



Consensus-based evaluation for advancing sustainable public transport indicators in developing countries using AHP

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Abstract

Sustainable public transportation (SPT) is crucial for national development, environmental preservation, congestion reduction, and promoting economic growth. Indicators related to SPT form the foundation of sustainable mobility. Selecting appropriate indicators to measure sustainability in Public Transportation (PT) is essential, especially in developing countries where local conditions and structural constraints differ from global standards. The significance of this research lies in the development of context-appropriate sustainability indicators customised to the demands and structural realities of developing nations (the West Bank, Palestine, as a case study), thereby filling a gap in trustworthy frameworks for assessing and improving SPT. The study employs the Analytical Hierarchy Process (AHP) to evaluate and align sustainable transport indicators for developing countries, incorporating experts' judgment to select the most relevant indicators. This method enables the comparison and prioritisation of indicators based on their importance. Additionally, the study compares these indicators with the Sustainable Urban Transport Index (SUTI) to assess their alignment with international frameworks and applicability in developing contexts. Key priority indicators identified include active mobility, average trip distance, air pollution, and service reliability. The findings provide a structured and adaptable framework to guide sustainable public transport planning in developing countries.

Keywords AHP analysis · Developing countries · Experts' judgment · Public transportation · Sustainable indicators

Introduction

Since the 1990s, the global population has more than doubled, and resource consumption has skyrocketed [1]. The global average annual car growth rate was 3% from 1990

to 2015 [2], while it reached 8.6% in developing nations [3]. According to recent data, the global vehicle market is still expanding, with new vehicle sales climbing by approximately 2.7% in 2024, indicating that motorisation remains a major problem for sustainable transportation planning [4]. A significant obstacle for developing nations is aligning the desire for individual mobility with the substantial economic, environmental, and social consequences of automobile use [5]. Developing countries are home to approximately 85.4% of the global population [6, 7]. According to the International Energy Agency (IEA), some developing cities have become unliveable due to traffic congestion, safety concerns, and environmental damage [8]. For example, around 4,000 people die in Tehran every year as a result of ambient air pollution due to heavy traffic congestion [9]. Approximately 72% of the overall transport greenhouse gas emissions and noise pollution are produced by road traffic [10, 11]. Road-transport CO₂ emissions exceeded 6 Gt in 2024, 8% above 2015 levels [12]. Passenger automobiles accounted for more than 60% of these emissions [13].

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Developing nations are predominantly agrarian, exhibit lower living standards, and possess fragile economies characterised by sluggish or no growth [14, 15]. Developing nations face numerous challenges, including limited financial resources [16, 17], population growth, rapid increases in car ownership, traffic congestion, fatal accidents, and environmental degradation [11, 18]. As a result, an increasing number of developing countries became uninhabitable [6]. Developing countries are particularly vulnerable due to their instability in all facets of life [17, 19]. The main characteristics of developing countries vary, but they share common attributes like improper infrastructure and the destruction of transportation networks [20, 21], eroding the capacity, authority, and legitimacy of state institutions [22], state fragility, poverty, and security threats [23], and environmental degradation [24, 25].

In recent years, the all-encompassing issue for transportation has been sustainability and its linkage to economic growth, consumption, and the environment [26] particularly in the developing world [27]. This is because the need for transportation system improvement in developing countries is much greater, with motorised transport expected to expand by more than 100 percent over the next decade [28]. Policymakers and planners have been increasingly concerned about environmental sustainability in recent decades [21, 29].

The transportation system faces many challenges and can't continue in its current situation; therefore, the solution is to implement sustainable transportation [30]. Sustainable transportation is one of the themes guiding the transportation sector's sustainable development initiatives and decreasing global risks [31, 32]. A sustainable transportation system is characterised by accessibility, safety, environmental friendliness, and affordability [15, 33]. Just half of urban areas have convenient access to public transit [8]. The existing global transportation networks have serious problems and do not encourage sustainable development [4, 34]. The transition to sustainable transportation can create a more eco-friendly, efficient, and equitable future [35].

According to Santos et al., [36], there is no "one-size-fits-all" solution for moving toward more sustainable mobility. Creutzig et al., [37] stated that in large cities like Barcelona and Sofia, increasing the share of people who use public transit is the most effective technique, however, in smaller cities like Malm and Freiburg, increasing the share of people who cycle may be more beneficial. Pucher and Handy [38] evaluated governmental initiatives to increase cycling participation through infrastructure enhancements, pro-cycling advocacy, suitable spatial design, and restrictions on automobile usage. Ameen and Mourshed [5] proposed achieving urban development in unstable regions such as Iraq, including boosting infrastructure projects, implementing

sustainable and diverse modes of transportation, and using walking and cycling as transit modes.

There are numerous indicators for establishing and measuring sustainable transport in developed countries, since many countries worldwide have begun to implement sustainable transportation to address global issues [39]. While Gudmundsson and Regmi [40] mentioned that there was no comprehensive system for assessing and reporting sustainable transportation. Furthermore, no single tool exists to evaluate, analyse, and track sustainable urban transportation, so indicators must be developed to evaluate the sustainable transport [41]. Recent studies that dwell on the contexts of the developing countries have also indicated that current methods require further attention, considering the lack of a unified and similar framework restricts the successful assessment of the urban mobility and public transport systems [42, 43]. The indicators must be standardised to be appropriate for developing regions, and developing countries must collaborate to create metrics for sustainable transportation [28, 44].

Sustainability and sustainable transport issues have become a global concern. Developing countries are still searching for solutions to provide an efficient and sustainable transportation system. There are some gaps in previous studies:

- Many of the available sustainable transport indicators are designed with a focus on particular institutional and governmental settings, which limits their universal applicability, and there is an unbalanced level of development of these indicators for advanced settings, as opposed to developing country urban mobility and public transport systems.
- The majority of scholarly research focused on one aspect of sustainability more than others. For example, some studies focused on economic factors when selecting indicators, while others concentrated on environmental or social aspects. This fragmented approach limits the ability to capture the integrated nature of sustainability in public transportation systems, where economic, social, and environmental dimensions are closely interrelated.
- Over the years, previous studies have shown that existing indicators should be normalised and aligned with the nation specific goals and standards prior to be adopted for evaluating the sustainable transport system of a country. This is particularly evident in public transport systems, where local conditions, data availability, and institutional settings strongly influence the applicability of indicators.

