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Celebrating 15 Years of Contribution to Sustainable Development

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A Composite Index for Assessing Sustainability of Urban Transport Interventions

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Outline

- Introduction
- Objectives
- Methodology
- Sustainable Transport Indicators
- Case Study: Bangalore Metropolitan Region
- Policy Scenarios
- Results & Discussion
  - Scenario Analysis
  - Comparison across indicators, sub-index and CSTI
- Policy Implications
- Conclusion

Introduction

- **Sustainable Transportation**: Satisfying current transport and mobility needs without compromising the ability of future generations to meet these needs (WCED, 1987).

- Traditional development strategies have **degraded** the resources to a huge extent.

- **Minimize** negative environmental, social and economic impacts such as GHG emissions, road fatalities and injuries, exposure to pollutants, high usage of private vehicles etc.

Traffic congestion on Bellary Road (KIA Road) on Hebbal flyover, Bengaluru; Source: The Hindu

Introduction

- United Nations (UN) in 2015 prepared **17 Sustainable Development Goals (SDGs)** to be achieved by all the UN member states by 2030.
- These **17 goals** were measured with **169 targets**.
- There are 27 direct transport-related targets defined under 17 goals (Nitwal et al., 2022).
- Lack of studies in literature that **assess sustainability of urban transport system** using a **comprehensive set of indicators** and **policy scenario analysis.**

Aim and Objectives

- Evaluate the impact of sustainable urban transport interventions based on 29 STIs.
- To develop a Composite Sustainable Transportation Index.
- Conduct scenario analysis for Business-As-Usual (BAU) 2031 and two Sustainable Transport (ST) 2031 scenarios.

