered in the present manuscript.

- What are the current research trends in assessing transport sustainability through composite indicators?
- What are the existing research gaps and what are the possible research works in this domain?

This review paper is organized as follows: Section 2 defines composite indicators. Section 3 provides an overview about the existing approaches using the composite indicators to evaluate transport sustainability. Section 4 analyzes the obtained results. Section 5 discusses research trends and gaps in the research on the sustainability of the transport system and identifies some directions for future research. Finally, Section 6 provides a brief conclusion.

2. Definition of Composite Indicators

Assessing sustainability exclusively through elementary indicators presents a significant challenge [4,5]. Therefore, the best alternative involves aggregating these indicators into a composite indicator (Figure 1). As defined by [6], a composite indicator is "the mathematical combination of single indicators that represent different dimensions of a concept whose description is the objective of the analysis". While it offers several advantages, such as providing a simplified, coherent, and multidimensional perspective of a system, allowing for the prioritization and analysis of the current situation, and facilitating communication among stakeholders, it also comes with limitations. The primary drawback is its potential to convey misleading messages, leading to incorrect decisions. To mitigate this risk, the steps of its construction must be clearly and adequately defined.

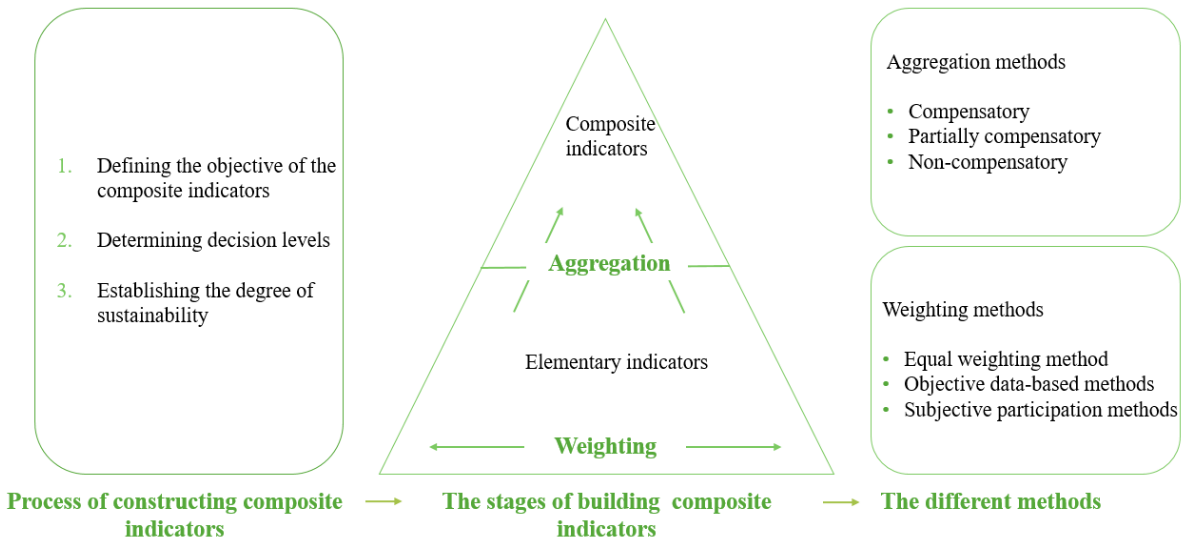

Figure 1. A visual representation depicting the relationships among the key steps in constructing sustainability indices and selecting methods.

A graphical depiction showcasing the interconnections between crucial stages in forming sustainability indices and the selection of weighting and aggregation methods is illustrated in Figure 1.

The process of constructing composite indicators can be completed by following three main steps: (1) defining the objective of the composite indicators; (2) determining decision levels; and (3) establishing the degree of sustainability (weak; limited or strong sustainability) (Figure 1).

The initial step of defining objectives for composite indicators involves a thorough exploration of both exogenous and endogenous factors. Key considerations in this context include geographical location, natural resource abundance, levels of economic development, the strategic positioning of key stakeholders within the transport system, production and distribution potential, stakeholder demand, transport distances, and the capacity of the transport network in terms of routes and nodes. These factors collectively play a pivotal role in enhancing our comprehensive understanding of sustainable transport development.

The weighting and aggregation steps play a crucial role in the construction of a composite indicator (Figure 1). Below, we outline the stages involved in building composite indicators and the associated methods.

- Normalization becomes necessary only when indicators are incomparable, i.e., when they possess different measurement units. If all elementary indicators are expressed in the same units (or dimensionless), normalization is not required. In the application of multiple-criteria decision-making (MCDM) methods, "benefit"-type elementary indicators and "cost"-type elementary indicators undergo distinct normalization processes.
- The weighting step significantly influences the composite indicator and the obtained results. It involves assigning varying levels of importance to each indicator. The most commonly utilized weighting methods fall into three categories:
  - i. The equal weighting method is an objective technique that assigns the same weight to all variables.
  - ii. Objective data-based methods determine weights using statistical-based techniques.
  - iii. Subjective participation methods consider the subjective opinions of experts and/or stakeholders.
- Aggregation involves the mathematical combination of elementary indicators. The choice of an appropriate aggregation technique is crucial in constructing a composite indicator. Aggregation can be classified into three categories, each with distinct characteristics as outlined in Table 1 [7–9].

Table 1. Characteristics of the different aggregation techniques.