Therefore, weighted indicators tailored explicitly for developing countries like the West Bank—Palestine must be

developed, as a sustainable system is the most effective solution for mitigating global risks, such as pollution and congestion. The novelty of this study lies in the creation of a context-based, expert-led approach to selecting and prioritising sustainable public transport indicators, tailored to the situation in developing countries. In contrast to the currently available literature, the given approach incorporates systematic screening of indicators, Delphi expert judgment, and AHP weighting, and explicitly matches the identified indicators to international standards, including SUTI, while addressing local data, institutional, and governance limitations. This research aims to identify SPTI suitable for the West Bank- Palestine as a developing country and establish a methodology for ranking their significance. It uses a hybrid technique, incorporating AHP analysis, to identify and assess these sustainable transportation indicators.

Sustainable public transportation indicators

Sustainability is assessed using several indicators [15, 45]. Indicators are the most commonly used instruments for measuring, evaluating, and helping achieve goals [46]. Indicators are variables that can measure anything, help achieve goals, and lessen the complexity of managing and intervening in the system [47]. It indicates the state or level of something [48], and a parameter, a measure, a statistical measure, a proxy or an instrument for a measure [14]. The SPTI is a holistic evaluation instrument that integrates the transport system together with economic, social, and environmental elements of sustainable transportation services and systems [7, 49]. Indicators depend on several criteria and policies that can be evaluated and applied [50]. The indicators can be quantitative or qualitative, which must be simple, reasonable, quantifiable, accessible, and complete [51]. Furthermore, indicators must be adaptable to temporal changes, autonomous, standardised for comparative analysis, explicitly stated, and capable of capturing long-term trends [52, 53].

There are many indicator types related to countries' aims and objectives. Also, different methodologies were used to analyse the data, as shown in Table 1, which presents the key parameters, methodologies, and findings in transport sustainability research.

A systematic review of SPTI for developing countries was conducted. From 39 related papers published between 2019 and 2025, the criteria for selecting indicators were identified, including feasibility, applicability, economic and environmental impacts, social aspects, and goals, as presented in Fig. 1. Table 2 presents the indicators derived from the systematic review.

Measurement methods of SPTI

Senne et al. [78], attempted to understand the interactions of people and goods mobility in the urban environment. They used a transportation model as a tool to generate qualitative and quantitative results on the effects of potential solutions and frequently employed multi-criteria decision analysis methodologies in mobility projects. They used AHP because it can address the typical challenges of complex scenarios that require consideration of several criteria and stakeholder groups. Illahi and Mir [79] established Multivariate Analysis for evaluating and reporting the sustainability of transportation systems, produced a composite index called the Sustainable Transportation Attainment Index (ISTA), and proposed a tool called Bargain Matrix. A total of 116 indicators were employed, which were standardised using the rescaling approach before being weighted and aggregated using Principal Component Analysis/Factor Analysis.

Regmi [49] presented SUTI for Asian Cities. A typical strategy in composite index design, the Linear Rescaling Method, was used with equal weighting, and the data were analysed using the SUTI Excel Sheet. The results were presented in a spider diagram of the state of each indicator to make it simple for policymakers to understand the system. Liu et al. [80] applied the Framework for Strategic Sustainable Development (FSSD) to study the urban transport system and provided a strategy guideline for prioritising specific measures to select sustainable transport policies using quantitative methodologies. A questionnaire was prepared to quantify popular preferences. Two conceptual, multidimensional, structured models of public views toward urban transport policy were tested using Structural Equation Modelling (SEM), which can build correlations among many variables.

Al-Sahli [44] developed a set of indicators of the United Nations Economic Commission for Europe to measure the degree of sustainable internal transport connectivity in Palestine called "Sustainable Inland Transport Connectivity Indicators (SITCIN)". The methodology was based on interviews with stakeholders (from public and private sectors and civil society organisations), holding a national policy dialogue, and a national capacity-building workshop to weigh indicators. While Zito and Salvo [52] conducted a European comparison to find an urban Transport Sustainability Index (TSI), and to group sustainable mobility strategies to develop a core set of specialised Transport Performance Indicators (TPI), then normalised the TSI using a multi-criteria Analysis method.

Furthermore, Awashti and Chuahan [81] used the AHP to create a TSI and assigned equal weights to the indicators. Shiddiqi et al. [51] consulted professionals from government agencies, non-governmental groups, and universities

Table 1 Summary of selected studies on urban transport sustainability indicators

Author(s) and study	Parameters considered	Study methodology	Key deliverables / findings
Zito and Salvo [52]	Defined a set of Transport Performance Indicators (TPI) like population, length of road network, and PT lanes, PT vehicle-km, energy consumption, PT coverage, affordability, and infrastructure	Collected data at the city level (36 European cities), normalised each TPI to [0,1] scale, then constructed a Normalised Transport Sustainability Index (NTSI) by treating the worst-case city (hypothetical), and all TPIs are treated with equal weight	No globally accepted standard for gathering, assessing, and normalising indicators, but there are processes essential for establishing a set of indicators that are effective in both cost and time. Also, smaller to medium-sized cities tend to score higher on sustainability (higher NTSI)
Litman [3]	Economic indicators: productivity, efficiency, and affordability. Social indicators: equity and fairness, safety, and accessibility. Environmental indicators: climate impacts, air pollution and noise, and energy consumption	Analytical review of transport sustainability indicators. Classified indicators into major categories (economic, social, and environmental). Evaluates indicator selection criteria. Integrating sustainability indicators into transport planning processes	Identified essential economic, social, and environmental indicators needed for sustainable transport evaluation and evaluated how they should be selected based on relevance, measurability, and data availability. The paper provides a structured methodology for integrating these indicators into transport planning and policy assessment. It indicates that compared to conventional mobility-based measurements, accessibility-focused indicators provide a more meaningful assessment of sustainability
Aisen [54]	Political instability indicators include government transitions, social unrest, and political violence. Macroeconomic indicators include GDP growth, investment levels, productivity, and policy effectiveness	From 1960 to 2004, an econometric panel-data model was applied to over 160 nations. We examined the statistical association between political instability and long-term economic growth. Controlled for important macroeconomic variables to isolate the impact of political instability	Political instability has a severe negative impact on economic growth by lowering productivity, discouraging investment, and affecting policy efficiency. Maintaining stable governance systems is critical for promoting long-term growth
Regmi [49]	Access to PT, modal share, affordability, intermodal facilities, active mode infrastructure (walking and cycling), air quality, traffic fatalities, and PT coverage are all indicators of urban transport sustainability	Comparative analysis of Asian cities using sustainable transport indices	Selected and studied significant sustainable transportation variables for multiple Asian cities using comparative analysis
Al-Sahili and Qaisi [41]	Social indicators: traffic regulations, infrastructure, vehicle systems, administration, and governance. Economic metrics include efficiency, cost, operations, and intermodal transportation. Environmental indicators include noise and air pollution, as well as emissions management	Reviewed and evaluated 114 sustainable transportation parameters related to Palestine. Each indicator was evaluated for its relevance to national transportation strategy and compatibility with the Sustainable Development Goals (SDGs)	Provided a comprehensive framework for connecting sustainable internal transport metrics to SDGs. Priority indicators have been identified for planning and evaluating transportation sustainability in Palestine

to create standards for evaluating SPTI. Moreover, Mahdinia et al., [48] proposed methodology to create composite indices for transportation sustainability using the Principal Component Analysis/Factor Analysis approach (PCA/FA). Additionally, Amrina and Berti [82] identified the indicators and confirmed them with expert input. They then utilised the Analytic Hierarchy Process (AHP) to weight the indicators and the Interpretive Structural Modelling (ISM) method to build links among them. Jiang and Huan [83] developed a hybrid approach based on the hierarchical Bayesian Network Model (BNM) and Principal Component Analysis (PCA) to obtain a better measurement of transport sustainability performance.