Methodology

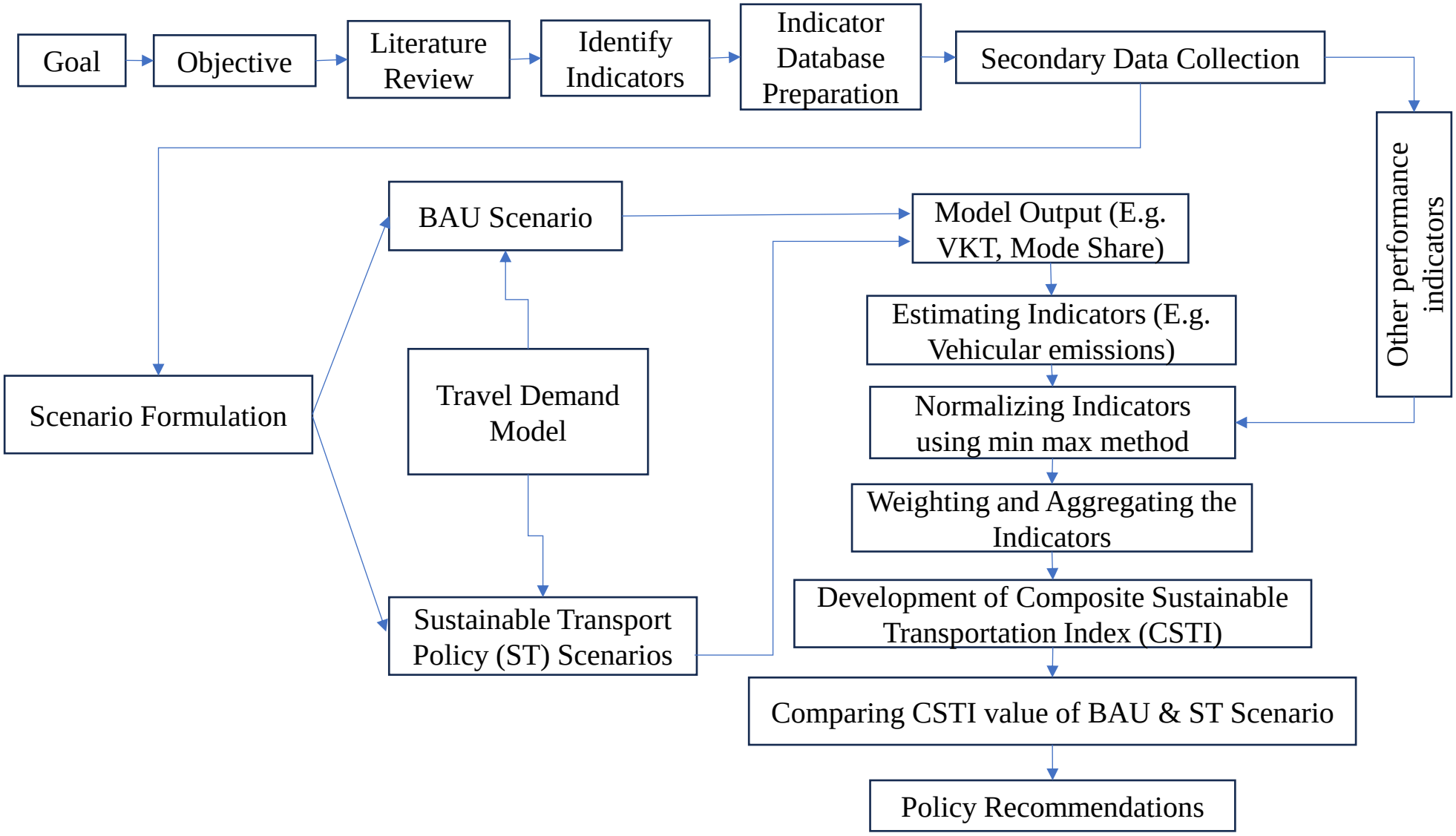


Fig. Overall methodological framework

Sustainable Transport Indicators

S. No.	Sustainable transport pillars	Labels	Sustainable transport indicators	Definition	Impact on transport sustainability (+/-)
1	Environment	$I_{Env\,1}$	CO emission	CO emission from transport (Tonnes/ Year)	-
2		I_{Env2}	HC emission	HC emission from transport (Tonnes/ Year)	-
3		I_{Env3}	NOx emission	NOx emission from transport (Tonnes/ Year)	-
4		I_{Env4}	CO_2 emission	CO2 emission from transport (Tonnes/ Year)	-
5		I_{Env5}	$PM_{2.5}$ emission	PM 2.5 emission from transport (Tonnes/ Year)	-
	Social	I_{soc1}	Exposure to $PM_{2.5}$	Commuters' exposure to PM2.5 emissions from motorized modes	-
		I_{soc2}	Traffic injuries*	Total number of traffic injuries over a year	-
		I_{soc3}	Traffic deaths	Total number of traffic deaths over a	-
	Economic	I_{Econ1}	Population Density*	Persons per square km	+
		I_{Econ2}	Carbon emission intensity	Carbon emission intensity (CO2 emissions per unit GDP)	-
		I_{Econ3}	Transport investment cost	Rupees allocated for upgrading and maintaining road infrastructure	-
		I_{Econ4}	Public transit network (Metro)	Total public transit network coverage (Metro)	+

Formation of CSTI: Normalization, Weighting and Aggregation