Aggregation Technique	Compensatory	Partially Compensatory	Non-Compensatory
Sustainability perspective	Weak sustainability	Limited sustainability	Strong sustainability
Priority	Economic	Balance between dimensions	Environmental
Target	Short term	Medium term	Long term
Principle	No environmental protection without a strong economic base	Reconcile environmental protection, social equity and economic growth	Sustainability of the human capital cannot be ensured without taking into account the capacities of the ecological support

  - i. The compensatory technique operationalizes weak sustainability, employing additive aggregation methods (e.g., arithmetic mean). This implies full compensation between elementary indicators, meaning an unfavorable result of one indicator can be compensated by a favorable result of another.
  - ii. The partially compensatory technique operationalizes the limited sustainability through techniques based on the geometric mean. In this case, elementary indicators are mutually and preferentially independent, but they have certain limitations related to the compensations of indicators.
  - iii. The non-compensatory technique operationalizes strong sustainability. This aggregation method is used when full compensation between elementary indicators is deemed unacceptable. Therefore, an unfavorable result of one indicator cannot be compensated by a favorable result from another indicator.

3. Literature Review

Given the interdependency of freight transport and public transport, both systems are addressed in this section. Through these research works, we extract the existing approaches to assess transport sustainability using indicators and composite indicators and we identify the research gaps in this field. The methodology employed in this study comprises four distinct steps:

- Step 1: Search criteria. In the initial phase, we utilized a comprehensive set of keywords to identify existing approaches for assessing sustainable transport using indicators and composite indices. Key terms included "sustainable transport", "sustainability indicators", "compo-site index", and "assessment". Research articles related to case studies in sustainable transportation were sourced from the Scopus database, renowned as the largest abstract and citation database of peer-reviewed literature, including scientific journals, books, and conference proceedings. Consequently, our literature search incorporated a diverse set of source databases, such as Google Scholar, Web of Science, Scopus, Taylors & Francis, Springer, Science Direct, and Wiley Online Library.
- Step 2: Collect data. We examined diverse data sources to provide a comprehensive perspective on sustainable transport assessment approaches. Clear key terms were established for the inclusion or exclusion of articles, ensuring the selection of the most relevant studies. The study involved identifying 61 pertinent articles in the literature, prioritizing the most frequently referenced approaches, thereby emphasizing established and widely recognized methodologies.
- Step 3: Research refinement. The process of refining the research focused particularly on elucidating the methodologies associated with constructing composite indicators, excluding approaches related to the selection of elementary sustainability indicators. This refinement involved a comprehensive examination of 47 studies conducted between 2002 and 2022, providing a nuanced understanding of the evolution and trends in composite indicator construction.
- Step 4: Analysis and discussion of results. This critical step aimed at synthesizing the literature and presenting the findings. The process involved an initial descriptive analysis of the identified literature, followed by a detailed examination of the reviewed studies. The latter focused on identifying gaps and future research directions, thereby contributing to a more nuanced understanding of sustainable transport assessment methodologies.

By refining the search criteria, focusing on frequently referenced approaches, narrowing the scope to composite indicator construction, and conducting a thorough analysis of a specific subset of studies, the methodology was designed to extract meaningful insights and offer a comprehensive perspective on sustainable transport assessment practices. Figure 2 summarizes the methodology used in this study.

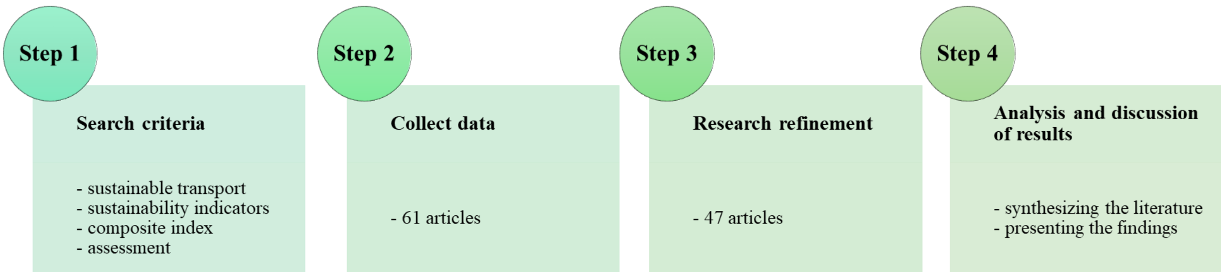

Figure 2. Description of the research methodology.

Table 2 systematically presents various approaches based on composite indicators in the field of transport, organized chronologically. It includes details such as the composite indicator's name, the sustainability dimensions, the number of selected indicators and the distinct steps involved in constructing the composite indicator.

Black [10] employed an index to measure public transport sustainability by considering potential mobility in a country. The sustainability of nine indicators was measured by means of the principal component analysis (PCA) method in his study. Additionally, Rassafi and Vaziri [11] introduced a composite indicator to rank countries according to the transport sustainability achieved in these regions. They aggregated 33 elementary indicators using the concordance analysis technique. Dobranskyte-Niskota et al. [12] proposed a composite indicator to assess the sustainability of the transport activities.

Campos et al. [13] presented another composite indicator to evaluate sustainable mobility, with the introduced elementary indicators being weighted by the analytic hierarchy process (AHP) method.

Researchers, as documented in [14–16], utilized cartographic composite indicators based on spatial analysis of a geographic information system. Specifically, Yigitcanlar and Dur suggested, in [16], introduced a composite indicator to compare and assess urban sustainability, aiming to assist decision makers in formulating policies for sustainable transport development. Dizdaroglu and Yigitcanlar [14] developed a composite indicator, revealing results that indicate an increase in pollution from transport and the poor accessibility of the public transport. Nadi and Murad [15] assessed the urban transport sustainability employing composite indicator, modeling five sustainability indicators using a geographic information system. The proposed composite indicator provided a spatial measure of sustainability and defined the current situation in Jakarta city.

da Silva, A.N.R. et al. [17] introduced an index of sustainable urban mobility by aggregating 87 elementary indicators of public transport sustainability. The authors in [18] proposed a composite indicator to extract widely employed indicators from the literature. Zito and Salvo [19] selected a set of elementary indicators of transport sustainability to assess the effects of policy measures on the urban level in Europe. These indicators were aggregated using Euclidean distance to construct a composite indicator.