On the other hand, according to the systematic review of SPTI for developing countries, the evaluation methods are illustrated in Table 3.

It was observed that various strategies were duplicated, with multiple evaluation methods. Some of these methods complemented each other. The AHP method, as well as Multi-criteria or Multi-Variation Methods, was the most popular evaluation methodology. Experts' judgment was the most often utilised way for weighing indicators. Previous studies used various weighting techniques, including equal weighting [60, 84]. However, researchers disagreed on the most appropriate and reliable weighting method. Additionally, some suggested that equal weighting may not be ideal for analysing complex issues [60]. Several studies utilised expert judgment [27, 47, 50, 51, 85]; or AHP weighting [64, 68], which can introduce subjectivity into the results [60].

Fig. 1 List of criteria for selecting indicators based on a previous study [53]



The sustainable urban transport index (SUTI)

The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) established SUTI to analyse the sustainability performance of Asian cities and ensure alignment with SDG target 11.2. The goal is to assess the status of urban transportation systems in cities [49]. SUTI is a quantitative instrument that enables partner states and cities to evaluate their performance in sustainable transportation systems and policies compared to their peers [86]. It can assist in identifying further policies and efforts to improve urban transportation infrastructure and amenities, as well as in monitoring the impact of transportation on SDG attainment [40]. It has ten indicators that cover the system, economic, environmental, and social domains [49].

SUTI was successfully organised in ten cities: In 2017, Greater Jakarta, Colombo, Hanoi, and Kathmandu; and in 2018, Suva, Ho Chi Minh City, Dhaka, Surat, Surabaya, and Bandung. The cities considered the SUTI a valuable framework for assessing the status and implementing sustainable mobility strategies [86]. Gudmundsson and Regmi [40] identified the objectives of SUTI as:

- Reflect the SDGs and other sustainability concern relevant to urban transportation.

- Restrict the number of indicators to the most crucial ones.
- Avoid signs that are too difficult or complex to collect.
- Adopt a calculation method for the index that is as straightforward, open, and objective as possible.

The SUTI calculation is based on the ten indications listed in Table 12, and data must be obtained using the SUTI Sheet guideline [86].

Methodology to select context-based indicators for developing countries

Figure 2 summarises the technique used to provide a scientific approach to selecting metrics for SPT systems in developing nations. The main steps were:

- Check if the literature review is suitable for this research case study and add more papers if needed [87]. About 62% of the reviewed papers related to developing countries, and 16% to transition countries, so that is accepted.
- Use the Delphi method to choose criteria. The Delphi technique is a survey method that relies on the input of experts [66]. It has three main aspects: keeping respondents anonymous, using a step-by-step approach,

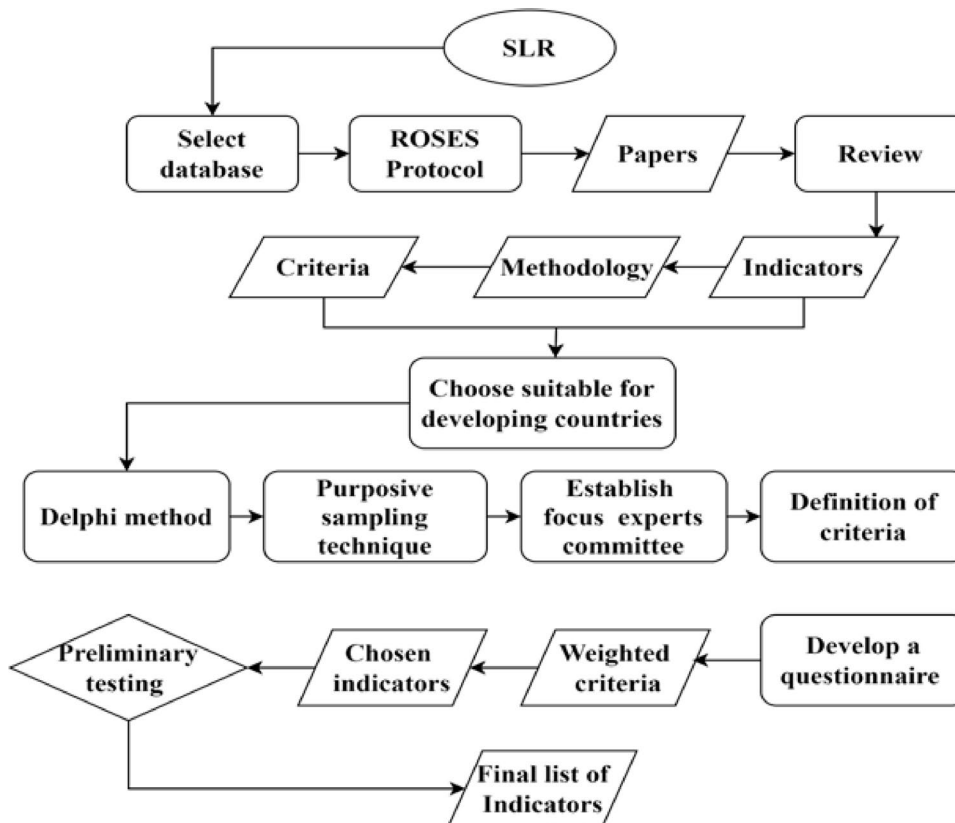
Table 2 The SPTI retrieved from the literature review

