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ASSESSING TRANSPORT SUSTAINABILITY IN IRAQ USING SUSTAINABLE DEVELOPMENT INDICATORS A COMPOSITE TIME-SERIES ANALYSIS OF ECONOMIC-OPERATIONAL SOCIAL AND ENVIRONMENTAL DIMENSIONS (2015–2023)

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SUMMARY

The issue of transport sustainability evaluation is difficult in developing countries since transport growth does not necessarily reflect the improved state of environmental conditions, road safety, and efficiency. In Iraq, the data on transport sector performance is provided separately for each sector and thus cannot be evaluated collectively. The present paper proposes the development of the Iraq Sustainable Transport Index (I-STI), the national composite index reflecting transport sustainability for 2015–2023. The suggested framework is based on three dimensions, namely economic-operational performance, social safety, and environmental pressure. Five indicators were selected for evaluation, namely rail passenger-kilometres, rail freight tonne-kilometres, road mortality rate, road injury rate, and transport CO₂ emissions per capita. The indicators were scaled using min-max scaling, and the dimension weights were calculated as equal with entropy-based weighting used for robustness assessment. It was found that the sustainability of transport in Iraq declined significantly as the I-STI decreased from 0.556 in 2015 to 0.201 in 2023, which is 63.8%. The trend was found significant by means of Mann-Kendall analysis ($\tau = -0.611$, $p = 0.0247$), with a Sen slope of -0.0555 index points per year. The environmental dimension demonstrated the largest deterioration due to a 45.6% increase in transport CO₂ emissions with a significant declining trend ($\tau = -0.722$, $p = 0.0059$). The improvement in 2020 can be explained by the effects of the pandemic and not by any structural changes. Exclusion of 2020 strengthened the declining trend ($\tau = -0.857$, $p = 0.0017$). Robustness assessment revealed identical results between weighting approaches ($p = 1.000$; mean absolute difference = 0.0165). The proposed I-STI provides an engineering decision-support framework for sustainable transport planning, emphasizing emission reduction, road safety, public transport improvement, and railway modal diversification.

Key words: *sustainable transport, Iraq, composite index, rail transport, road safety, transport CO₂ emissions, mann-kendall, sustainable development goals.*

INTRODUCTION

Transportation is important for the economic development of any economy since it is the process through which people and goods are moved from one place to another. However, increased transportation does not automatically mean sustainable transport since more transport leads to greater energy use, pollution, accidents, and other negative factors. Hence, the assessment of the sustainability of the transport system should consider issues of efficiency, safety, and environmental impact and not just the growth of the transport system [1] [8].

The composite sustainability indicators give a good means of evaluating the transport systems that involve many variables into one measure of sustainability. But their effectiveness will depend on choosing proper indicators, normalization, weighting, and validation techniques. Past literature points to the importance of transparency of the index development process and robustness of the indices for sustainability assessment [6] [11].

Modern research points out that sustainable transport involves balancing the development of infrastructure with environmental considerations, accessibility, safety, and efficiency of mobility [1] [3] [15]. The goals of sustainable development confirm this approach because they include such goals as road safety, resilient infrastructure, sustainable mobility, and climate action (SDG 3, SDG 9, SDG 11, SDG 13). Passenger kilometres and tonne-kilometres should be considered separately due to the different functions of transport.

Developing countries are confronted by the challenge of fast-growing demand for transport services, dependency on fossil fuels, poor public transportation systems, and infrastructural upgrade needs. Sustainable transport transformation necessitates reductions in emissions, diversifications in modes, energy efficiency, and increased accessibility rather than infrastructure growth alone [7] [8].

Despite the existence of several approaches for measuring the sustainability of transport systems, most of the approaches concentrate in urban settings with the availability of sufficient data. Most developing countries lack comprehensive national-level sustainable transport assessment measures. In the case of Iraq, transport indicators concerning roads, rail, safety, and emissions are assessed independently, leading to inadequate assessment.

To bridge this gap, this paper presents the development of a new composite framework known as the Iraq Sustainable Transport Index (I-STI). The index is engineering-based and considers economic-operational performance, social safety, and environmental sustainability.

The main contributions of this study are summarized as follows:

1. A national-scale index of Iraq's sustainable transportation (I-STI) is generated through the synthesis of railway efficiency measures, road safety criteria, and transport sector CO₂ emissions in one sustainability appraisal system.
2. An approach to long-term sustainability change assessment is suggested based on min-max normalization, dimension weighting, the Mann–Kendall test, and Sen's slope estimation.
3. An alternative weight determination algorithm based on entropy is employed to assess the robustness of the proposed sustainability index.
4. The paper provides engineering implications for the planning of transport infrastructure development, differentiating transport development from sustainability enhancement.

The rest of this paper is structured as follows. Section 2 reviews the existing literature on sustainable transport assessment and composite sustainability indices. Section 3 illustrates transport system characteristics, research problem, and research objective. Section 4 details the I-STI framework, the choice of indicators, data collection, normalization procedure, weighting techniques, and statistical methodology. Results, which include trends of selected indicators, evaluation of index, robustness

testing, and sustainability assessment, are discussed in Section 5. Concluding remarks are made in Section 6.

LITERATURE REVIEW

Sustainable transport evaluation has become quite relevant to balance the development of mobility with economic efficiency, social safety, and environmental protection. Traditional transport assessment was primarily concerned with infrastructure development and performance, but current research stresses the importance of using an integrated approach with respect to various sustainability aspects via composite indicators [1] [15].

Studies about transportation infrastructure reveal that connectivity and accessibility are important factors in economic development; yet, infrastructure development does not guarantee sustainability, as higher transportation needs can result in more energy usage and pollution [1]. It is vital to be able to distinguish between transport development and sustainable transport performance.

Composite indices for sustainability have also been extensively used in combining several transport indicators regarding efficiency, safety, and environmental aspects. Nevertheless, the success of such composite indices is based on how well indicators are selected, normalized, weighted, and aggregated. Previous works stress the need for conducting a sensitivity analysis to make sure that the results are robust across varying assumptions [6][11]. Therefore, considering these results, the current research uses equal and entropy weighting in the validation of the proposed Iraq Sustainable Transport Index (I-STI).

Past approaches towards transport sustainability assessment have assessed transport sustainability at urban and regional levels through indicators such as accessibility, emissions, infrastructure performance, and safety [15]. However, many existing indices were developed for cities or regions with established monitoring systems, and sustainability assessments at the national level are difficult to obtain in developing nations with disjointed transport data [2] [16] [17]. This situation forms the motivation behind the development of the national framework in this work.