Kolak et al. [20] suggested a composite indicator utilizing the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method. Their main objective was to assess the sustainability of the transport networks in 15 European countries and to identify the elementary indicators crucial for enhancing sustainability. Ramani et al. [21] proposed an index to evaluate the sustainability of the transport corridors. The Multi-Attribute Utility Theory (MAUT) method was applied in this study to determine the current status of the corridor. In a similar context, Awasthi and Chauhan [22] presented a composite indicator of transport sustainability using the AHP method and Dempster–Shafer theory. The main objective of the research work was to assess the impact of sustainable transport solutions, such as multimodal transport, mode sharing, intelligent transport, on city sustainability. In another study, Shiau [23] utilized the AHP method to weight 10 indicators and assess sustainable transportation strategies. A literature review [24] conducted between 1999 and 2010 revealed a lack of study developing composite indicator addressing freight transport issues. Haghshenas and Vaziri [24] proposed a composite indicator to compare the transport sustainability of 100 cities globally. The authors applied the equal weighting method to weigh nine transport indicators. In [25], researchers suggested an index based on four sustainability dimensions to integrate sustainability into transport planning. Equal weighting was also applied to each indicator and sustainability dimension in this study. The sustainability of three transportation plan alternatives in the Atlanta metropolitan area was assessed. Zheng et al. [26] aggregated a set of elementary indicators into a composite indicator. The study aimed, essentially, to evaluate transport sustainability in the United States.

Reisi et al. [27] aggregated nine elementary indicators to create an urban transport index, aiming to assess the current transport policies under different sustainability dimensions. Their study was conducted in Melbourne, Australia. Shiau et al. [28] developed a list of elementary indicators selected through rough set theory to measure the transport sustainability, with two indicators specifically related to the freight transport. The PCA method was then applied to aggregate these indicators and determine sustainability in the city of Taiwan from 1993 to 2010. In [29], the authors formalized a composite indicator to assess the urban transport sustainability and identify sustainable policies. Alonso et al. [30] evaluated the sustainability of transport in 23 European cities, employing an index to measure the sustainability of urban passenger transport systems. Nine elementary indicators were weighted using the equal weighting method and aggregated into three indexes representing the traditional sustainability dimensions. Verma et al. [31] suggested a composite indicator to measure the sustainability impacts of the transport practices on the variation in three traditional sustainability dimensions. In their work, the AHP method was employed to weight sustainability indicators. Their main objective was to study the effects of implementing congestion pricing in Bangalore, India on environmental, economic and social dimensions.

Ahangari et al. [32] formulated a national composite indicator to compare the United States' transport sustainability with that in 28 European countries from 2005 to 2011, aggregating 10 indicators. Miller et al. [33] established an index to analyze public transport by employing different normalization techniques. Rajak et al. [34] proposed a fuzzy model for evaluating the performance of the transport system and identifying gaps across four sustainability dimensions: economic, environmental and social and transportation system efficiency. First, a fuzzy transport sustainability index was calculated to measure transport sustainability. Subsequently, the main barriers preventing sustainable transport were identified to pinpoint areas with the lowest sustainability. Finally, appropriate actions were derived to enhance the sustainability of the urban transport companies.

In study [35], a multi-criteria approach was applied to assess the transport sustainability and address the problem of developing the best practices under uncertainty. Economic, environmental and social indicators were defined and prioritized to select the most suitable alternative. In another study [36], the researchers compared the sustainability of public transport. Using 15 indicators weighted by the equal weighting method, a composite indicator was calculated to identify transport gaps between different cities. Gudmundsson and Regmi [37] analyzed the transport sustainability in four Asia-Pacific cities using the urban transport index, developed from 10 elementary indicators applying the equal weighting method. Costa et al. [38] introduced an urban mobility index to evaluate transport sustainability using equal weighting, applied in Greater Vitoria, Brazil.

Mahdinia et al. [39] utilized PCA/factor analysis (FA) statistical methods to weigh and aggregate economic, environmental and social/societal indicators into an index. Danielis et al. [40] developed a composite indicator by employing various normalization, weighting and aggregation methods to assess the sustainability of urban mobility. The authors proved that the use of different methods significantly influences the values obtained by composite indicator. Lopez-Carreiro and Monzon [41] presented an approach to evaluate sustainability and smart mobility in certain Spanish cities. They selected elementary indicators and aggregated into an index to determine the intelligence of the urban mobility. Similarly, Bandeira et al. [42] employed a multi-criteria fuzzy approach to assess the sustainability of the distribution chain and identify sustainable configurations for freight transport operations. The researchers aggregated a set of indicators related to freight transport into a composite indicator. Subsequently, sensitivity analysis was conducted to assess the impact of the weights assigned to the input parameters on the final priority ranking and, consequently, on the final decision. The introduced composite indicator was utilized to evaluate alternative courier operations in Rio de Janeiro, Brazil, by comparing traditional distribution with that of e-tricycles. This study facilitated a quick and easy comparison of different configurations of distribution chains for companies and transport operators.

Pathak et al. [43] suggested a composite indicator for assessing the sustainability of freight transport, aiming to identify undervalued areas and devise appropriate corrective measures for enhancement. This approach extended beyond traditional sustainability dimensions by incorporating three emerging aspects: efficiency, advanced technology and safety. This study initially compiled a list of key success factors affecting freight transport sustainability through a literature review and Delphi method. Subsequently, the Total Interpretive Structural Modelling (TISM) method was used to identify structural relationships among these factors and to determine their mutual influence. Following this, the Fuzzy Analytical Hierarchy Process (F-AHP) was applied to prioritize these factors. The results indicate that the advanced technology dimension holds the highest importance, followed by the social and safety dimensions. In a related study [44], equal weighting was employed to assess the elementary indicators. The authors aimed to improve public transport potential, calculating four composite indicators (economic transport, environmental transport, social transport and sustainable transport) to compare the sustainability of the public transport in seven cities: Pune, Surat, Ahmedabad, Chennai, Kolkata, Bangalore and Mumbai.