Aspect	Indicator	Sub-indicator	Reference
Environment	Air pollution	Toxic air contaminants emission by transportation, CO ₂ emissions (g/pkm), PM10 emissions (g/pkm), NOx emissions (g/pkm), and Low-or zero emissions	[4, 26, 34, 47, 51, 53, 55–61]
	Active mobility		
	Energy consumption (MJ/km)	Fuel/oil consumption (MJ/km)	
	Land-use resilience		
	Repairability		
Economic	Area of paved roads		
	Noise pollution		
	Operation and maintenance (O&M) costs	Operating costs in \$USD), Annual operating cost per pkm (\$USD/pkm)	[7, 44, 53, 55, 62–69]
	Cost of biodiversity-related services lost	Area of land consumed by transportation infrastructure	
	Vehicle productivity (Veh-km/day)	Vehicle lifetime (durability), Average PT fleet age (y)	
	Income devoted to PT (%)	Users' costs (\$USD/trip), Incomes from public passenger vehicle trips, PT tariffs, Annual average expenditure on transport, Per capita households' expenditure on transportation	
	Average user trip distance (km)	Passenger km per capita (pkm/inh)	
	Accessible PT stations/stops (%)	Accessible PT vehicles (%), Average household distance to nearest PT stop/station	
	PT subsidies (%/total PT cost)	Public Expenditure, Investment, and Subsidies Government	
	Fiscal expenditures on transport		
	Energy efficiency		
	Value of travel-time reductions		
	Cost of noise pollution		
	Cost of accidents		
	Cost of CO ₂ emissions		
	GDP of the transportation industry		
	Number of new-energy vehicles		
	Citizen participation		
	Fuel prices and taxes		
	passenger revenues/total		
Vehicle price per year per seat			
Passenger capacity			
Social	Facilities	Disability, Childhood, Elderly, Low income, Unemployment, Illiteracy, and Student	[1, 4, 7, 27, 34, 41, 50, 61, 62, 65, 70–77]
	Safety	Fatalities/injured people in formal PT (#fatalities/injured people per 1,000 pkm), Fatalities/injured people at paratransit (%), Ratio of annual recorded crime incidents/total pkm (%), Actions for Female safety in PT system (y/n), Gender violence in PT (% female aggression/total female)	
	Serviceability		
	Female drivers in PT fleet (%)		
	Health		
	Equity		
	Reliability		
	Congestion index		
	Security		
	Personal vehicle ownership		
	Waiting time		
	Prestige		

Table 3 Evaluating and weighting methods for SPTI

Elements	Analysis approach
Evaluation methods	A spider chart or Radar map, Integrated cost–benefit analysis, Indicator or modified methods, Assessment Indicator Model, A Bayesian (Belief) network, Questionnaire with Likert scale, Sensitivity analysis, Servqual method, Financial modelling, The Green Economy Model, The SAVi method, Interviews, Extension cloud theory, Multi-stakeholder approach, Extension cloud theory, Possibly scenario analysis, Multi-Criteria Analysis, Spatial modelling, A comparison, Chi-Square tests for gender, Composite Transport performance, Cost–benefit analysis (CBA), Customer satisfaction index, Emission modelling, Index of Mass Transport Provision, Social Transport Needs (ISTN), Lipta model, LMDI decomposition analysis, Multilevel modelling, Multiple linear regression
Weight methods	A pairwise comparison judgement, Analytic Hierarchy Process (AHP), Comparisons with case studies, Consistency test, Correlation, Cross-country comparison, ELECTRE III methods, Entropy weighting method, Equal weighting aggregation method, Equations or Questionnaire, Expert organisations, international standards or benchmarks, Linear weighting, Mean average, Normal distribution method (TNORM), Sensitivity analysis

Fig. 2 A methodology for selecting indicators for developing countries



and providing a group-based statistical summary of responses [88].

- Develop a set of criteria to prioritise indicators based on their relevance, measurability, reliability, sensitivity to local conditions, and potential for impact. Additionally, in line with recommendations from other researchers, criteria such as validity, data availability, transparency, independence, and standardisation were considered [51].
- The criteria for sustainable transportation were developed by professionals who considered the unique needs of emerging countries.
- The experts' committee was selected using purposive sampling based on their experience and knowledge. To

guarantee accurate representation and the required skills and perspectives, the group size required for the Delphi research is determined by the quality of the sample, not the number [88]. Expert committees may comprise government agencies, transportation professionals, NGOs, committee organisations, and citizens [27, 47, 50, 58, 64].

- Develop a questionnaire to prompt responses to choose a suitable list of indicators for developing countries from Table 2 using the Delphi method. Quantitative expert-judgment methods were used to assign weights to each criterion based on its relative importance in developing countries.

Identification of experts and the Delphi process

A questionnaire containing three sections was designed. The first section included personal information about participants; the second section asked participants to rate the criteria for selecting indicators on a scale of 1–100; and the last section asked participants to assign weights to indicators on a scale of 1–100. A distinct group of 20 participants was selected during the three stages. Table 4 presents the characteristics of the 60 respondents, as the questionnaire was administered three times to ensure accurate, unbiased results. 67% of the respondents were from the West Bank, Palestine; 48% had a Ph.D.; 45% worked at government ministries; and 44% had 20 to 29 years of experience. The Delphi process was carried out in three consecutive stages, using a unified model that includes all indicators to select the appropriate indicators and assign scores. After each stage, the results were evaluated without disclosure to ensure that the experts assessed without external influence.

It is worth noting that experts were used in this research in two phases, each with a different methodology and purpose. A broad group of professionals ($n=60$), as shown in Table 4, was selected using the Delphi method in the first stage to aid in screening indicators and to include a wide range of institutional, professional, and regional perspectives. This phase places greater emphasis on representativeness and inclusiveness rather than on years of experience in isolation. In the second phase, the AHP analysis, a smaller, more discriminating panel of experts ($n=12$) was contacted directly to provide input on the indicators' weighting and

prioritisation. In this part, only professionals who have worked in the field for at least 20 years were included, as expert judgment is vital to determining weights, and the decision-making process is sensitive. The two-step approach to expert selection strategy guaranteed not only diversity in indicator identification but also an in-depth expertise in indicator prioritisation.

Questionnaire-based findings

Data collection was conducted in two sequential stages using structured questionnaires, each serving a distinct purpose. The first questionnaire set was designed to support the selection of suitable indicators from the global SPTI and was implemented using a Delphi-based approach. It consisted of three sections: personal information of participants, weighting of criteria for indicator selection using a 1–100 scale, and preliminary weighting of indicators using the same scale. A distinct group of 20 participants was engaged in each stage, selected based on variations in academic qualifications, job nature, and involvement in public transportation decision-making. The sample reflected diversity in professional backgrounds and nationalities, with particular emphasis on experts from developing and unstable countries, including individuals with experience related to the West Bank context.