The connection of transport sustainability indicators to Sustainable Development Goals (SDGs) has enhanced the transport sustainability evaluation procedure. Transport sustainability indicators based on SDGs include road safety, infrastructure resilience, accessibility, and climate change [14]. Specifically, passenger kilometres and tonne kilometres reflect different functions of transport and should be evaluated separately as the indicator selection approach used in this research [14].

Environmental impacts pose major obstacles to sustainable transport planning. Studies have indicated that transport emissions are significantly affected by travel demand, urban development structure, and infrastructure characteristics [12][13]. Sustainable mobility transition involves reduced emissions, better energy efficiency, and modal shift rather than infrastructure expansion alone [7] [8]. Hence, transport CO₂ emissions have been included as one of the important environmental indicators in this framework.

The pandemic experience has confirmed the need for taking into account the contextual factors in the assessment of the transport sustainability. It is possible to achieve some positive results on the indicators of emissions and safety through temporary mobility reduction, which may not imply the improvement of the sustainability level [4]. For this reason, the influence of the 2020 disruption is assessed in this study in addition to the trend analysis.

The developing countries are faced with the problem of rising demand for mobility, energy dependence, lack of developed public transport, and the need for modernization of the infrastructure. The previous research stresses the necessity of the integration of infrastructure development with the issues of environmental protection and social accessibility [8] [17]. Meanwhile, the available studies dedicated to the issues of Iraq and comparable countries do not offer a complete national sustainability index that accounts for operational, safety, and environmental aspects [18] [20].

Nevertheless, there are still some deficiencies in the field of the transport sustainability assessment. First, most indices take into account only the urban transport. Second, there are few studies that assess the national transport sustainability [9]. In addition to that, the current indices do not consider all three aspects of transport sustainability in a composite way. Moreover, there are few studies focused on sustainability trends.

For the solution of the aforementioned problems, this study offers the Iraq Sustainable Transport Index (I-STI) that takes into account railway performance, road safety indicators, and CO₂ emissions of the transport in the period of 2015–2023. The proposed methodology is able to distinguish transport development from sustainability improvement through composite indexing, trend analysis, and robustness analysis.

TRANSPORT SYSTEM IN IRAQ

As indicated by the statistical bulletin of transport and communication of Iraq, the length of external roads in kilometers covered with concrete or asphalt amounted to 49,530 km in 2023, increasing to 59,745 km in 2024. Nonetheless, variations in the scope of coverage in some years historically have made road length a better contextual indicator of infrastructure development than an accurate measurement of transport sustainability. This implies that there is a necessity to distinguish between the size of infrastructure and its utilization, effectiveness, and consequences (CSO, 2024).

However, there is a completely different situation in the rail transport sector. The passenger-kilometers rose from 139 million in 2015 to 178 million in 2018 and plummeted to 31 million in 2020. Nevertheless, there was a partial recovery that saw the passenger kilometers rise to 101 million in 2023. On the other hand, freight transport activity took a completely different path by rising from 71 million tonne-kilometers in 2015 to 559 million in 2020 and then decreasing to 272 million tonne kilometers in 2023. This makes a good case for having them separated as distinct measures (CSO, 2024).

Statistics of public transport usage collected by the General Company for Passenger Transport and Delegations also point to a marked disruption of passenger mobility. While there were 19.013 million passengers in 2015 and 19.220 million passengers in 2019, the number decreased to 4.825 million in 2020 and further to 3.504 million in 2021; afterwards, it recovered partially up to about 8 million passengers in 2023. Thus, it can be seen that the pandemic created an extraordinary interruption of transport activities. As a result, the pandemic-related factors should be separated from structural improvement when evaluating a composite sustainability index.

Another key indicator is related to road safety. In 2015, Iraq had 2,514 deaths and 9,429 injured people in road traffic. In 2023, the number rose to 3,019 deaths and 12,314 injuries. Adjusted for population, the mortality rate remained at about 6.7 per 100,000 population. At the same time, the injury rate rose from 25.10 to 27.32 per 100,000 population. It means that while other transport sector factors improved significantly, transport safety has not been improving as fast (CSO, 2024).

Table 1. Selected iraqi transport indicators providing context for the study

Indicator	Value	Year	Source
Paved external road length	49,530 km	2023	CSO (2024)
Paved external road length	59,745 km	2024	CSO (2024)
Railway passenger-kilometres	101 million	2023	CSO (2024)
Railway freight tonne-kilometres	272 million	2023	CSO (2024)
Road deaths	3,019	2023	CSO (2024)
Road injuries	12,314	2023	CSO (2024)
Transport CO ₂ emissions per capita	930.5 kg CO ₂ /person	2023	Climate Watch/OWID

Source: Table 1 data from the Iraqi Central Statistical Organization (Central Statistical Organization [CSO], 2024) for road length, railway activity, and road deaths and injuries, and Climate Watch (2026) data processed and published through this World in Data (2026) for per-capita CO₂ emissions from the transport sector.

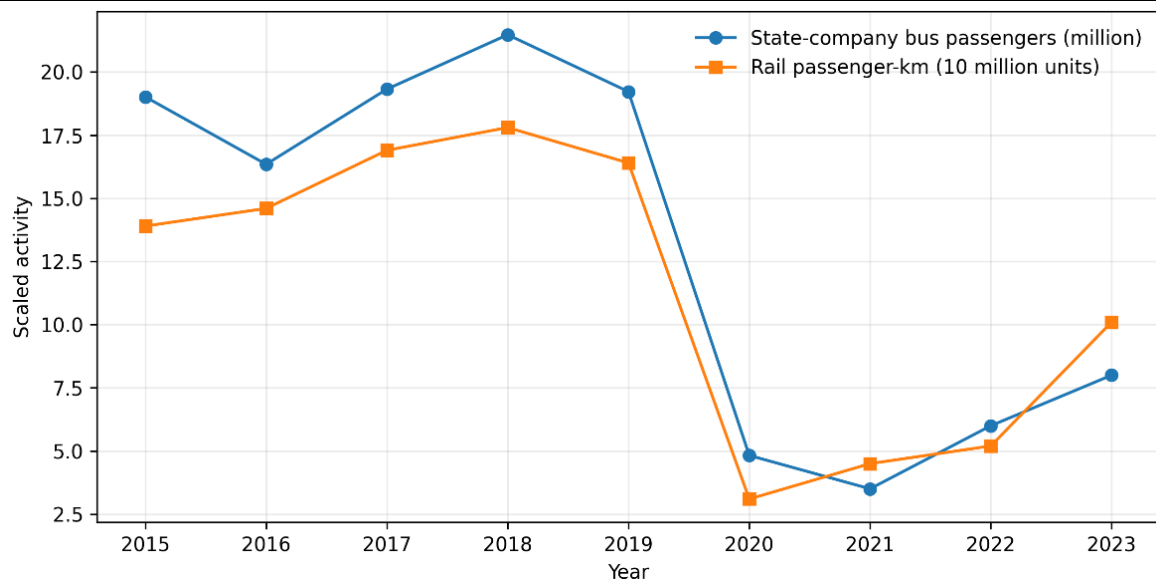


Figure 1. Shock to passenger transport activity and partial recovery in Iraq, 2015–2023

Source: compilation based on CSO (2024) data.