Kumar and Anbanandam [45] proposed a method for enhancing social sustainability within the freight transport industry. Initially, they identified enablers, dimensions and attributes for measuring social sustainability in freight transport through a literature review, which was subsequently validated by industry experts. The proposed approach incorporated 74 attributes categorized into 16 dimensions and 4 enablers of social sustainability (internal human resources, external population, stakeholder participation and macro-social performance). The fuzzy logic method was then employed to calculate the social sustainability index. In a third step, the approach was validated by both experts and freight transport industry in a northern Indian region.

Hendiani and Bagherpour [46] introduced a composite sustainability indicator applying the Z-number to assess the freight transport sustainability. The Z-number was adopted to introduce a possibilistic approach, eliminating mathematical complexity. Essentially, the model incorporated linguistic possibilistic variables based on the verbal certainty expressed by experts. The model's validation involved comparing its results with those derived from conventional fuzzy sets and a crisp approach, demonstrating its superiority through improved outcomes.

Kumar and Anbanandam [47] developed an index to assess the environmental and social sustainability of the freight transport industry. Following the identification of sustainability attributes by experts, the Fuzzy Best Worst Method (F-BWM) was employed to calculate the importance weight of the sustainability dimensions and indicators. Subsequently, the index was applied in the Indian freight industry to pinpoint unsustainable attributes and formulate effective policies for enhancing the environmental and social sustainability of the sector.

Yazdani, Pamucar et al. [48] presented a decision-making approach by combining the multi-criteria methods with Rough Set Theory (RST) for assessing the sustainability of transport companies. The Rough DEcision-MAking Trial and Evaluation Laboratory (R-DEMATEL) and the Rough Multi-Attributive Border Approximation Area Comparison (R-MABAC) methods were utilized to evaluate sustainability. The approach was then used to evaluate the sustainability of seven Spanish freight transport companies, each employing different transportation modes (e.g., truck and train) and different vehicle fleets.

Illahi and Mir [49] suggested a fuzzy composite indicator for urban mobility, wherein sustainability indicators were normalized, weighted and aggregated using the FA method. This composite indicator was used to compare the sustainability of 16 cities in India.

Table 2. Approaches proposing composite indicators in the field of transport.

The Name of the Composite Indicator	Case Study	Selection of Indicators					Steps in the Construction of the Composite Indicator				Reference
		Sustainability Dimensions							Aggregation		
		Economic	Environmental	Social/Societal	Others	Number of Indicators	Normalization	Weighting	Methods	Aggregation Technique	
STPM	Countries (28 countries, OECD and USA)		*			9	Z-score	PCA	Linear Aggregation	C	[10]
SI	Countries (79 countries)	*	*	*		33	Z-score	Equal weighting	Concordance Analysis Technique	NC	[11]
SusTrans	Countries (27 Member States)	*	*	*	Technical	55	Min–Max	Equal weighting	Simple additive rules	C	[12]
SMI	City (Belo Horizonte, Brazil)	*	*	*		26	Min–Max	AHP	Linear Aggregation	C	[13]
SILENT	City (Gold Coast, Australia)		*		Demography, Land use and urban form, Transport	30	Likert scale	Delphi	Simple additive rules	C	[16]
I_SUM	City (São Paulo, Brazil)	*	*	*		87	Lookup Table	Expert opinion	Linear Aggregation	C	[17]
WIPS	Countries (United Kingdom)	*	*	*		233	Likert scale	AHP	SAW	C	[18]
TPI	Cities (36 European cities)	*	*	*		24	Min–Max	Equal weighting	DE	C	[19]
CIMI	Countries (15 European countries)	*	*	*		17	--	AHP	TOPSIS	C	[20]
Index	City (San Antonio, Texas)	*	*	*		13	Min–Max	Delphi	MAUT	C	[21]
TSI	SUCCESS Project (Smaller Urban Communities in CIVITAS for Environmentally Sustainable Solutions)	*	*	*	Transport, Energy	9	--	AHP	Dempster–Shafer theory	C	[50]
IOST	Cities (100 world cities)	*	*	*		9	Z-score	Equal weighting	Linear Aggregation	C	[24]
SCI	City (Taipei, Taiwan)	*	*	*	Finance, Energy	10	Min–Max	AHP	Simple additive rules	C	[23]
ESI	Country (United States)	*	*	*		19	Min–Max	Equal weighting	Linear Aggregation	C	[26]
CSI	Countries (13 countries, Atlanta Metropolitan region)	*	*	*	Efficiency	15	Min–Max	Equal weighting	Linear Aggregation	C	[25]
ICST	City (Melbourne, Australia)	*	*	*		9	Min–Max	PCA, FA	Linear Aggregation	C	[27]
SDi	Country (Taïwan)	*	*	*	Energy	19	Min–Max	PCA	Linear Aggregation	C	[28]
IOST	City (Esfahan, Iran)	*	*	*		9	Z-score	Equal weighting	Simple additive rules	C	[29]
CIsust	Cities (23 European cities)	*	*	*		9	Z-score	Expert opinion	Simple additive rules	C	[30]