The experts' committee weighed the evaluation criteria and indicators based on their significance in the realities of developing countries. Table 5 presents the definitions of the criteria and the average weights assigned to each criterion

Table 4 Experts' (respondents) characteristics

(Total No.= 60)		N*	Percentages of total sample (%)
Region	Palestine	40	67
	Jordan	5	33
	Iraq	4	
	Yemen	6	
	Bangladesh	2	
	Egypt	2	
	Lebanon	1	
Educational	Ph.D.	29	48
	Master	23	38
	Bachelor	7	12
	Other	1	2
(Total No.= 60)		N*	Percentages of total sample (%)
Work	Government sector	27	45
	Academia	14	23
	Private sector	11	18
	Municipality	4	7
	NGOs and UN	4	7
Experience	(0–9)	10	17
	(10–19)	16	27
	(20–29)	27	44
	> 30	7	12

Table 5 Criteria weights

Criteria	Definition	Average weight	Rank
Relevant	Indicators should be appropriate for applicability in developing countries	83.3	4
Available data	Indicators should be trustworthy, practical, and straightforward to calculate or estimate	87.3	3
Measurability	Indicators should be quantified and allow for objective measurement using numerical data	87.8	2
Public Involvement	Indicators must promote public engagement and reflect the general opinion	75.22	5
Sensitivity to local conditions	Indicators should be sensitive enough to detect meaningful changes in the performance in local conditions	88.00	1

Table 6 Chosen indicators and their weights

Chosen indicators	Average weight	Declined indicators	Average weight
Safety	85.2	Cost of air pollution	69.45
Air pollution	82.76	Equity	69.35
Vehicle productivity (Veh-km/ day)	82.73	Income devoted to PT (%)	68.78
Waiting time	82.10	Fuel prices and taxes	68.38
Accessible PT stations/stops	81.38	Repairability	65.65
Congestion Index	81.18	Area of paved roads	64.16
Energy consumption (MJ/km)	81.166	Land-use resilience	63.85
Reliability	81.06	Number of new-energy vehicles	60.96
Vehicle price per year per seat	78.60	Personal vehicle ownership	60.63
Climate change	78.25	Fiscal expenses on transportation	59.81
Facilities	78.20	passenger revenues/total	57.81
PT network coverage	78.10	Noise pollution	56.81
Passenger capacity	77.71	Prestige	56.1
Energy efficiency	75.40	GDP of the transportation industry	53.25
Value of travel-time reductions	75.15	Cost of biodiversity-related services lost	52.06
Average user trip distance (km)	74.33	Cost of noise pollution	50.90
Serviceability	72.73	Citizen participation	49.86
Operation and maintenance costs	72.56	Female drivers in PT fleet (%)	38.21
Cost of accidents	72.56		
Security	72.40		
Health	70.83		

Table 7 Resulted indicators with weights higher than 70/100

Item	Indicator
Environment (3/7)	Air pollution, Active mobility, Energy consumption (MJ/km)
Economic (10/20)	Operation and maintenance costs, Vehicle productivity (Veh-km/ day), Average user trip distance (km), Accessible PT stations/stops (%), Energy efficiency, Value of travel-time reductions, Cost of accidents, PT network coverage (km/ urban area in km ²), Vehicle price per year per seat, Passenger capacity
Social (8/12)	Facilities, Safety, Security, Serviceability, Health, Reliability, Congestion index, Waiting time

based on experts’ judgment. The average weights range from 75 to 88, and the results are closely aligned, indicating the significance of all the criteria.

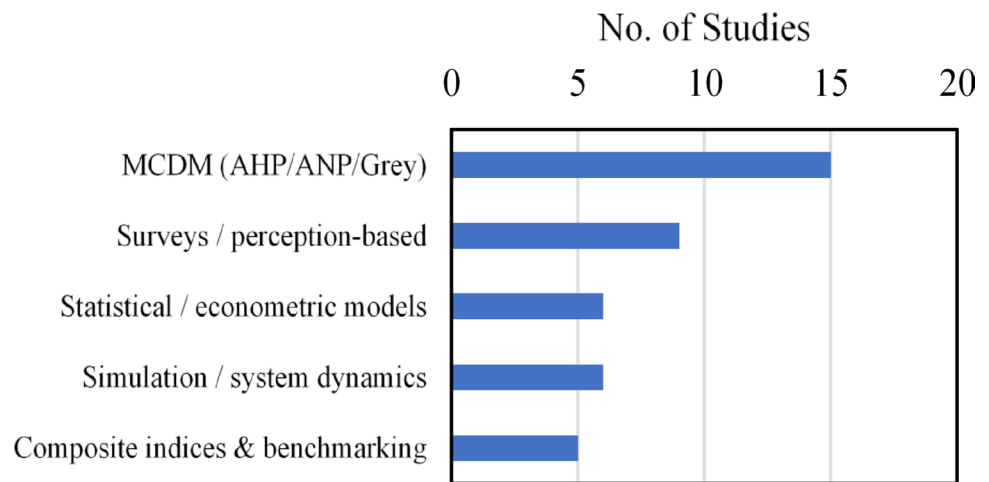
Table 6 summarises the results of weighted indicators. The average weight ranged from 38.21 to 85.20. The number of indicators that scored below 60 was 9/39, and those below 70 were 18/39. Experts’ judgment was used to decide which indicators would be deleted. After reviewing the results of the three steps, the experts decided to retain

only the indicators that scored 70 or higher. Table 7 lists the selected indicators related to sustainability.

Ranking of indicators in AHP analysis

Based on the systematic literature review, several Multi-Criteria Decision-Making (MCDM) techniques have been widely applied to evaluate sustainable public transport. As illustrated in Fig. 3, approaches such as AHP, ANP, and Grey-based models are the most prevalent techniques, reflecting a strong methodological focus on indicator weighting and prioritisation.

User perception and satisfaction surveys frequently follow these approaches, emphasising the dominant role of subjective evaluation in the existing literature. Accordingly, AHP was selected in this study for its ability to systematically incorporate expert opinions, support transparent pairwise comparisons, and prioritise indicators under conditions characterised by data limitations and institutional constraints.

Fig. 3 Most frequently used methodologies

Experts committee

A diverse group of experts was selected to evaluate the criteria and indicators, with each expert's assessment informed by their professional background and area of specialisation. This is ensured throughout the review process by allocating weights depending on importance, preferences, and requirements [89]. For example, the government focuses on policies and needs, the private sector on economic benefits, and academics on scientific foundations in the assessment.

Experts were chosen from different regions and from several institutions, including government, private, and NGO sectors, with at least 20 years of work experience across several fields. The main characteristics of the experts for effectively assessing the indicators were strong knowledge of sustainable transport, policy frameworks and regulations, awareness of relevant environmental and social impact assessment methods, experience in project implementation in Palestine and developing countries, and familiarity with the obstacles to sustainable development in those areas. A sample of 12 experts participated in the AHP questionnaire.