Environmentally speaking, per capita transport CO₂ emissions increased from 639.2 kg per capita in 2015 to 930.5 kg per capita in 2023, based on Climate Watch data available through this World in Data website. Besides, the percentage of transport in national emissions was evaluated. However, due to a very high correlation ($r = 0.936$) between this indicator and per capita transport emissions throughout the period of analysis, this indicator was regarded as informational redundant and excluded from further analysis (Figure 1).

Research Problem, Questions, and Hypotheses

The central research problem is the absence of an integrated national time-series measure capable of distinguishing the expansion of Iraq's transport system from actual improvements in its sustainability. Growth in transport activity or infrastructure may occur alongside increasing emissions and road casualties, while exceptional disruptions may temporarily improve selected indicators simply because transport demand contracts. A meaningful sustainability assessment therefore requires a composite measure that captures the individual dimensions as well as their combined performance and is subjected to statistical trend and sensitivity testing.

The main research question is:

Did the performance of Iraq's transport sector move toward greater economic-operational, social, and environmental sustainability during 2015–2023, or did the expansion of selected transport activities coincide with an overall deterioration in sustainability performance?

The study also addresses the following questions:

1. How did the economic-operational, social, and environmental dimensions change during the study period?
2. What was the temporal direction of the I-STI, and was this trend statistically significant?
3. To what extent did the 2020 pandemic affect the trajectory of the index?
4. Does the overall conclusion remain stable when alternative weighting procedures are applied?

Three hypotheses are examined:

1. The trajectories of the three sustainability dimensions are not necessarily identical.
2. The overall sustainability trend during the study period is not necessarily positive, even when selected transport activities expand.
3. If the composite index is robust, the ranking of years and the general temporal direction should remain stable under an alternative weighting scheme.

This section has been restructured rather than translated literally, while retaining the original research logic and hypotheses.

DATA AND METHODOLOGY

Study Period and Data Sources

The study period was defined as 2015–2023 after examining the temporal coverage and consistency of the available datasets. The analysis begins in 2015 because the official injury series reports a markedly different value for 2014—2,021 injuries compared with more than 9,000 during 2015–2017. This discontinuity may reflect differences in reporting or statistical coverage and therefore should not be resolved through assumptions or artificial adjustment. The analysis ends in 2023 because the Climate Watch/this World in Data transport-emissions series used in this study terminates in that year. Accordingly, a balanced dataset comprising nine annual observations was constructed without interpolating or estimating missing values.

Data on railway activity, road fatalities and injuries, and public transport were obtained from Chapter 6, *Transport and Communications Statistics*, in the 2024 Iraqi Annual Statistical Abstract. Mortality and injury rates per 100,000 population were calculated using the population series available through this World in Data. Per-capita transport CO₂ emissions were obtained from Climate Watch (2026), as processed by this World in Data. The Climate Watch energy-sector dataset draws on international sources, including the OECD and International Energy Agency (IEA) [5].

Conceptual Framework and Indicator Selection

The Iraq Sustainable Transport Index (I-STI) was designed around three complementary dimensions: economic-operational performance, social safety, and environmental pressure.

Table 2. Final set of indicators used in the I-STI

Dimension	Indicator	Unit	Direction	Source	SDG
Economic-operational	Rail passenger-km	million passenger-km	Positive	CSO (2024)	9
Economic-operational	Rail freight tonne-km	million tonne-km	Positive	CSO (2024)	9
Social	Road mortality rate	deaths/100,000 population	Negative	CSO + population	3
Social	Road injury rate	injuries/100,000 population	Negative	CSO + population	3
Environmental	Transport CO ₂ per capita	kg/person	Negative	Climate Watch/OWID	13

Source: Table 2 using CSO (2024) data for railway activity and road deaths and injuries; population data published through this World in Data (2026) for calculating mortality and injury rates per 100,000 inhabitants; and Climate Watch (2026) data processed and published through this World in Data (2026) for per-capita transport CO₂ emissions. The classification of indicators into economic-operational, social, and environmental dimensions, together with their expected directions, follows the conceptual

approaches, while the relevant indicators were aligned with the United Nations Sustainable Development Goals framework (United Nations Statistics Division, 2025).

The economic-operational dimension represents the role of railways in passenger and freight transport. Railway activity was selected because rail transport contributes to modal diversification and can accommodate relatively large passenger and freight volumes. The social dimension captures transport safety through road mortality and injury rates. The environmental dimension represents climate pressure through per-capita CO₂ emissions from transport.

Road-network length and total transport activity were deliberately excluded as automatically positive indicators. An increase in either variable may simply indicate greater infrastructure supply or higher demand without necessarily reflecting improvements in safety, efficiency, or environmental performance.