- Normalization (min-max method):

$$I_N = \frac{I - \min(I)}{\max(I) - \min(I)}$$

Indicators having a positive impact on transport sustainability

$$I_N = \left(1 - \frac{I - \min(I)}{\max(I) - \min(I)}\right)$$

Indicators having a negative impact on transport sustainability

$$I_{Env} = \frac{\sum_i \alpha_i I_{Ni}}{\sum_i \alpha_i} \qquad I_{Econ} = \frac{\sum_k \alpha_k I_{Nk}}{\sum_k \alpha_k}$$

$$I_{Soc} = \frac{\sum_j \alpha_j I_{Nj}}{\sum_j \alpha_j} \qquad \alpha = 1$$

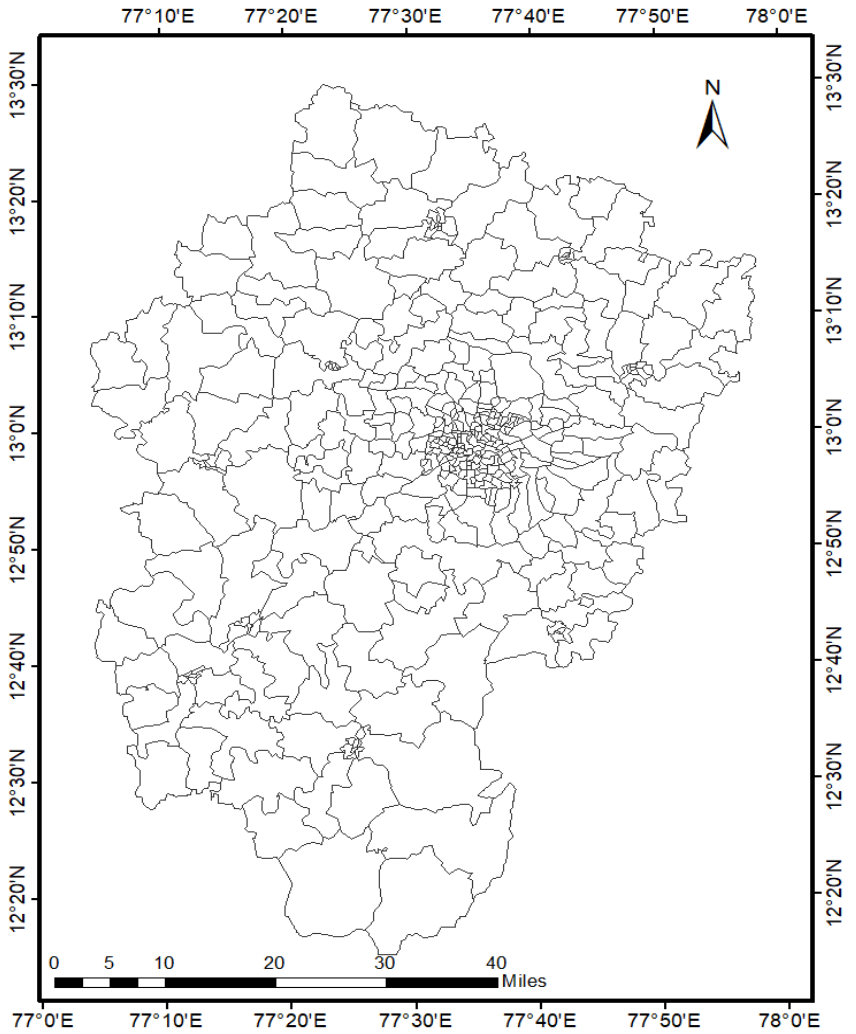
- Normalized indicators are then weighted (Equal weighing) and aggregated (linear aggregation) to obtain the index.
- Sub-indices are formed for three pillars of sustainability, namely I_{Env}, I_{Econ}, and I_{soc}.
- Further aggregated to obtain the final composite sustainable transportation index (CSTI).

$$CSTI = \frac{\gamma_1 I_{Env} + \gamma_2 I_{Soc} + \gamma_3 I_{Econ}}{\gamma_1 + \gamma_2 + \gamma_3}$$

$$\gamma = 1$$

Case Study: Bangalore Metropolitan Region

- **Bangalore Metropolitan Region (BMR): 8005** sq km; **384** Traffic Analysis Zones (TAZ).
- Travel Demand Model (TDM) is used to obtain indicators such as transport emissions, VKT, Public Transit ridership etc.
- Two sustainable transportation (ST) policies are evaluated.