Table 2. *Cont.*

The Name of the Composite Indicator	Case Study	Selection of Indicators				Steps in the Construction of the Composite Indicator					Reference
		Sustainability Dimensions							Aggregation		
		Economic	Environmental	Social/Societal	Others	Number of Indicators	Normalization	Weighting	Methods	Aggregation Technique	
CSILINK	City (Bangalore, India)	*	*	*		16	Min–Max	AHP	Simple additive rules	C	[31]
MUSIX	City (Gold Coast, Australia)		*			14	Likert scale	Expert opinion	Linear Aggregation	C	[14]
CSI	City (Vancouver, Canada)	*	*	*	Efficiency	19	Z-score, Min–Max DR	Equal weighting	Linear Aggregation	C	[33]
FTSI	Companies (Transport companies in India)	*	*	*	Efficiency	60	--	Expert opinion	Linear Aggregation, Euclidean distance	C	[34]
NTSI	Countries (28 European countries)	*	*	*		10	Z-score	Equal weighting	Linear Aggregation	C	[32]
--	City (City in a developing country)	*	*	*		13	--	F-AHP	Geometric aggregation	PC	[35]
--	Cities (26 cities in Asia and the Middle East)	*	*	*	Efficiency	29	Min–Max	Equal weighting			[36]
SUTI	Cities (4 cities in the Asia-Pacific region)	*	*	*		10	Min–Max	Equal weighting	Geometric aggregation	PC	[37]
IMUS	City (Greater Vitoria, Brazil)	*	*	*		20	Min–Max	Equal weighting	Simple additive rules	C	[38]
CI	Cities (116 Italian provincial cities)	*	*	*		16	Z-score, Min–Max, DR	Equal weighting, PCA	Geometric, linear and concave aggregation	CP, C, NC	[40]
ITS	Country (United States)	*	*	*		89	Min–Max	PCA/FA; Equal weighting	Linear Aggregation	C	[39]
SIUFT	City (Rio de Janeiro, Brazil)	*	*	*		10	--	Equal weighting	Linear Aggregation	C	[42]
ISM	Cities (6 cities, Spain)	*	*	*	Technology	16	Min–Max	Equal weighting	Square root	NC	[41]
FTSSI	Companies (7 companies, India)			*		74	--	Expert opinion	Linear Aggregation, Euclidean distance	C	[45]
SUTPI	City (Jakarta, Indonesia)	*	*	*		5	--	Weighted average	Linear Aggregation	C	[15]
SPI	Logistics service providers in India	*	*	*	Efficiency, Safety, Advanced Technology	34	Likert scale	Delphi, TISM, F-AHP	Linear Aggregation	C	[43]
CSTI	Cities (7 cities, India)	*	*	*		8	Min–Max	Equal weighted; Expert opinion	Square root		[44]
IFSM	Cities (16 states and 1 Union territory of India)	*	*	*		12	Min–Max	FA	Linear Aggregation	C	[49]

Table 2. *Cont.*

The Name of the Composite Indicator	Case Study	Selection of Indicators					Steps in the Construction of the Composite Indicator				Reference
		Sustainability Dimensions							Aggregation		
		Economic	Environmental	Social/Societal	Others	Number of Indicators	Normalization	Weighting	Methods	Aggregation Technique	
ZSI	Companies (Freight transport companies)	*	*	*		16	--	Linguistic variables	Linear Aggregation	C	[46]
FTE-nSoSI	Companies (Freight transport companies)		*	*		63	--	F-BWM, Expert opinion	Linear Aggregation	C	[47]
--	Companies (7 freight transport companies in Spain)	*	*	*		15		R-DEMATEL	R-MABAC	PC	[51]
ISTA	Cities (26 States and 1 Union Territory of India)					116	Min–Max	PCA/FA, Equal weighting	Linear Aggregation	C	[52]
I	Cities (4 metropolitan cities in India)	*	*	*		10	Min–Max	PCA, Equal weighting, Fuzzy-Weighted	Linear Aggregation	C	[53]
ISFT	Companies (Indian freight transport companies)	*	*	*		31	Min–Max	Consensus model	FERA		[54]
--	Freight transport operators in India	*	*	*	Efficiency, Safety, Advanced Technology	34			ERA	C	[55]
--	Companies (Transport and logistics companies in India)	*	*	*	Technology	22	Min–Max	Equal weighting	--	C	[56]
FLS	City (Sfax, Tunisia)	*	*	*	Political, Spatial	15	Min–Max	F-FUCOM	F-MAIRCA, F-PROMETHEE	C, PC	[57]
FLS	City (Sfax, Tunisia)	*	*	*	Political, Spatial	15	--	F-FUCOM	F-MAIRCA	C, PC	[58]

C: compensatory; PC: partially compensatory; NC: non-compensatory; *: The dimension is considered in the reference.

The same researchers [53] defined an index to evaluate the sustainability of the transport industries holistically. Various methods, including the equal weighting, fuzzy logic and PCA methods, were combined to construct the index. PCA was utilized to transform a larger number of indicators into a smaller set of 10 indicators, were then combined using fuzzy logic. The authors in [52] proposed a composite indicator to assess the sustainability of the public transport based on PCA/FA methods.

Fulzele and Shankar [54] developed a composite indicator for assessing the sustainability of freight transport operators. The consensus model determined the degrees of importance for indicators in the three sustainability dimensions. To address decision-making imprecision, the developed composite indicator incorporated the Fuzzy Evidential Reasoning Algorithm (FERA) along with Dempster–Shafer theory. The FERA technique was also adopted to aggregate belief degrees, managing uncertainties associated with subjective judgments and incomplete information. A sensitivity analysis was conducted to assess the robustness of the model output.

Pathak et al. [55] used the FERA technique to assess freight transportation sustainability based on competitive priorities. They identified key success factors for sustainability that impact four main competitive priorities: cost, delivery, quality, innovation and flexibility. The authors emphasized the insufficient capacity of the operators for sustainability assessment capacity and the lack of monitoring tools to evaluate their sustainability practices.