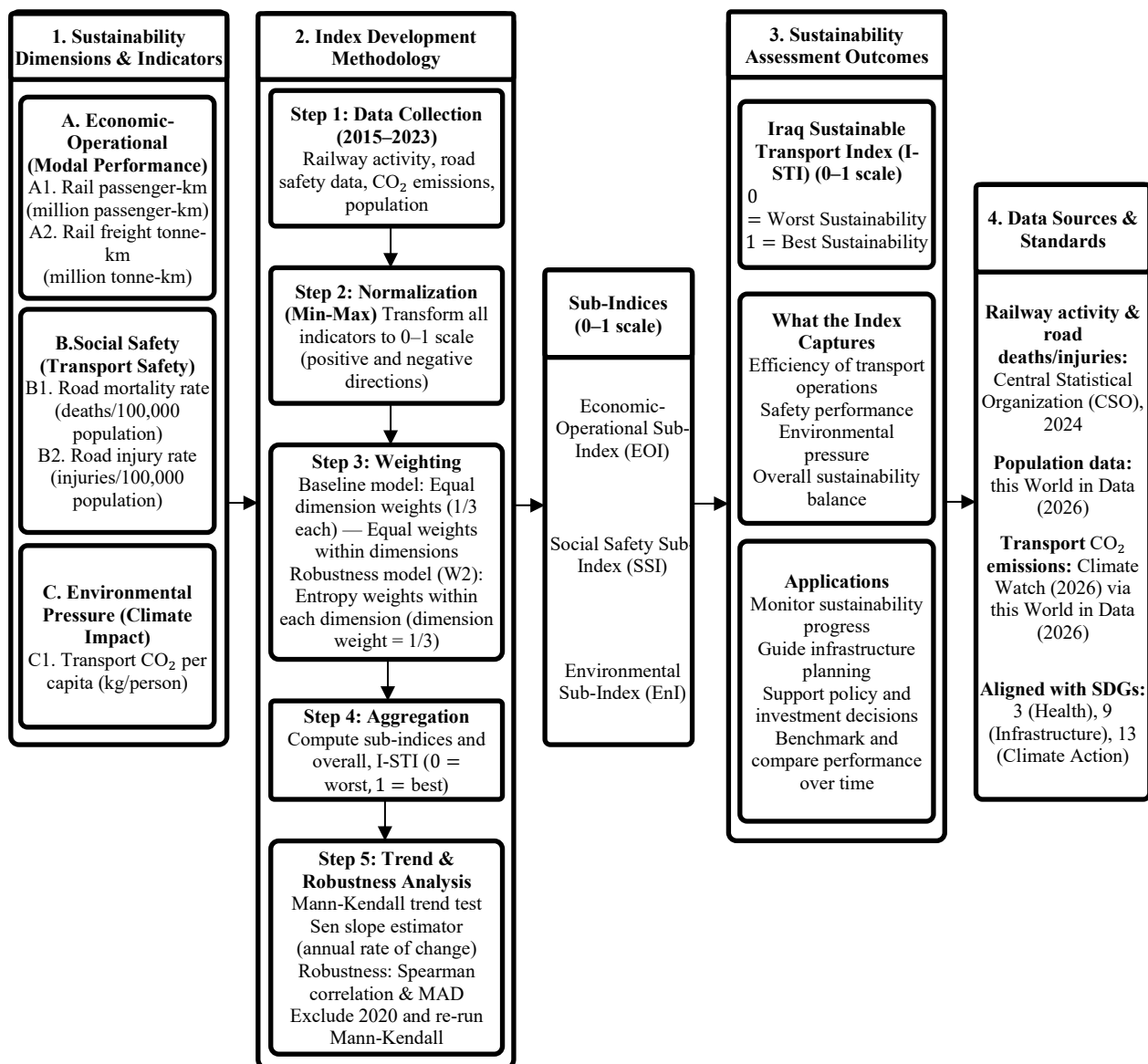


Figure 2. Conceptual framework for the development of the Iraq Sustainable Transport Index (I-STI)

The conceptual framework that was used to develop the Iraq Sustainable Transport Index (I-STI) is depicted in figure 2. The framework incorporates the integration of three dimensions of sustainability, which include economic-operational performance, social safety, and environmental pressure. The chosen indicators undergo the process of normalization, weighting, and aggregation to produce the sub-indices for each of the dimensions and the composite sustainability score.

Normalization, Weighting, and Aggregation

All indicators were transformed to a common 0–1 scale using Min–Max normalization. For indicators with a positive contribution to sustainability, the normalized value was calculated as:

For indicators with a negative contribution to sustainability, the reverse transformation was applied:

Following normalization, a higher value represents better sustainability performance.

The baseline model assigns equal weights to the three dimensions, with one-third (1/3) allocated to each. When a dimension contains two indicators, its weight is divided equally between them. This approach prevents a dimension from receiving greater influence merely because it contains more variables (Greco et al., 2019; OECD, 2008).

The three sub-indices were therefore calculated as follows:

The overall Iraq Sustainable Transport Index was then obtained from:

Thus, the resulting index gives equal importance to economic-operational performance, social safety, and environmental performance rather than allowing the number of indicators within a dimension to determine its overall influence.

Normalization, Weighting, and Aggregation

All selected indicators were transformed into a common 0–1 scale using Min–Max normalization. For indicators with a positive contribution to sustainability, the normalized value was calculated using equation (1):

$$Z_{i,t} = \frac{x_{i,t} - x_i^{\min}}{x_i^{\max} - x_i^{\min}} \quad (1)$$

For indicators with a negative contribution to sustainability, the reverse normalization procedure given in equation (2) was applied:

$$Z_{i,t} = \frac{x_i^{\max} - x_{i,t}}{x_i^{\max} - x_i^{\min}} \quad (2)$$

Where $Z_{i,t}$ represents the normalized value of indicator i in year t , while $x_i^{\max}$ and $x_i^{\min}$ represent the maximum and minimum observed values of the corresponding indicator. After applying equations (1) and (2), all indicators were converted into comparable values, where higher values indicate better sustainability performance.

The three sustainability dimensions were assigned equal weights, as expressed in equation (3):

$$W_E = W_S = W_{Env} = \frac{1}{3} \quad (3)$$

The economic-operational sub-index was calculated using the normalized railway indicators according to equation (4):

$$ETSI_t = \frac{Z_{RP,t} + Z_{RF,t}}{2} \quad (4)$$

Similarly, the social safety sub-index was obtained from road mortality and injury indicators using equation (5):

$$SSTI_t = \frac{Z_{MR,t} + Z_{IR,t}}{2} \quad (5)$$

Since the environmental dimension consists of a single indicator, the environmental sub-index was directly calculated using equation (6):

$$EnvTSI_t = Z_{CO2,t} \quad (6)$$

Finally, the overall Iraq Sustainable Transport Index (I-STI) was calculated by combining the three dimension indices according to equation (7):

$$I - STI_t = \frac{1}{3} (ETSI_t + SSTI_t + EnvTSI_t) \quad (7)$$

The aggregation procedure in equation (7) ensures equal representation of economic-operational performance, social safety, and environmental sustainability, preventing dimensions with more indicators from receiving greater influence.

Trend and Robustness Analysis

The temporal trend of the I-STI was evaluated using the Mann–Kendall test, which is suitable for short time-series analysis without requiring normal distribution assumptions. The Mann–Kendall statistic was calculated using equation (8):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n sgn(X_j - X_k) \quad (8)$$

Where X_j and X_k represent observations at different time periods. The annual magnitude of the observed trend was estimated using Sen's slope estimator given in equation (9):

$$Q_i = \frac{X_j - X_k}{j - k} \quad (9)$$

The median value of all possible slope estimates obtained from equation (9) represents the overall rate of change.

For robustness evaluation, the baseline index and entropy-weighted index were compared using the mean absolute difference calculated using equation (10):

$$MAD = \frac{1}{n} \sum_{t=1}^n |I - STI_{W1,t} - I - STI_{W2,t}| \quad (10)$$

A high Spearman correlation and low MAD value from equation (10) indicate that the sustainability assessment remains stable under alternative weighting assumptions. Additionally, the influence of the exceptional 2020 pandemic year was examined by repeating the Mann–Kendall analysis after excluding that observation.