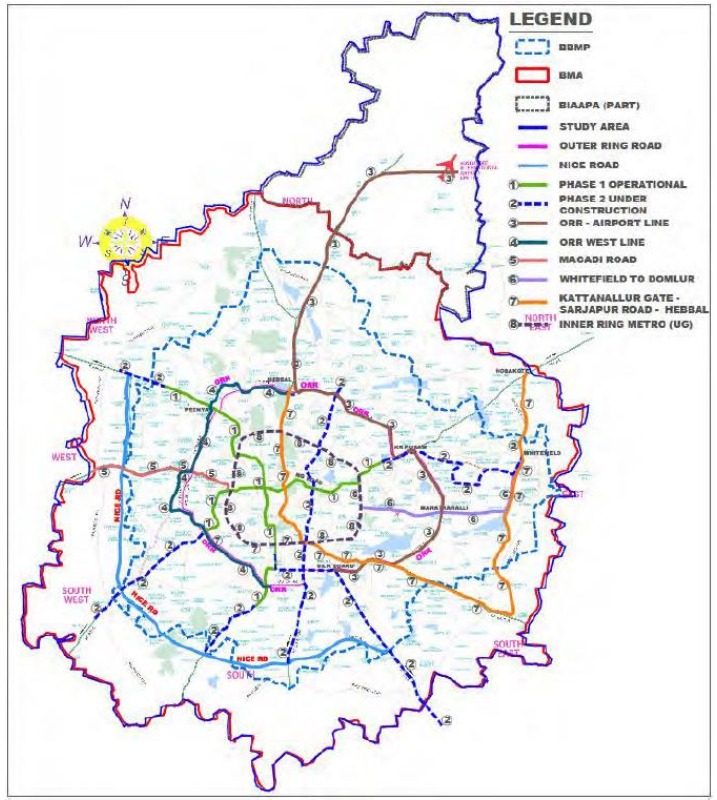
BMR Zone Map

Policy Scenario 1

Table: Metro rail project for year 2031

Sl. No.	Metro Corridor	Length (km)
1.	Phase 1 (Operational) • EW Line 24 km & NS Line 18 km	42
2.	Phase 2 (Under construction) • EW Line Extensions 22 km & NS Line Extensions 10 km • Electronic City Line 19 km & IIMB Line 21 km	72
3.	ORR-Airport Line	58
4.	ORR West Line	30
5.	Magadi Road (Metrolite - Elevated)	13
6.	Whitefield – Domlur Line (Metrolite (Elevated) / MRT)	16
7.	Katamanallur Gate – Sarjapura Road –Hebbal (Metrolite (Elevated) / MRT)	52
8.	Inner Ring Metro (UG)	34
	Total	**317**

(Source: Comprehensive Mobility Plan 2020)



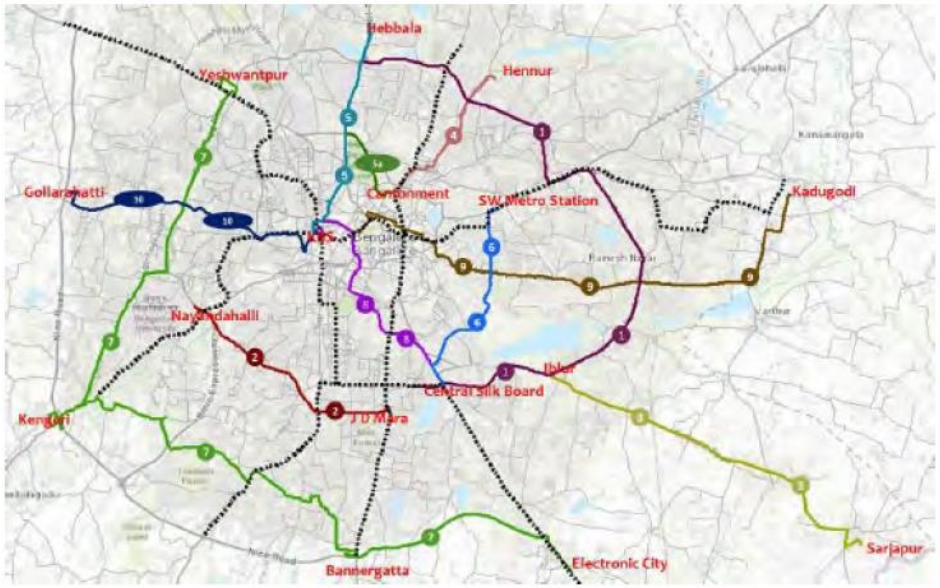
Map showing metro corridor, Metro Rail Project 2031

Policy Scenario 2

Table: Bus Priority Corridor & Non-Motorized Transport Infrastructure 2031

S. No.	Name of Corridor	Length (in kms)
1.	Silk Board to Hebbal - Outer Ring Road	30
2.	Nayanda Halli - JD Marra - Outer Ring Road	11
3.	Sarjapur Road	19
4.	Hennur Road	8
5.	Hebbala Road	13
5A.	JRC Junction to Circle Mekhri	5
6.	SV Metro Station to Silk Board	10
7.	Electronic City to Yeshwantpur	53
	Total	**149**

(Source: Comprehensive Mobility Plan 2020)



Map showing bus priority corridor

Model Development

- **Travel demand model for the base year 2022** is forecasted (Trip Generation; Trip Distribution; Modal Split; Trip Assignment for 2022).

- This base model is further used to forecast the travel demand for 2031 for BAU scenario, Policy Scenario 1 (S1), and Policy Scenario 2 (S2).