On the other hand, in [56], the researchers examined the transport sector based on the Grey-Decision Making Trial and Evaluation Laboratory (G-DEMATEL) method. They identified barriers to the implementation of sustainable transport. This study aimed to identify the interrelationships between these barriers and prioritize them based on their causal relationship. In our previous work, we introduced a Facility Location index according to sustainability perspectives (FLS) [57]. The Fuzzy Full Consistency Method (F-FUCOM) was applied to estimate the importance weight of the proposed indicators. Subsequently, fuzzy Multi-Attribute Ideal Real Comparative Analysis (F-MAIRCA) was conducted and the Fuzzy Preference ranking Organization Method for Enrichment Evaluation (F-PROMETHEE) was applied to rank the location of logistics platform under weak sustainability and limited sustainability, respectively.

4. Findings and Results

In the forthcoming sub-sections, we will delve into the pertinent aspects of sustainability examined in the current research. Sections 4.1 and 4.2 delineate the application field of composite indicators and the associated sustainability dimensions. The subsequent sub-sections will detail the methods employed in constructing composite indicators.

4.1. Application Field of Composite Indicators

It is crucial to highlight that only a limited number of studies have put forth composite indicators for assessing the sustainability of freight transport. Almost fifty percent of the studies have proposed composite indicators exclusively for the assessment of sustainability in public transport. In contrast, the other research works have addressed both freight transport and public transport, as illustrated in Figure 3.

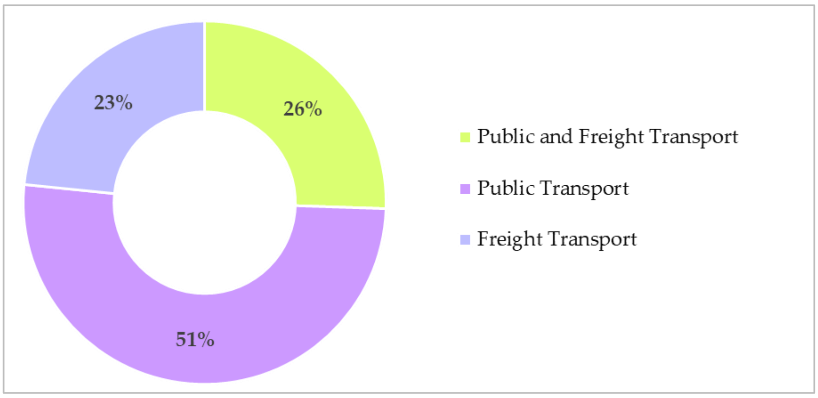

Figure 3. Application fields of composite indicators.

4.2. Sustainability Dimensions

Within each sustainability dimension, a set of elementary indicators was carefully defined. In previous studies, the number of indicators utilized in each approach varied significantly from 5 to 233.

Examining the sustainability dimensions of these indicators, it is noteworthy that more than half of the existing approaches focused solely on the traditional dimensions of sustainability (economic, environmental, and social/societal). Meanwhile, over a quarter of these approaches expanded their scope by including additional sustainability dimensions (such as political, spatial, activity, mobility, etc.) alongside the three mentioned dimensions. Figure 4 illustrates the dimensions incorporated into the construction of composite indicators, while Figure 5 outlines the additional dimensions considered.

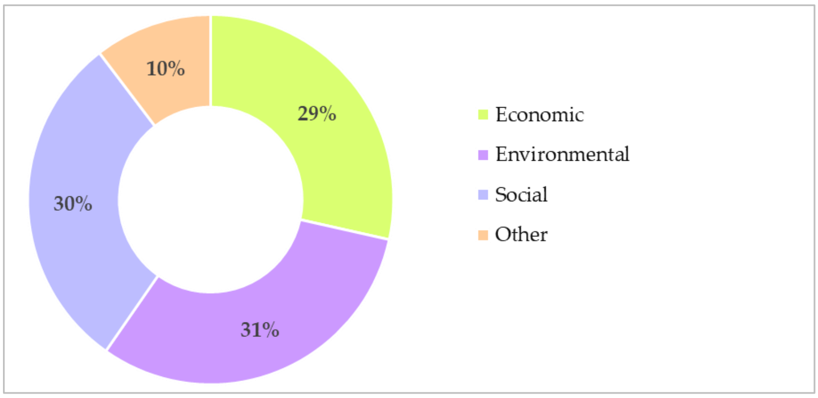

Figure 4. The sustainability dimensions retained to the construction of the composite indicators.

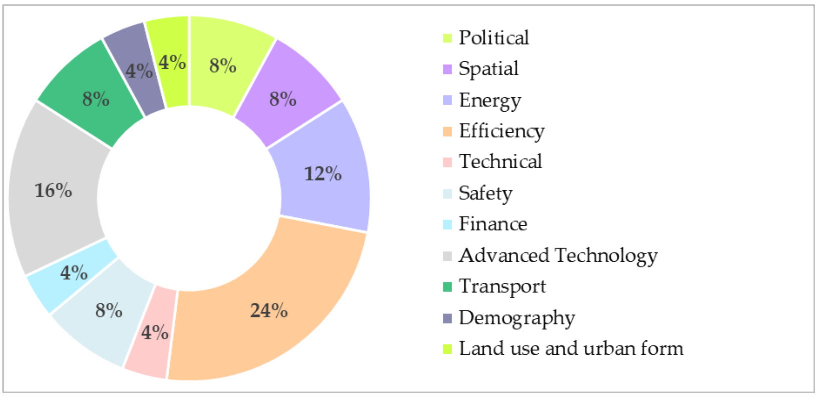

Figure 5. Others sustainability dimensions.