Trend and Robustness Analysis

Temporal changes were evaluated using the non-parametric Mann–Kendall trend test, which is appropriate for relatively short time series without requiring an assumption of normality. The Sen slope estimator was also calculated to quantify the median annual rate of change (Mann, 1945; Sen, 1968).

To assess robustness, the index was recalculated under a second weighting scenario, designated W2, using Entropy-derived weights for the two dimensions containing two indicators while maintaining the overall weight of each dimension at 1/3. The baseline and alternative series were then compared using Spearman's rank correlation coefficient and the mean absolute difference.

Finally, to determine whether the unusually high 2020 value was driving the observed trend, the Mann–Kendall analysis for I-STI was repeated after excluding 2020. Importantly, the series was not re-normalized for this additional analysis, thereby allowing the effect of the pandemic year to be evaluated without altering the original normalization framework.

Entropy Weights Used in the Sensitivity Analysis

Table 3. Entropy weights used in the sensitivity analysis

Indicator	Entropy weight within dimension
Rail passenger-km	0.459
Rail freight tonne-km	0.541
Road mortality rate	0.663
Road injury rate	0.337
Environmental dimension	1.000

Table 3 shows the entropy procedure therefore assigns slightly greater internal weight to railway freight activity within the economic-operational dimension and substantially greater weight to mortality than injuries within the social dimension, while the environmental dimension contains only one indicator and consequently receives a weight of 1.000 within its own dimension.

RESULTS

Raw Data and Safety Rates

Table 4. Final dataset used to construct the I-STI, 2015–2023

Year	Rail passenger-km (million)	Rail freight tonne-km (million)	Deaths/100,000	Injuries/100,000	Transport CO ₂ kg/person
2015	139	71	6.69	25.10	639.2
2016	146	19	6.58	23.44	637.4
2017	169	55	6.66	23.87	704.9
2018	178	199	6.87	25.93	803.9
2019	164	190	6.40	28.28	835.8
2020	31	559	5.11	19.90	680.7
2021	45	335	6.57	26.07	826.1
2022	52	287	6.85	28.77	929.0
2023	101	272	6.70	27.32	930.5

Source: Table 4 shows CSO (2024) data for railway passenger-kilometres, railway freight tonne-kilometres, and road deaths and injuries; population data published through this World in Data (2026) for calculating mortality and injury rates per 100,000 inhabitants; and Climate Watch (2026) data processed and published through this World in Data (2026) for per-capita transport CO₂ emissions. Road mortality and injury rates were calculated by study.

The raw data demonstrate substantial differences among the individual components of the transport system. Railway passenger activity decreased by 27.3% between 2015 and 2023, whereas railway freight activity increased by 283.1%. The road mortality rate was broadly unchanged between the beginning and end of the study period, moving from 6.69 to 6.70 deaths per 100,000 population. In contrast, the injury rate increased by 8.8% (Figure 3).

The most pronounced deterioration occurred in the environmental dimension. Per-capita transport CO₂ emissions increased by 45.6%, rising from 639.2 kg/person in 2015 to 930.5 kg/person in 2023.

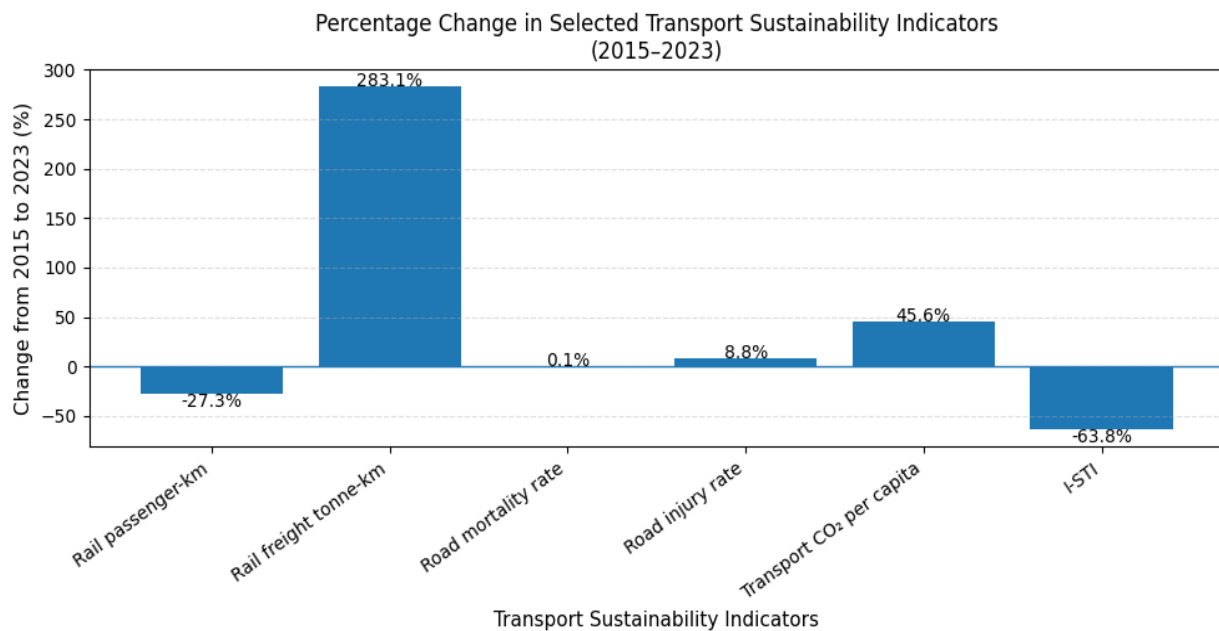


Figure 3. Percentage change in selected indicators between 2015 and 2023.