- STIs are obtained using various outputs of the developed TDM model such as VKT, VHT, mode share.

Results & Discussion: Scenario Analysis

- Traffic Assignment Maps: Comparing BAU and MS 2031.

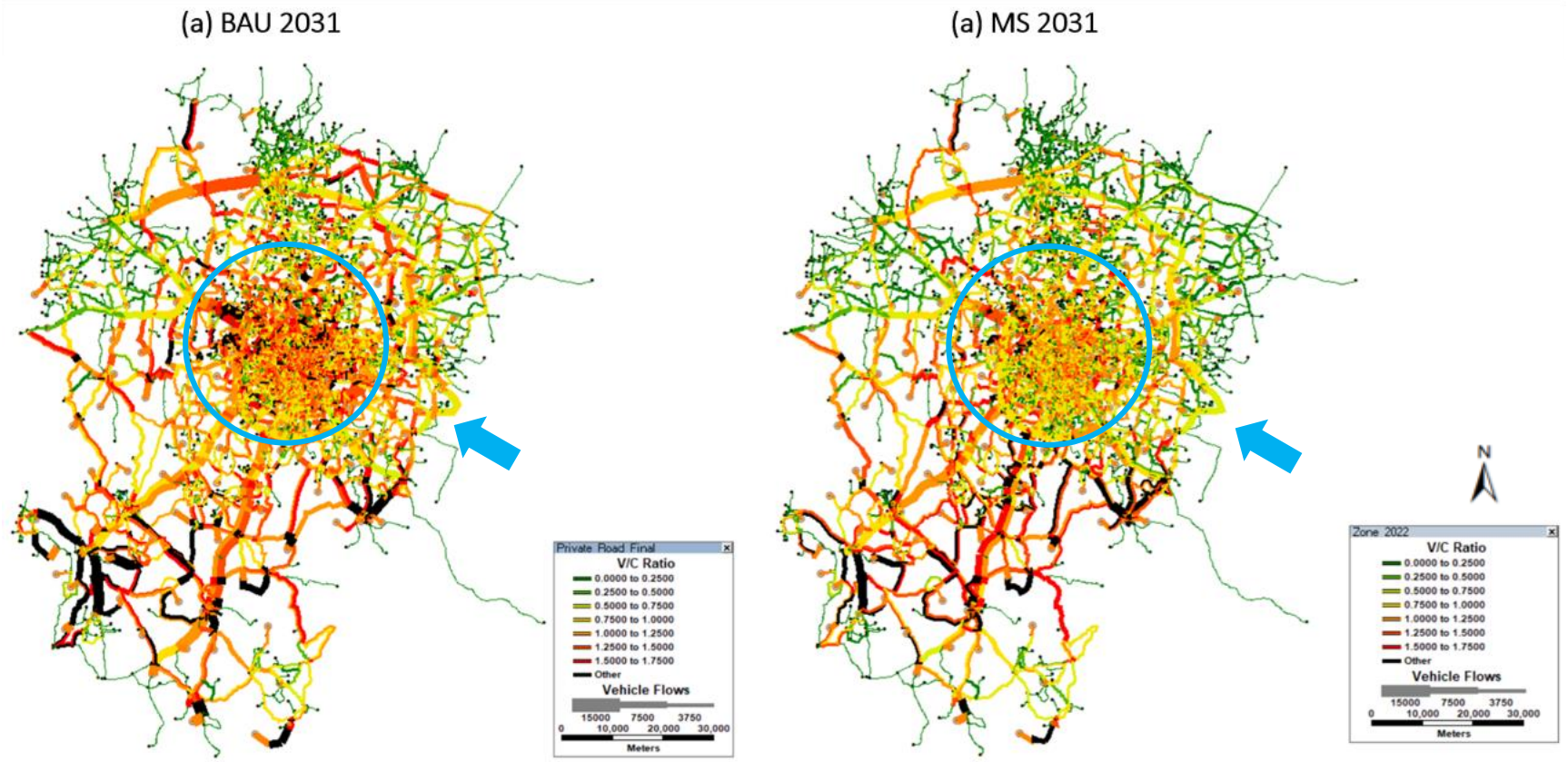
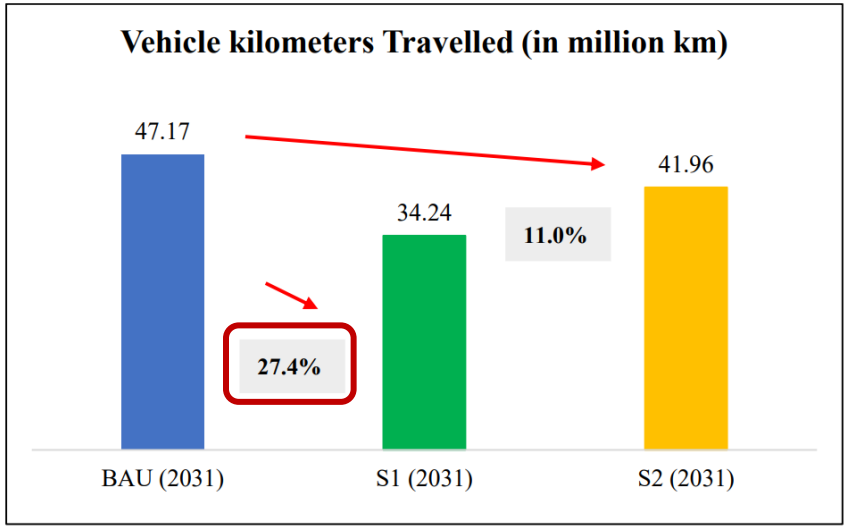
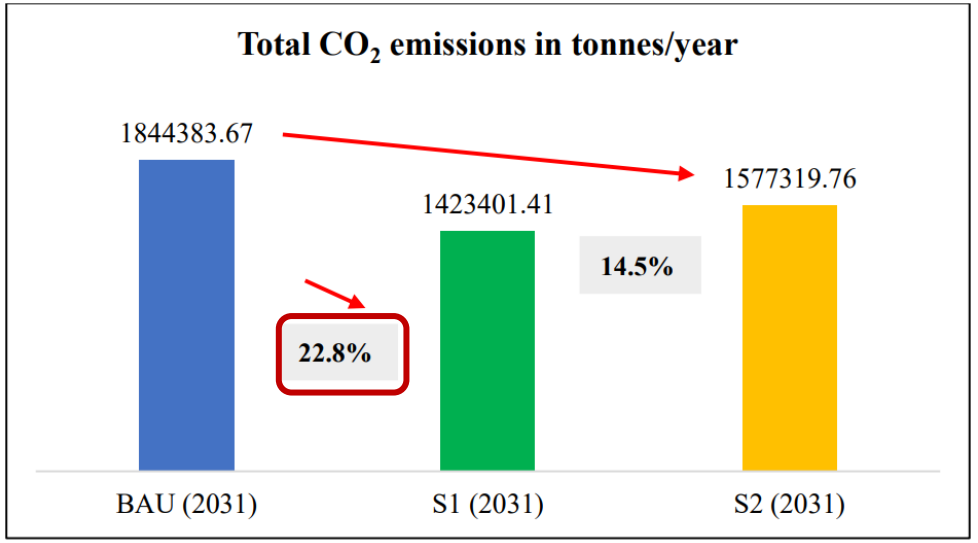
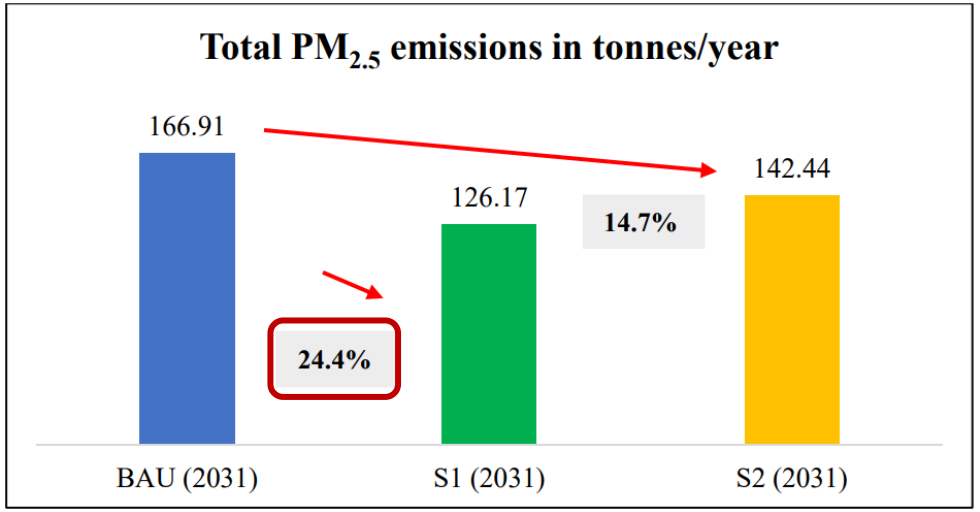