4.3. Normalization Methods

Concerning normalization, the predominant choice among composite indicators has been the adoption of Min-Max normalization (Re-scaling). As outlined by Nardo et al. [59], this method is considered the most useful for normalization. In contrast, the utilization of the Z-score method has been less widespread, proving effective in situations where extreme values might be considered unreliable outliers. However, the third normalization method is based on categorical scaling and distance from a reference (DR). Despite the straightforward implementation of categorical normalization methods, such as Likert scale and lookup table, their usage has not been extensive, primarily due to their reliance on stakeholders' opinions. Similarly, normalization methods based on distance from a reference (e.g., average, leader) present certain limitations, particularly their dependence on extreme values, rendering them less reliable. Figure 6 defines the existing normalization methods.

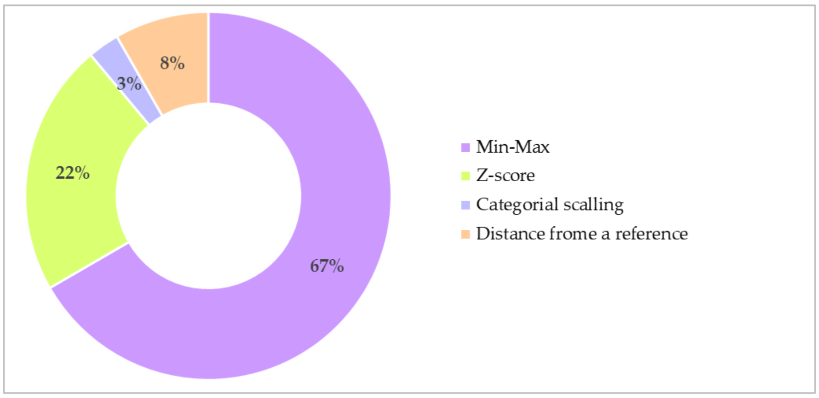

Figure 6. The normalization methods.

4.4. Weighting Methods

The weighting approaches can be categorized into three main groups: equal weighting, weighting based on expert opinion and weighting relying on statistics. A notable observation is that at least two-fifths of the existing approaches employ equal weighting. While this method offers simplicity, its utility diminishes when dealing with correlated data points or when the assessment's time scale is prolonged. As it has some limitations, AHP, BWM [47], FUCOM [57] and Delphi comprise the most often implemented participatory methods. The application of the latter is important because it involves the opinions of many experts with different backgrounds. However, managing larger datasets using these participatory methods poses challenges. On the other hand, statistical methods like DEA and PCA/FA, which determine weights from collected data, were not extensively utilized in previous studies, despite their efficiency. It is important to note that these statistical techniques require feasibility checks. Figure 7 illustrates the various weighting methods employed.

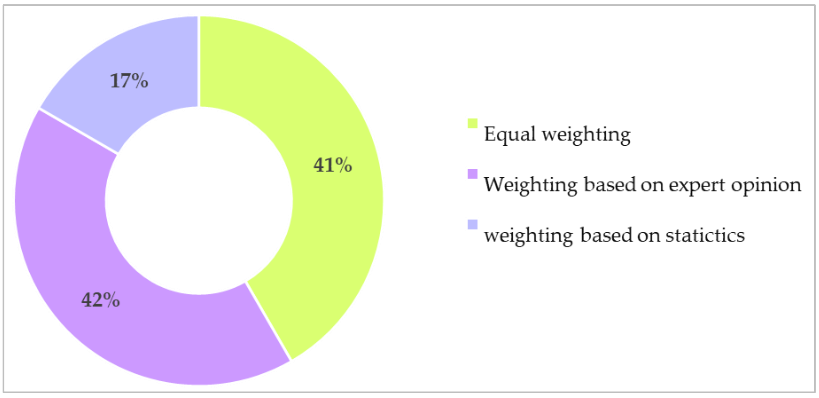

Figure 7. The weighting methods.

4.5. Aggregation Methods

Aggregation methods can be categorized into three main types: compensatory approaches, partially compensatory approaches, and non-compensatory approaches. Notably, linear aggregation methods and simple additive rules emerge as the most widely adopted techniques. These methods essentially allocate rewards to indicators proportionally based on their assigned weights, maintaining a constant level of compensation. In essence, the majority of the existing approaches use compensatory methods, signaling a preference for weak sustainability. A limited number of studies, such as [35,37,48], have opted for partially compensatory aggregation, indicating a nuanced approach to sustainability. Additionally, in [11], the authors proposed a non-compensatory composite indicator, demonstrating a commitment to strong sustainability. Additional studies, as evidenced by [40,57,58], introduced composite indicators through the implementation of diverse compensation techniques. These aggregation methods are presented in Figure 8.

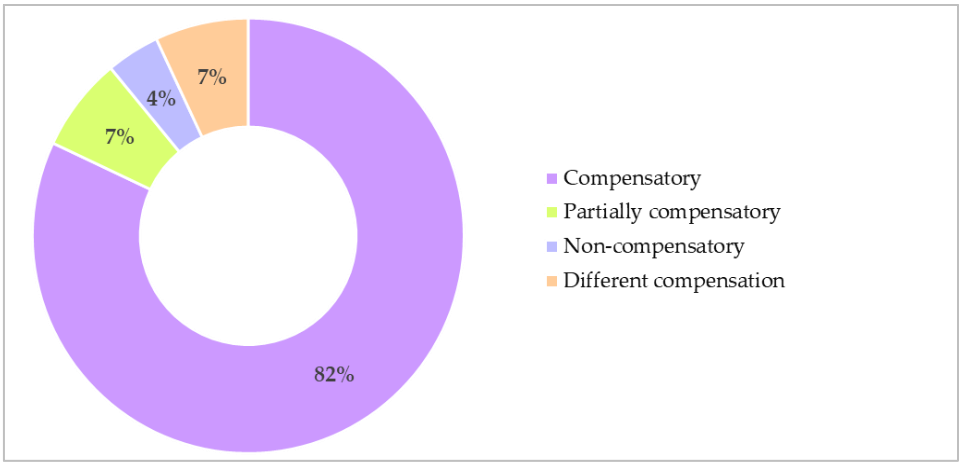

Figure 8. The aggregation methods.