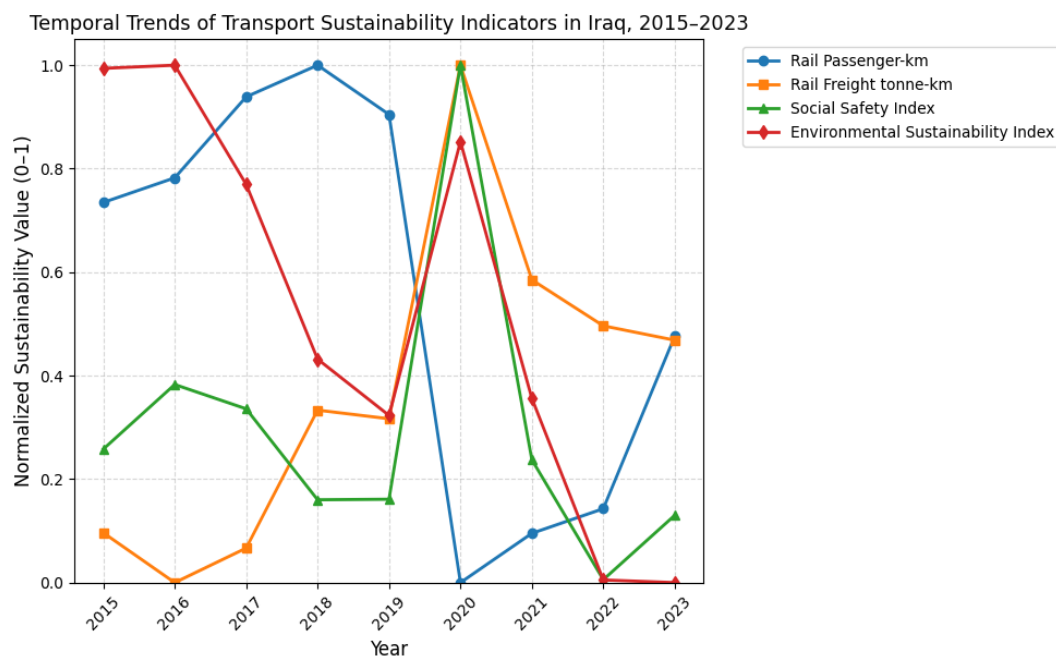


Figure 4. Temporal trends of transport sustainability indicators in Iraq, 2015–2023

Figure 4 shows the year-to-year variations of the chosen transport sustainability indicators during the period of the research. It is clear from the results that the trends differ in the transport dimensions, with significant improvement in the activity of railway freight transport along with a decline in the activity of passenger rail transport. On the other hand, environmental performance continued to worsen owing to higher CO₂ emissions from transport.

Sub-Indices and the I-STI

The resulting sub-indices and overall, I-STI values for the baseline and sensitivity models are presented table 5 below.

Table 5. Sub-indices and I-STI under the baseline and sensitivity models

Year	ETSI	SSTI	EnvTSI	I-STI W1	I-STI W2
2015	0.415	0.257	0.994	0.556	0.530
2016	0.391	0.384	1.000	0.592	0.557
2017	0.503	0.336	0.770	0.536	0.501
2018	0.667	0.160	0.432	0.420	0.393
2019	0.611	0.161	0.323	0.365	0.369
2020	0.500	1.000	0.852	0.784	0.798
2021	0.340	0.239	0.356	0.312	0.311
2022	0.320	0.005	0.005	0.110	0.115
2023	0.472	0.131	0.000	0.201	0.198

Source: These calculations based on the data presented in table 4. The indicators were normalized using the Min–Max procedure, after which the economic-operational (ETSI), social (SSTI), and environmental (EnvTSI) sub-indices were calculated and aggregated into the Iraq Sustainable Transport Index (I-STI). Model W1 applies equal weights across the three dimensions, whereas W2 applies entropy weights within the relevant dimensions as a sensitivity test, following the composite-index approaches of OECD (2008) and Greco et al. (2019).

The I-STI was 0.556 in 2015 and 0.592 in 2016, rising gradually. The following trend was downwards until 2019, where it stood at 0.365. There was an observable short-term surge to 0.784 in 2020. From there, it fell drastically to 0.312 in 2021 and 0.110 in 2022. Overall, the index declined by 63.8% between the beginning and end of the study period (Figure 5).

The sub-index results help explain the exceptional 2020 value. The social safety index reached 1.000, while the environmental index improved to 0.852, largely because transport activity contracted during the pandemic. The economic-operational dimension remained at 0.500. Therefore, the 2020 increase should not be interpreted as evidence of a successful sustainable-transport policy. Rather, it represents a temporary statistical improvement associated with reduced mobility during the pandemic. This distinction illustrates the difference between lower environmental and safety pressures caused by economic or mobility contraction and genuine structural progress toward a more sustainable transport system (Figure 6).

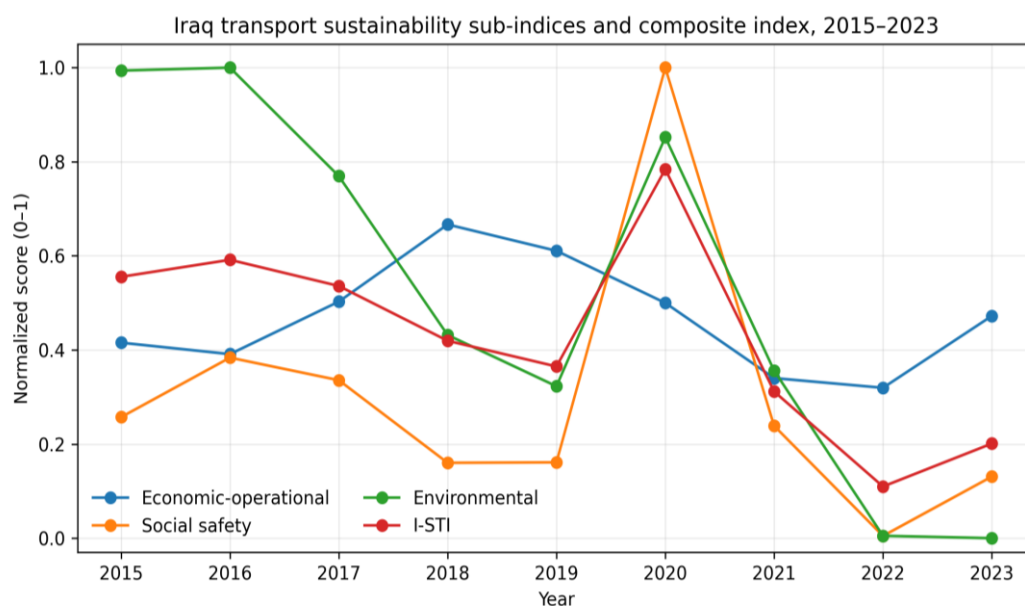


Figure 5. Evolution of the sub-indices and the Iraq Sustainable Transport Index (I-STI), 2015–2023

Source: Based on table 5.