Fig. Traffic Assignment Map: (a) Business as Usual 2031 scenario and (b) Metro 2031 Scenario

Results & Discussion

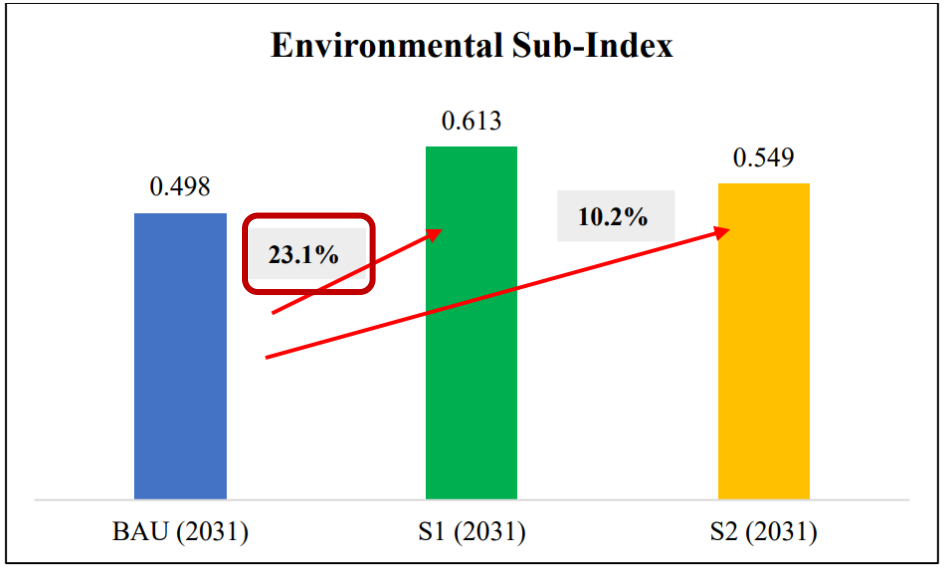


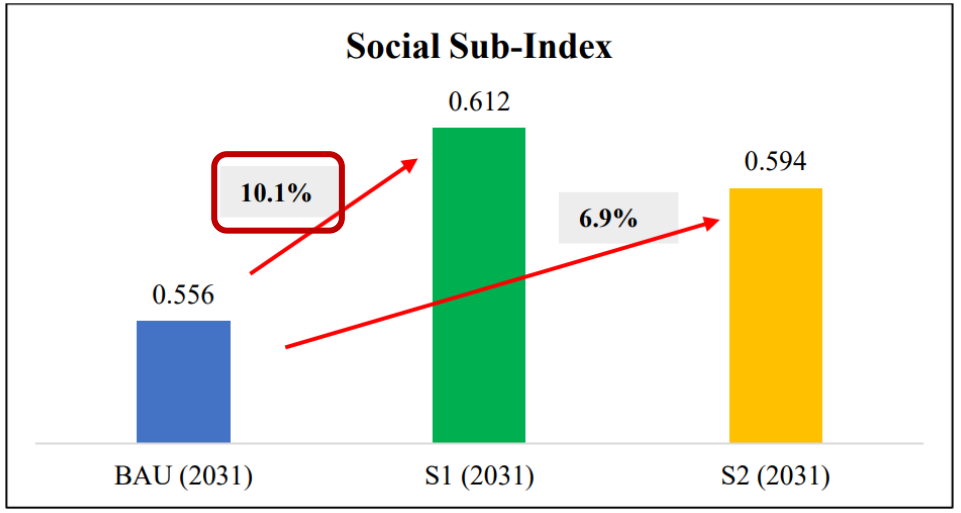


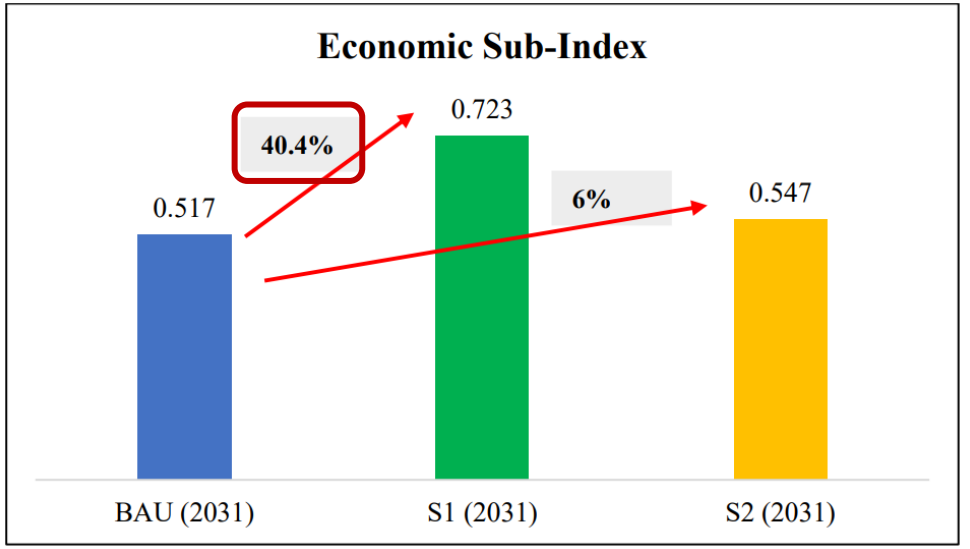


Sub-Index

Environment, Social, Economic sub-index comparisons for BAU and Policy Scenarios.