AHP questionnaire design

AHP-based questionnaire was employed to weight the selected criteria and indicators. This questionnaire consisted of three sections: evaluation of sustainability aspects using pairwise AHP comparisons, weighting of indicator-selection criteria, and weighting of pre-selected indicators, with total weights constrained to equal 100. Using purposive sampling, a committee of 12 experts was selected to conduct the AHP analysis, ensuring representation from government, private sector, and academia.

AHP analysis

The AHP is one of the most commonly utilised decision-making methods, mostly formed of strategies suitable for rating key management concerns [89]. Furthermore, AHP is a straightforward method that focuses on pairwise comparisons and is appropriate for evaluating both qualitative and quantitative designs [90]. The AHP involves decision-makers evaluating alternatives, criteria, and objectives using several scales, and priorities are created depending on the importance of the criterion for achieving the goal [89]. The AHP technique does not require a large number of participants, as the inclusion of "cold-called" respondents often leads to random answers and a high degree of inconsistency [90]. Moreover, when addressing a specific subject, AHP can be effectively applied with a limited group of experts, involving only those individuals capable of providing informed interpretations of the empirical investigation [89].

Determine the relative validity of the criteria

The expert's opinion is employed to determine the relative importance of each decision-making element. The required input scores are collected from experts either through interviews or online questionnaires. In this study, the paired-comparison technique is applied, an effective method for evaluating alternatives and assessing each factor and criterion. The classical AHP utilises a 1–9 scale for paired comparisons, as shown in Table 8, to translate evaluators' qualitative preferences into numerical values. In this case, the classical 1–9 AHP is used in this analysis, given that it is the original and most widely tested scale for transforming expert judgments into ratio-scale values [91]. In some research scenarios, the 1–5 or 3–7 scales are preferred due to their ease of use. However, the use of the complete nine-point ranking system enables greater discrimination

Table 8 Linguistic scale and the corresponding numeric value

Scale for comparison [91]			
Definition	AHP scale	Definition	AHP scale
Equal importance	1	Intermediate values	2
Somewhat more important	3		4
Much more important	5		6
Very much more important	7		8
Absolutely more important	9		

between alternatives and permits greater precision in expert judgments [86].

Developing an evaluation matrix and creating a decision hierarchy

Every multi-criterion decision-making scenario requires creating a decision hierarchy. This hierarchy organises indicators based on decision-making objectives. Complex circumstances often require a hierarchical structure that incorporates specific objectives and sub-criteria. Within the evaluation matrix, stakeholders assess each criterion, where the matrix consists of stakeholders, objectives, and criteria, each assigned a value between 0 and 1 (normalised weight matrix). Equation (1) represents the pairwise comparison process [53].

$$a_{ij} = \frac{W_i}{W_j}, \text{ where } i, j = 1, 2, 3 \dots n \tag{1}$$

where, n=number of criteria compared, w_i=weights for criterion i, and a_{ij}=weight ratio of criteria i and j. The matrix in Eq. (2) [53] displays the weight (w) ratio between n objects, including alternatives, objectives, criteria, and sub-criteria.

$$A = \begin{pmatrix} w_1/w_1 & w_1/w_2 \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 \dots & w_2/w_n \\ w_n/w_1 & w_n/w_2 \dots & w_n/w_n \end{pmatrix} \tag{2}$$

A normalised matrix is obtained by applying Eq. (3), in which each column (i) and row (j) in the matrix is divided by the most significant value in column (i).

$$a_{ij} = \frac{a_{ij}}{Max a_{ij}}, \forall i, j \tag{3}$$

In all consistent pairwise comparison cases, the assessment matrix A must achieve rank 1, with the maximum eigenvalue (λmax) equal to the number of criteria (h). This procedure is applied to each component of the hierarchy. The priority axes are then weighed according to their global priority, beginning at the highest level of the hierarchy. Finally,

Table 9 Criteria importance

Indicator	Weighted score (%)	Rank
Relevant (C1)	7.8	5
Available data (C2)	36.0	1
Measurability (C3)	25.0	2
Public involvement (C4)	16.6	3
Sensitivity to local conditions (C5)	14.6	4

the alternatives are ranked based on their relevance to the problem statement, as evaluated by the stakeholders [89].

Checking consistency

A consistency test is conducted to ensure the reliability of the decision-making process. This check is performed after calculating the eigenvalue and the maximum eigenvalue. When the pairwise comparison matrices (PCMs) are consistent, the priority matrix is derived from the principal eigenvalue (λmax). For matrix entries, A: a_{ij}. a_{jk}=a_{ik} indicates consistency. Equation (4) yields the Consistency Index (CI).

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

Results of the AHP questionnaire

Importance of criteria

Table 9 shows experts’ preferences for the criteria used to select the appropriate indicators. Available data (C2) is the most weighted criteria, at 36%, followed by Measurability (C3) with 25%, Public Involvement (C4), Sensitivity to local conditions (C5), and Relevant (C1). The difference in significance between the highest and lowest is (36.0% vs. 7.8%).

The available data (C2) criterion reflects “Contextuality.” Data availability is typically more restricted in developing countries, such as Palestine, than in developed countries. Given the expert’s understanding of the Palestinian data scene, it is recommended to assess data availability as part of the evaluation carefully. The Relevance (C4) criterion suggests that an indicator is appropriate for use in developing nations, given their socio-economic conditions, and that the urban context within these countries be thoroughly considered when devising the indicators. Since the experts determined that all previous indicators are relevant, this criterion is not significant for the current assessment.

Importance of sustainability aspects

Table 10 presents the importance of sustainability aspects related to experts' judgment. It is noticed that the social and economic aspects took the highest score and were approximately equal, while the environment got the lowest score of 22.

Table 10 Weights of sustainability aspects

Rank	Aspect	Score
1	Social	39.71
2	Economic	38.21
3	Environment	22.08

Indicators weights

Table 11 presents the outcomes of 12 experts evaluating the relative importance of indicators associated with the criteria (Wn). The final score for each indication was calculated by averaging respondents' replies, weighted by the criterion-specific weight scores from Eq. (5).

$$\text{Rank} = C1.W1 + C2.W1 + C3.W1 + C4.W1 + C5.W1 \quad (5)$$

Consistency results

Before determining the maximum eigenvalue λ_{max} in an AHP analysis, the consistency index (CI) was computed. Matrix acceptance requires a consistency ratio of less than 0.1. In this study, the majority of experts' judgments had a CR less than 0.1 (average CR of 0.09), and the average CI was 0.08, which is acceptable.