4.6. Consideration of Uncertainty

One-third of the proposed approaches for composite indicators considered uncertainty during the construction process, with a majority opting for fuzzy logic due to its ability to integrate expert opinions into decision-making. Fuzzy decision rules were implemented in studies such as [42,49,53], while linguistic variables were employed in [34,45,46]. Various MCDM methods, coupled with fuzzy set theory, were applied in the development of composite indicators [35,43,47,48,57,58]. Indeed, the utilization of MCDM methods assists stakeholders in evaluating transport sustainability by assigning weights to the indicators used and identifying optimal solutions.

5. Research Trends and Gaps

This section explores diverse research viewpoints extracted from our review covering the period from 2002 to 2022. We conduct a thorough examination of 47 articles, focusing on the construction of composite indicators. Through this literature analysis, we bring attention to significant limitations within the existing approaches. Our goals are twofold: (i) to identify research trends and pinpoint existing gaps and (ii) to outline potential directions for future research.

Firstly, the current state of research in freight transport is constrained, with a limited number of studies dedicated to this field. As part of our future endeavors, we aim to delve into urban freight transport, recognizing and addressing its specific challenges and dynamics.

Secondly, as underscored in the literature review, the traditional dimensions, which have been the central focus of existing studies, fall short in comprehensively addressing sustainability aspects. Furthermore, these traditional dimensions prove inadequate in capturing the current state of the transport system. To address these limitations, we introduce a conceptual framework that extends beyond traditional dimensions to incorporate crucial dimensions such as political and spatial ones. This framework serves as a comprehensive tool for evaluating freight transport on a broader scale.

Thirdly, another critical observation is the lack of specificity regarding the number of elementary indicators in previous studies. According to Sdoukopoulos et al. [60], it is recommended that the average number of indicators employed in constructing composite indicators should be approximately 23. This recommendation aims to facilitate the practical application of the assessment methods in use. Consequently, we suggest the utilization of a manageable set of indicators and discouraging the use of a limited number of indicators that may not comprehensively represent all dimensions of sustainability.

Fourthly, our review underscores the pivotal role played by normalization, weighting, and aggregation methods in determining the results of composite indicators. While many studies favor equal weighting or the analytic hierarchy process (AHP) method, we argue that the FUCOM method distinguishes itself through its efficiency, stability, reliability, and robustness. Its extensive application across diverse fields underscores its simplicity of implementation and effectiveness. Furthermore, for robust assessments of strong sustainability, it is crucial that appropriate weighting and aggregation methods employ non-equal weights and consider different aggregation techniques (compensatory, partially compensatory, and non-compensatory). Although the selection of weighting and aggregation methods is often addressed independently, they are interconnected. The equal weighting method lacks the ability to differentiate between important and less important indicators, treating them uniformly. Hence, the use of participation methods based on expert judgments is strongly recommended. It is noteworthy that the majority of the employed methods utilize the compensatory aggregation technique in short-term decision-making. While the compensatory approach can mitigate low sustainability in certain indicators with good sustainability in others, the sustainability of the UFT is particularly linked to weak components. An indicator with low sustainability in this context can have significant implications for the current situation. In such cases, it is advisable to explore other types of compensation methods. Employing various aggregation techniques is essential to illuminate the nuances in stakeholders' perspectives.

In summary, our article not only reviews the existing literature but also identifies gaps, proposes a conceptual framework, supports a thoughtful selection of indicators, and emphasizes the importance of employing diverse aggregation techniques to enrich the understanding of sustainability in freight transport.

6. Conclusions

The transport system plays a decisive role in the economic progress and the development of other sectors. However, given the numerous challenges it currently faces, a comprehensive evaluation of its sustainability is highly recommended. To address this, sustainability indicators are recognized as valuable tools for decision-makers in assessing the sustainability of transport systems by providing pertinent information about its present state. In this paper, we present a thorough review of sustainability assessment approaches within the transport sector, covering publications from the past two decades. Firstly, we introduce the concept of composite indicators along with the various steps involved in their construction. Second, we delve into the examination of the existing approaches applied to select indicators and formulate indexes. Third, we conduct an analysis of the results obtained. Additionally, we provide information on research trends, engage in a brief discussion and offer a critical analysis of different approaches found in the literature. Finally, we identify gaps in sustainability evaluation and highlight directions for future research focus.

The results derived from our analysis indicate that the majority of existing studies have focused on public transport. Furthermore, the majority of the existing approaches are based exclusively on sustainability considering the traditional dimensions by including undefined number of elementary indicators. Additionally, the use of different normalization, weighting and aggregation methods provide different results for composite indicators.

Notably, our exclusive emphasis on composite indicators as assessment tools might constrain the exploration of elementary indicators and their inherent contributions to the sustainability assessment. This last point could be considered as a limitation of this study.

Based on the findings obtained, we recommend exploring further research avenues, particularly in the domain of freight transport. Additionally, our study emphasizes the importance of considering not only traditional dimensions but also other significant dimensions when evaluating the performance of the transport system. We underscore the critical role of defining sustainability dimensions in assessing the sustainability of global freight transport. Furthermore, we advocate for the use of a manageable number of elementary indicators to facilitate the application of composite indicators. Finally, we propose the careful selection of the most appropriate methods for normalization, weighting, and aggregation to construct composite indicators.

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