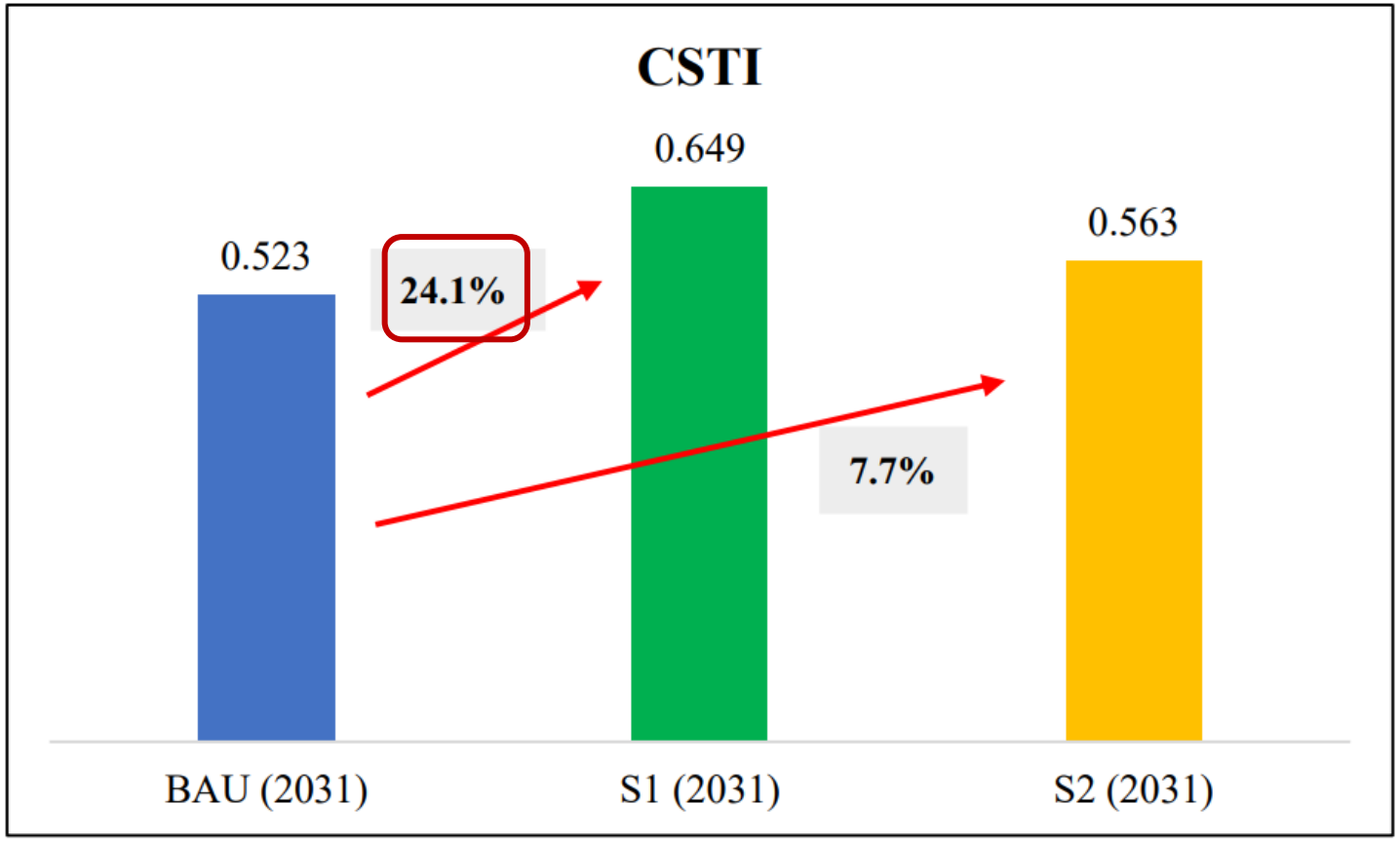






CSTI

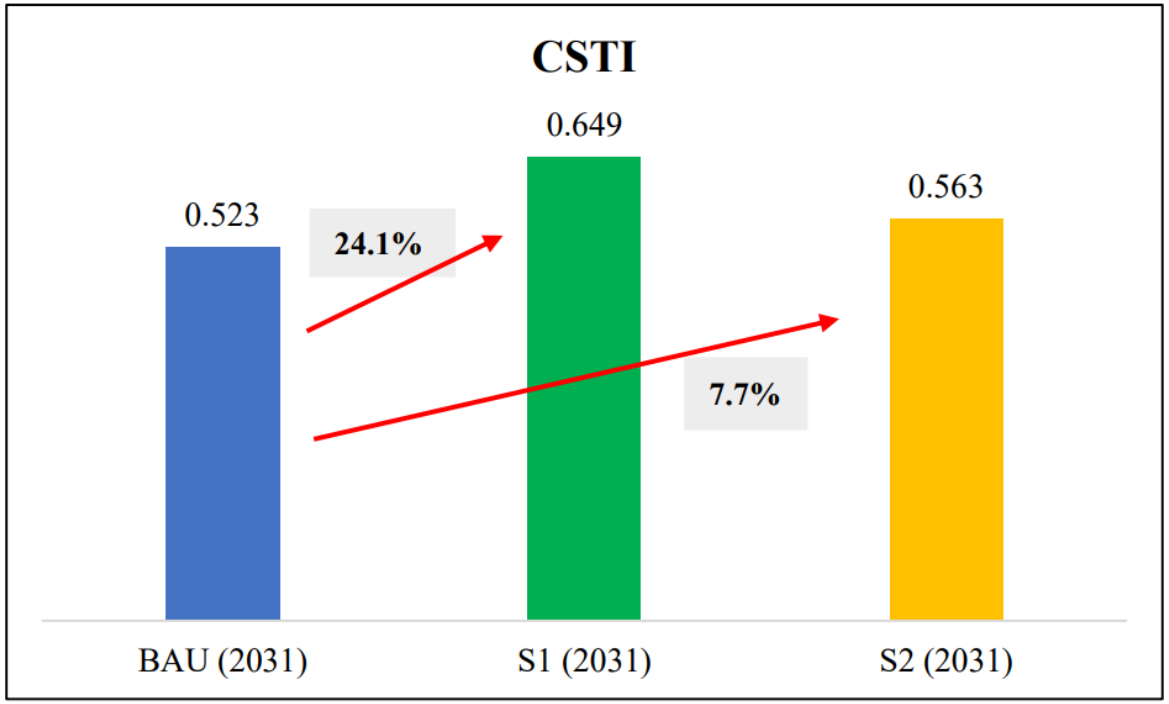
CSTI comparisons for BAU and Policy Scenarios.



CSTI

Performance categorization CSTI	Range	Description
A	0.605 – 1	Excellent performance towards sustainability
B	0.532 – 0.605	Good performance towards sustainability
C	0.468 – 0.532	Average performance towards sustainability
D	0.395 – 0.468	Bad performance towards sustainability
E	0 – 0.395	Worst performance towards sustainability

- Estimated CSTI values for BAU 2031 falls under performance category '**C**' indicating **average performance towards sustainability**.
- S1: category '**A**' indicating **excellent performance towards sustainability**.
- S2: category '**B**' indicating **good performance towards sustainability**.



CSTI comparisons for BAU and Policy Scenarios

Policy Implications

- This study establishes a foundation for assessing the impact of two policy scenarios and **can be extended** to assess alternative transportation initiatives and infrastructure developments.
- **Implementing** sustainable transport **policies** to create a system that caters to a broader population through **sustainable modes**, while **reducing environmental, social, and economic externalities**.
- The framework generates three sub-indices for each pillar of sustainability, along with a composite index, **enabling the assessment** of policy impacts on individual sustainability **pillars**.
- This **comprehensive** analysis, utilizing **STIs** and the development of **CSTI**, provides **valuable insights** for **policymakers and transport planners**, supporting the evaluation of future policies aimed at steering the transportation system towards a more sustainable trajectory.