Comparison with SUTI

The research results are compared and integrated with other indices, such as SUTI, to create a context-specific indicator for metropolitan regions in developing nations. Table 12 presents the comparison results.

The results indicate similarities with SUTI initiatives, with the exception of investment in PT systems, as all the criteria covered in SUTI are incorporated in this study. The SUTI includes most of the selected indicators; however, it does not yet include waiting time, congestion index, and energy consumption, which are crucial in our analysis. Energy consumption surpasses transportation efficiency in terms of provider, investment, and greenhouse gas emissions. According to respondents, energy consumption measurements were more effective in measuring transportation sustainability, aligning with SDG 7, Affordable and Clean Energy, and SDG 12, Responsible Consumption and Production. As a result, this paper recommends that SUTI's methodology incorporate an energy consumption indicator.

Table 11 Final scores of indicators

Aspects	Indicators	Weighted C1	Weighted C2	Weighted C3	Weighted C4	Weighted C5	Avg	Rank
Environment	Air pollution	0.31	13.68	10.08	3.32	1.46	5.77	28.85
	Active mobility	0.23	14.40	10.80	3.15	1.17	5.95	29.76
	Energy consumption	0.78	9.00	9.00	3.32	2.92	5.00	25.02
Economic	Operation and maintenance costs	0.62	13.68	7.20	2.99	2.34	5.37	26.83
	Vehicle productivity (Veh-km/ day)	0.94	12.60	7.92	2.99	1.90	5.27	26.34
	Average user trip distance (km)	0.62	12.60	12.60	1.99	1.46	5.86	29.28
	Accessible PT stations/stops	1.40	7.92	7.56	3.32	2.77	4.60	22.98
	Energy efficiency	0.70	9.00	8.64	3.82	2.77	4.99	24.93
	Value of travel-time reductions	1.01	8.28	8.28	3.82	2.63	4.80	24.02
	Cost of accidents	1.17	9.00	8.64	3.15	2.48	4.89	24.45
	PT network coverage	0.55	10.08	9.00	3.65	2.63	5.18	25.91
	Vehicle price per year per seat	0.70	10.08	9.36	3.32	2.48	5.19	25.94
Social	Passenger capacity	0.47	10.08	9.00	3.65	2.77	5.19	25.97
	Facilities	1.33	8.28	7.92	3.32	2.63	4.69	23.47
	Safety	0.39	9.00	9.00	3.82	3.21	5.08	25.42
	Security	0.70	9.00	9.00	3.49	2.92	5.02	25.11
	Serviceability	1.40	7.92	7.92	3.32	2.63	4.64	23.19
	Health	0.94	9.00	9.00	3.32	2.63	4.98	24.88
	Reliability	0.62	14.40	9.00	2.49	1.75	5.65	28.27
	Congestion index	0.86	8.64	8.28	3.65	2.92	4.87	24.35
	Waiting time	1.09	8.64	7.92	3.49	2.77	4.78	23.91

Table 12 Indicator’s comparison with SUTI

No	SUTI indicators	Related indicators resulted from this study	Average weights	Rank
1	Extent to which transport plans cover PT, intermodal facilities and infrastructure for active modes	PT network coverage (km/ urban area in km ²)	5.18	5
2	Modal share of active and PT in commuting	Active mobility	5.95	1
3	Convenient access to PT service	Accessible PT stations/stops (%)	4.60	9
4	PT quality and reliability	Reliability, Facilities, Serviceability	4.99	7
5	Traffic fatalities per 100.000 inhabitants	Safety	5.08	6
6	Affordability – travel costs as share of income	Vehicle price per year per seat	5.19	4
7	Operational costs of the PT system	Operation and maintenance costs	5.37	3
8	Investment in PT systems	-	0	10
9	Air quality (pm10)	Health	4.98	8
10	Greenhouse gas emissions from transport	Air pollution	5.77	2

Analysis and discussion

In this study, indicators of SPT for developing countries were weighted by experts who ranked them based on their anticipated significance using the AHP. Because no studies have examined the sustainability of PT in Palestine, this study may pave the way for more in-depth future research on the topic. As per recent research work in developing-country settings, the results indicate that indicator weighting and prioritisation is heavily determined by local restraints, especially relative to information accessibility, measurability, and institutional environments, which also justifies the imperative of a context-specific method of assessment.

Criteria

The criteria were weighed up to determine which aspects applied to developing countries’ urban regions. Therefore, Available data and Measurability were the top-ranking indicators, reflecting the role of a local condition. Due to socioeconomic challenges, developing countries may place greater emphasis on certain qualities than developed countries do. Indicators should be easy to collect, measure, and predict, as well as affordable and timely. This is not startling in line with the developing country reviews where feasibility of data collection and measurement is considered as a core condition to implementing the sustainability indicators in the transport systems, and the emphasis on indicator prioritisation based on expert judgment is applied within the local socioeconomic and institutional conditions.

According to the findings, the second-highest scoring criterion was Public Involvement, emphasising the importance of social indicators in developing nations, as public engagement is required to establish a new system and change behaviours. Relevance and Sensitivity to local conditions have the lowest scores, implying that any measurable criteria with available data in developing nations could be considered as sustainable indicators.

Indicators

Although the environmental aspects of sustainability had the lowest score, environmental indicators ranked highest in Active mobility and Air pollution. This ranking can be compared to previous indicator-based models that had reported the same focus on the key measures of urban transport performance and sustainability, and it also validates previous evidence of active mobility, air and noise exposure, and service reliability to be routinely regarded as crucial indicators of urban sustainability and transport health quality. The 21 identified indicators are regarded as more realistic and may include all transportation-related sustainability challenges, similar to the 36 and 49 indicators identified by Ghafouri et al. [47, 64] respectively. The rank scores range from 29.76 to 22.98. The first indicator with the highest score was the environmental indicator, followed by the economic and social indicators. While the sustainability scores for the aspects were 39.71% for social, 38.21% for economic, and 22.08% for environmental, these findings emphasise that social indicators are central to promoting a sustainable system without causing environmental degradation.