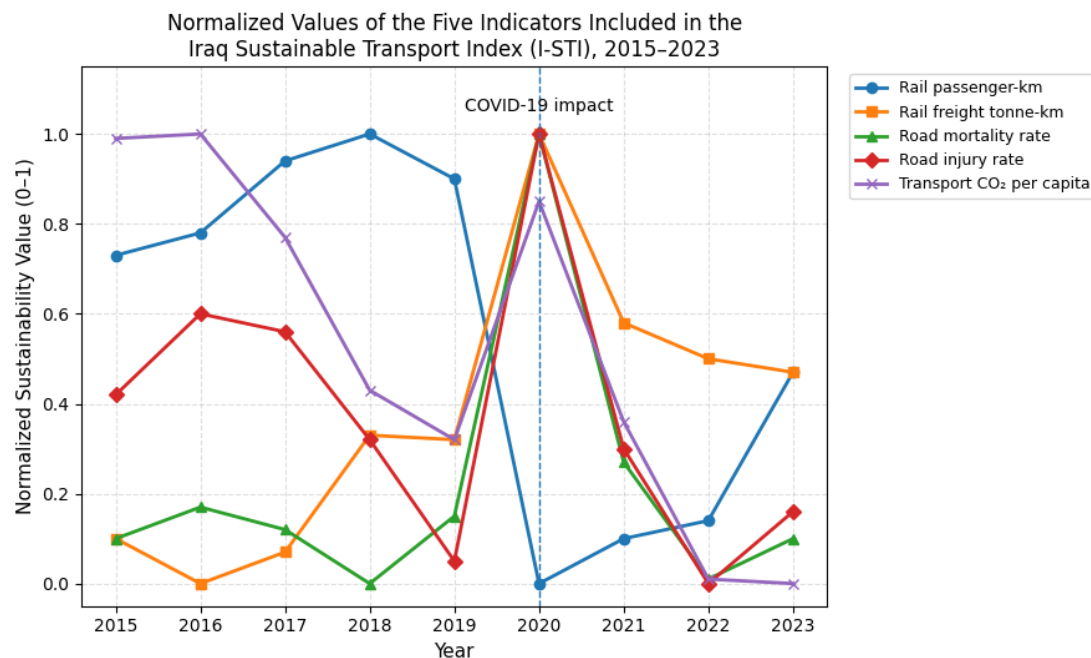


Figure 6. Normalized values of the five indicators included in the composite index

Source: Based on table 5.

Statistical Trend in Transport Sustainability

Table 6. Mann–Kendall trend test and sen's slope estimates

Indicator	Kendall's τ	p-value	Sen's slope/year	95% CI lower	95% CI upper
Economic-operational	-0.222	0.4767	-0.0111	-0.0560	0.0488
Social safety	-0.389	0.1802	-0.0307	-0.0662	0.0388
Environmental	-0.722	0.0059	-0.1262	-0.2233	-0.0370
I-STI	-0.611	0.0247	-0.0555	-0.0850	-0.0266

Source: Table 6 calculations based on the time series of the sub-indices and the overall Iraq Sustainable Transport Index (I-STI) reported in table 5. The Mann-Kendall test was conducted for trend analysis, and the Sen slope was applied for estimating the rate of annual changes [10].

The Index of Sustainable Transport in Inner city areas (I-STI) revealed a statistically significant decreasing trend for 2015–2023 period; Kendall's $\tau = -0.611$, $p = 0.0247$. The Sen slope was equal to -0.0555 index points per year and had a confidence interval between -0.0850 and -0.0266 . Thus, it can be stated that the decrease in the transport sustainability index was not accidental but intentional.

Among the three dimensions, the environmental dimension showed the clearest and strongest deterioration. Its trend was statistically significant ($\tau = -0.722$, $p = 0.0059$), with a Sen slope of -0.1262 points per year. By contrast, neither the economic-operational dimension nor the social-safety dimension reached the 0.05 significance threshold.

To examine whether the exceptional 2020 observation influenced the overall conclusion, the trend analysis was repeated after removing that year while retaining the original normalization. The resulting trend became substantially stronger, with $\tau = -0.857$ and $p = 0.0017$, while the Sen slope remained almost unchanged at -0.0557 points per year. This result indicates that the unusually high 2020 score temporarily obscured the underlying deterioration rather than generating it.

Sensitivity Analysis

The entropy-weighted scenario produced exactly the same ranking of years as the baseline model. The Spearman correlation between the two I-STI series was $\rho = 1.000$ ($p < 0.001$), while the mean absolute difference between the two series was only 0.0165 index points. These findings demonstrate that the principal conclusion—namely, the deterioration in transport sustainability, apart from the temporary 2020 anomaly—is highly robust to changes in the internal weighting procedure (Figure 7).

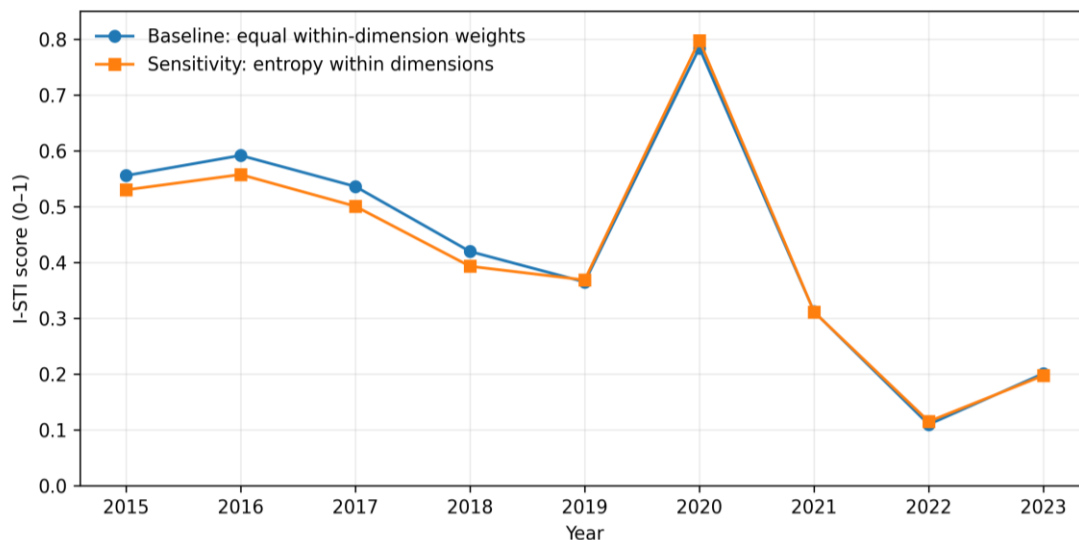


Figure 7. Comparison of I-STI values under equal and entropy-based weighting schemes

Source: These calculations based on the I-STI results reported in table 5. The baseline model (W1) uses equal weights, whereas the sensitivity model (W2) applies entropy-derived weights within the relevant dimensions.

Comparative Perspective with Regional Transport Sustainability Systems

Although the I-STI was specially developed for Iraq and is not designed to create an international ranking of transport sustainability, it becomes possible to compare the transport sustainability assessment of the country with the existing studies of other regions to find out what sustainability issues it might face. Prior studies of transport sustainability conducted in Europe and developing countries found out that sustainable transport performance is not achieved through maximization of transport activity but through the balance between its efficiency, environmental impact, and social aspects [15] [17]. Compared with the transport systems of Europe, where railway passenger transportation, integrated public transport and the strategies for reducing the emissions of greenhouse gases are more developed, Iraq is struggling with such problems as dependency on fossil fuels, development of public transport systems and road safety.