Policy Implications

- The results indicate that the public transport share, including both bus and metro, increased from 50.6% in the BAU scenario to 62% and 54.1% in Policy Scenarios 1 and 2, respectively.
- Both policy scenarios also **resulted** in a **notable reduction** in total vehicular emissions compared to the BAU scenario.
- Therefore, transport policies **must be designed** to focus on **public transport modes** as they yield significant impact to make the transportation system more sustainable and efficient.
- Indicators along with the framework for obtaining the CSTI, can be valuable tools for **decision-makers**. These tools can be used to **track progress toward broader development goals** in **cities**.

Conclusion

- Study proposes a **methodological framework** that uses STIs to evaluate sustainable transport measures using CSTI.
- Indicators used in the study are forecasted for the year 2031 for BAU and Policy Scenarios which **enables** these **indicators to capture the improvements** caused by **different policy scenarios**.
- Highlights the importance of **prioritizing interventions that enhance sustainable transport modes** like metro, buses, and non-motorized transport to achieve sustainable transportation system.
- A valuable tool for assessing the sustainability of different transportation strategies (policies).
- Policy scenario analysis has been conducted **using a comprehensive** set of **29 varied STIs** which is lacking in literature.
- STIs established in this study can **serve as a template** for **creating databases** for other Indian cities.

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Thank You

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STIs

- Env STIs.

S. No.	Sustainable transport pillars	Labels	Sustainable transport indicators	Definition	Impact on transport sustainability (+/-)	Sources
1	Environment	$I_{Env\,1}$	CO emission	CO emission from transport (Tonnes/ Year)	-	Haghshenas and Vaziri (2012), Verma et al. (2018)
2		I_{Env2}	HC emission	HC emission from transport (Tonnes/ Year)	-	Verma et al. (2018)
3		I_{Env3}	NOx emission	NOx emission from transport (Tonnes/ Year)	-	Haghshenas and Vaziri (2012), Verma et al. (2018)
4		I_{Env4}	CO_2 emission	CO2 emission from transport (Tonnes/ Year)	-	Verma et al. (2018), Vajjarapu et al. (2023)
5		I_{Env5}	$PM_{2.5}$ emission	PM 2.5 emission from transport (Tonnes/ Year)	-	Verma et al. (2018)
6		I_{Env6}	Fuel consumption	Daily energy consumption from fossil fuels (kilolitres of fuel consumed per day)	-	Verma et al. (2015)
7		I_{Env7}	Air Quality Index*	Average quality index	-	Nitwal et al. (2023)
8		I_{Env8}	Average Trip Length for Private + NMT	Average Trip Length for PVT + NMT mode	-	Verma et al. (2018), Vajjarapu et al. (2023)
9		I_{Env9}	Average Trip Length for Public Transit	Average Trip Length for PT	-	Verma et al. (2018), Vajjarapu et al. (2023)
10		I_{Env10}	Per capita trip rate for Private + NMT	Average number of trips per person for PVT + NMT	-	Verma et al. (2018), Vajjarapu et al. (2023)
11		I_{Env11}	Per capita trip rate for Public Transit	Average number of trips per person for PT	+	Verma et al. (2018), Vajjarapu et al. (2023)
12		I_{Env12}	Transportation land consumption*	Land allocated for transportation per capita	-	Haghshenas and Vaziri (2012)

STIs

- Social STIs.

13	Social	I_{soc1}	Exposure to $PM_{2.5}$	Commuters' exposure to PM2.5 emissions from motorized modes	-	Verma et al. (2020)
14		I_{soc2}	Traffic injuries*	Total number of traffic injuries over a year	-	Verma et al. (2015), Nitwal et al. (2023)
15		I_{soc3}	Traffic deaths	Total number of traffic deaths over a year	-	Verma et al. (2015), Nitwal et al. (2023)
16		I_{soc4}	Physical activity (PA)	Walking and cycling as a measure of Metabolic Equivalent of Task (MET)	+	Verma et al. (2020), Allirani et al. (2022)
17		I_{soc5}	Vehicle ownership per capita*	Total registered motorised vehicles (per capita)	-	Zope et al. (2019)
18		I_{soc6}	Drunk driving cases*	No. of drunk driving cases registered per year	-	Nitwal et al. (2023)
19		I_{soc7}	Unsafe driving cases*	Number of unsafe driving incidents reported per year (e.g., signal violations, driving without a license)	-	Nitwal et al. (2023)
20		I_{soc8}	Vehicle Kilometres Travelled (VKT)	Total VKT	-	Verma et al. (2015), Vajjarapu et al. (2023)
21		I_{soc9}	Vehicle Hours Travelled (VHT)	Total VHT	-	Verma et al. (2015), Vajjarapu et al. (2023)

STIs

- Economic STIs.

22	Economic	I_{Econ1}	Population Density*	Persons per square km	+	Zope et al. (2019), Nitwal et al. (2023)
23		I_{Econ2}	Carbon emission intensity	Carbon emission intensity (CO2 emissions per unit GDP)	-	Verma et al. (2018), Vajjarapu et al. (2023)
24		I_{Econ3}	Transport investment cost	Rupees allocated for upgrading and maintaining road infrastructure	-	Verma et al. (2015)
25		I_{Econ4}	Public transit network (Metro)	Total public transit network coverage (Metro)	+	Author Defined
26		I_{Econ5}	Public transit daily ridership (Bus)	Average daily ridership of BMTC (in passengers per day)	+	Author Defined
27		I_{Econ6}	Public transit daily ridership (Metro)	Average daily ridership of Metro (in passengers per day)	+	Author Defined
28		I_{Econ7}	Public bus fleet size*	Public bus fleet size	+	Author Defined
29		I_{Econ8}	Road density*	Total length of road to total land area (length in km per sq km area)	-	Nitwal et al. (2023)