Although the underlying aspects of transport sustainability are conceptually the same in both developed and developing settings, in practice, the applicability and relevance of sustainability measures are considered different. In developed countries, indicator selection is supported by advanced data systems, consistent institutional structures, and well-developed policy instruments, enabling more sophisticated and comprehensive indicators. By comparison, the context in developing countries is constrained by data availability, institutional capacity, and governance structures that directly affect indicator feasibility and evaluation effectiveness. This paper, based on this, shows that sustainable indicators of public transport used in developing countries place a strong emphasis on their measurability, topicality, and local sensitivity. Indicators such as active mobility, average user trip distance, air pollution, reliability, and safety become priorities because they reflect immediate issues that affect the

Table 13 The final rank of indicators

No	Indicator
1	Active mobility
2	Average user trip distance (km)
3	Air pollution
4	Reliability
5	Operation and maintenance costs
6	Vehicle productivity (Veh-km/ day)
7	Passenger capacity
8	Vehicle price per year per seat
9	PT network coverage (km/ urban area in km ²)
10	Safety
11	Security
12	Energy consumption (MJ/km)
13	Energy efficiency
14	Health
15	Cost of accidents
16	Congestion index
17	Value of travel-time reductions
18	Waiting time
19	Facilities
20	Serviceability
21	Accessible PT stations/stops (%)

system's performance and user experience. In this way, the distinction of the developed and developing contexts is not in the sustainability objectives, but in the choice of indicators, their weighting, and the feasibility of implementation, which are clearly discussed in the framework suggested.

Ranking of SPTI

Table 13 shows the score of weighted indicators, arranged by importance, as well as the sub-indicators summarised exclusively in the review papers.

The top-scoring indicators were Active mobility, Average user trip distance, Air pollution, and Reliability. The majority of these are bound to the social-environmental dimension; however, economic dimensions are also addressed. Since PT is a service, indicators are typically qualitative [92]. Active mobility is essential in transportation systems because it plays a crucial role in maintaining ecosystem services that are directly or indirectly linked to transportation activities, such as producing fewer emissions, reducing traffic congestion, promoting public health through physical activity, and supporting a more livable urban environment [94–97]. Meanwhile, previous studies based on [41, 68, 98] discussed the trip distance in the PT system, which is a crucial measure of the success of citizen mobility. Gorzelanczyk and Madajczak [34, 73, 75, 85] demonstrated how PT may significantly contribute to urban sustainability. For example, it can achieve greater energy efficiency in urban settings than private vehicle use. In addition, it reduces greenhouse gas emissions and environmental pollution,

lowers per-unit operating costs compared to private cars, and fosters social inclusion, thereby enhancing residents' overall social experience.

Air pollution indicators are routinely used to assess the environmental impact of transportation systems. The indicator is directly tied to sustainability because it assesses its environmental dimension. Fattah and Morshed [57, 58, 60] considered air and noise exposure to be the most critical measures of health quality. Moreover, the results of the study indicate that passenger satisfaction with the Reliability of the transportation system is valued more highly than satisfaction with other aspects. As a result, the views of transport users in the cities of developing countries should not be overlooked.

The economic aspect of transportation is another quantitative indicator that is often used to assess transportation sustainability. Operation and maintenance costs, Productivity, and Affordability might help in establishing a sustainable system. On the other hand, sustainable transportation systems should meet the most significant feasible levels of safety and security. Global efforts often employ safety indicators. According to Thondoo et al. [93], Safety is the primary issue from both economic and societal viewpoints, with a high relevance score. Several elements influence transportation safety, including human, vehicle, road, and environmental considerations [94]. Safety, which includes being safe on the road and in other modes of transportation, avoiding accidents, and being protected from crime, is also an effective indicator of improving the quality of life [93].

Other findings revealed that both environmental indicators scored low on Land-use Resilience and Repairability. The environmental impact of transportation does not appear to be a concern for the responders. This is concerning because the environmental issue should be prioritised in terms of urban transportation sustainability. According to earlier research, this could be because the built environment makes up the majority of land use in developing nations [3]; the two indicators are also less common among international initiatives (for only three out of 39 papers); or both indicators are not directly related to people's interests, even though they are classified as environmental dimensions, and their effects on human health are not as direct as those of energy or air and noise pollution [51].

Comparison with SUTI results

The indicators that got the highest weights relative to SUTIs indicators were Active mobility (2 in SUTI rank), Air pollution (10), Operation and maintenance costs (7), Vehicle price per year per seat (6), and PT network coverage (1). At the same time, the final score was Accessible PT stations/stops (3), Health (9), and Reliability, Facilities, and Serviceability (4). The dismissed indicators were related to Investment in PT systems. The order of the resulting indicators in the study differed from the SUTI order. Still, all the SUTI indicators were reflected in the extracted indicators, which indicates that the results are acceptable. Nevertheless, the comparison proves that the extracted indicators are the reflections of the SUTI guide, and also the context-based additions are being accentuated by the experts, which were found to be of importance in this analysis, like energy consumption, waiting period, and congestion index. It is also noted that SUTI indicators focus more on social than on economic aspects, and ultimately on environmental aspects. This matches the study results.

Conclusions

The goal of this study was to assess indicators for the SPT sector in developing countries, using AHP for comparative analysis. Then compare the results against global standards, such as SUTI, to ensure the application of sustainability principles. Because developing countries often lack the resources to implement a comprehensive set of PT sustainability measures [59], the study proposes five criteria to guide the selection of indicators that are both context-appropriate and operationally feasible. These criteria help prioritise indicators that address strategic needs while accommodating local constraints. From a policy point of view, these criteria offer very useful guidance to policymakers on how to

concentrate on those indicators which are feasible to monitor and implement.

The findings show that air pollution, reliability, passenger capacity, productivity, affordability, and coverage are among the most critical for measuring SPT performance in developing-country context. Although the environmental dimension received the lowest total score, specific environmental indicators, notably air pollution, were among the highest. This reflects the realities of developing countries, where users emphasise immediate, visible environmental concerns that directly affect daily life, rather than broader or indirect environmental factors. Therefore, transport policies in such environments should focus on interventions that improve service reliability, operational efficiency, and emissions reduction, as these are key determinants of user satisfaction. This policy relevance is especially pertinent in developing countries, where the lack of a coherent policy framework makes the effective implementation of sustainable public transport strategies difficult. However, certain categories may be limited in practice because not all sustainability elements can be measured or implemented equally across contexts.

The extracted indicators were compared with the SUTI global guidelines to ensure the comprehensiveness of the outputs. The comparison confirmed that all indicators are covered in the SUTI guide, while experts emphasised additional indicators, such as energy consumption, for their environmental and economic significance. These findings reinforce the need for a refined, context-sensitive indicator set that supports integrated and practical transport strategies in developing countries. In this reverence, this proposed framework is a useful tool that could aid planners and authorities in prioritizing investments and enhancing operational planning, as well as aligning national transport policies with sustainability goals in resource-constrained environments.

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Data availability Data will be available on request.

Declarations

Conflict of interest The authors confirm that neither the manuscript nor any parts of its content are currently under consideration or pub-

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