The previous studies revealed that transport sustainability level is higher in those systems which demonstrate the better integration of modal transport types and carbon intensity [15]. Similar issues can be found in developing countries, in which the rapid development of transport infrastructure was accompanied by high levels of emissions and growing transport environmental pressures. It was stated by studies devoted to sustainable transport transition that expansion of transport infrastructure without improvement in efficiency, safety and energy performance does not bring the sustainability results [7] [8].

Robustness and Uncertainty Assessment

As the analysis is conducted on the basis of a relatively short annual time series (2015–2023), an additional uncertainty analysis was carried out in order to test the robustness of the sustainability trend

observed. In total, three types of uncertainty were taken into account: weighting uncertainty, the effect of the exceptional year related to the pandemic, and indicator-level sensitivity. First, weighting uncertainty was tested by comparing the baseline model, which uses equal weights (W1), with the entropy-weighted approach (W2). Both approaches yield exactly the same ranking of the years with the Spearman correlation coefficient of $\rho = 1.000$ and a mean absolute difference of 0.0165, meaning that the sustainability trend was independent from the chosen method of weighting.

Second, the effect of the exceptional year of 2020 was tested by running the Mann–Kendall trend test without it. This made the negative trend even more pronounced ($\tau = -0.857$, $p = 0.0017$), confirming that the deterioration observed was not driven by the pandemic anomaly but represented a trend. Third, the sensitivity of indicators was tested by analyzing the contribution of each of the sustainability dimensions. It appeared that the environmental one had shown the most significant decrease in value ($\tau = -0.722$, $p = 0.0059$), and increasing CO₂ emissions of transport were the major driving factor behind it.

Discussion

The results indicate that transport sustainability in Iraq should not be evaluated only based on transport infrastructure expansion and transport activity growth. The developed I-STI shows that the positive changes in one transport dimension could coincide with negative changes in others. In particular, railway freight activity rose considerably while railway passenger activity decreased and environmental pressure increased. Thus, the results confirm the idea suggested by previous studies that transport sustainability should be evaluated in a balanced way considering the efficiency, safety, and environmental dimensions of transport operation [1] [15].

The environmental dimension turned out to be the most significant problem in transport system sustainability in Iraq. The 45.6% increase in transport CO₂ emissions in the studied period resulted in the decrease of the environmental sub-index in a statistically significant way. It was also found in previous transport sustainability studies that increased mobility and dependency on conventional fuels are the key obstacles to sustainable transport transitions [7] [12]. Thus, in order to enhance transport sustainability in Iraq, it is necessary not only to expand the infrastructure but also to lower the carbon intensity of transportation [19].

The contrasting dynamics of railway passenger and freight activities give a valuable engineering insight. The increase in railway freight activity means that rail infrastructure can be used to reduce the dependency on road transport for freight movement. However, the decline in passenger railway activity means that the diversification of transportation modes remains underdeveloped. As it was shown previously, sustainable mobility is characterized by freight efficiency and an accessible passenger transport system [8] [15].

The increase in I-STI in 2020 shows the importance of contextual interpretation in the case of using composite sustainability indicators. Even though the index value was the highest in the pandemic year, the reason for the increase was not an enhancement in transport planning but the reduction of mobility. Such phenomena were also observed in previous post-pandemic emission studies which indicated that temporary changes in transport activity could bring some environmental benefits without ensuring sustainable transitions [4].

Robustness analysis helps to understand the quality of the results better. The coincidence of the results obtained using equal and entropy weighting shows that the decrease in sustainability is not related to the assumptions of the methodology used. It confirms the idea suggested by previous studies about the importance of transparency and sensitivity testing in developing composite indicators [6] [11].

Practical and Policy Implications

Some of the practical uses of the suggested I-STI include the following. First, the I-STI can help in infrastructure planning by determining if transport projects have an effect on balancing sustainable

development. Second, the use of the I-STI enables decision makers to consider such areas as railway projects, road safety projects, and emissions reduction projects under one common assessment.

For transport planners, the findings indicate the need to prioritize:

- Expansion of sustainable railway passenger services.
- Improvement of road safety engineering measures.
- Reduction of transport carbon intensity.
- Integration of sustainability indicators into infrastructure evaluation.

The framework can also support national transport monitoring systems by providing annual sustainability assessment rather than isolated sector-based reporting.

Study Limitations and Directions for Future Research

There are some drawbacks in the current study. First, the study used nine years of annual observations since the availability of national transport data is limited. Despite the test for robustness that proved the stability of results, further use of time series with a larger number of observations will improve the reliability of the results. Second, environmental aspects are considered through transport CO₂ emissions per capita since no alternative environmental indicators are available or are highly correlated with each other. Further research can introduce new variables like energy efficiency, fuel consumption, and renewable energy usage. Third, the current model is only national, so it does not take into account regional differences in Iraq. Further research can expand the I-STI model to the governorate level, taking into account the accessibility of transport, mobility of the population, and infrastructure characteristics.

CONCLUSIONS

This study created the I-STI, which is an index used to measure the sustainable performance of the transportation system of Iraq using integration of the economic-operational performance, social safety, and environmental pressure dimensions. Based on the results of this research, it can be seen that there was no parallel development between the transport development and sustainability improvement in 2015-2023. In general, the value of the I-STI index reduced from 0.556 in 2015 to 0.201 in 2023, marking a decline of 63.8% in the sustainability performance of the transportation system of Iraq. The trend is statistically significant ($\tau = -0.611$, $p = 0.0247$) based on the results of Mann-Kendall test with Sen slope equal to -0.0555 index points annually. The most substantial reduction occurred in the environmental domain, which revealed a significant negative trend ($\tau = -0.722$, $p = 0.0059$) due to CO₂ emission from transport increased from 639.2 kg/person in 2015 to 930.5 kg/person in 2023. Despite an increase in railway freight activity by 283.1%, there was a drop in the railway passenger activity by 27.3%, proving that one-dimensional improvement does not equate to sustainability progress. The rise in I-STI in 2020 (value of 0.784) was a result of reduced mobility because of the pandemic rather than a structural improvement. Exclusion of the 2020 value made the negative trend stronger ($\tau = -0.857$, $p = 0.0017$). The robustness of the framework was proved through an identical year ranking of equal and entropy weighting (Spearman $\rho = 1.000$), and the mean absolute difference was 0.0165. The proposed I-STI framework gives an instrument for decision support for sustainable transportation planning, emissions reduction, safety improvement, and future mobility strategy. Future research may incorporate accessibility, energy efficiency, quality of public transportation systems, and regional-level sustainability.

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