Carbon Footprints

Original Article

Open Access

Check for updates

Sustainable and inclusive low-carbon transport scenarios for Surat city, India

Darshini Mahadevia[1], Minal Pathak[2], Saumya Lathia[1], Chandrima Mukhopadhyay[1], Shannay Rawal[2]

[1]School of Arts and Sciences, Ahmedabad University, Ahmedabad 380009, India.
[2]Global Centre for Environment and Energy, Ahmedabad University, Ahmedabad 380009, India.

Correspondence to: Saumya Lathia, School of Arts and Sciences, Ahmedabad University, Commerce Six Roads, Navrangpura, Ahmedabad 380009, India. E-mail: saumya.lathia@ahduni.edu.in or saumyamlathai@gmail.com

How to cite this article: Mahadevia, D.; Pathak, M.; Lathia, S.; Mukhopadhyay, C.; Rawal, S. Sustainable and inclusive low-carbon transport scenarios for Surat city, India. *Carbon Footprints* **2025**, *4*, 11. https://dx.doi.org/10.20517/cf.2025.01

Received: 2 Jan 2025 **First Decision:** 19 Feb 2025 **Revised:** 5 Apr 2025 **Accepted:** 21 Apr 2025 **Published:** 27 Apr 2025

Academic Editor: Han Hao **Copy Editor:** Fangling Lan **Production Editor:** Fangling Lan

Abstract

The study examines the delivery of climate change mitigation and sustainable development goals (SDG) in Surat's passenger transport sector. The SDGs selected are 1-no poverty, 3-health and well-being, 5-gender equality, 8-economic growth, 11-sustainable cities, and 13-climate action. Over and above the Base Scenario, the three scenarios presented are: Scenario I involves recalibrating Surat's available Comprehensive Mobility Plan, Scenario II - a Deep Decarbonization Scenario, aligning with the global 1.5 °C temperature stabilization target via technology, and Scenario III - an SDG-adjusted Deep Decarbonization Scenario addressing social transformations applying assumptions derived from the primary survey in the city on Scenario II. Scenario II has the lowest motorized vehicle kilometers traveled (VKT) and, thus, the lowest GHG emissions. Scenario III has a higher motorized VKT and thus the emissions than Scenario II. Nonetheless, GHG emissions improve in Scenario III by 84.3% compared to Scenario I and push forward the SDGs.

Keywords: Urban transport, sustainable development goals, low-carbon transport, climate mitigation, emission inventory, scenario planning

INTRODUCTION

The Intergovernmental Panel on Climate Change's (IPCC's) 1.5 °C Report[1] and Assessment Report Six on Mitigation[2] locate climate change mitigation policies and actions within the sustainable development goals

(SDG), giving a new perspective to sustainable urbanization, and integrating climate change mitigation and SDGs at the national level as well as in the cities. With the expected high rate of urbanization in South Asia, specifically India, Indian cities will be at the forefront of delivering the national greenhouse gas emissions targets committed through the nationally determined contributions (NDCs) while balancing local development needs. Thus, climate change mitigation and SDG-related actions must be grounded and integrated with planning and development efforts at the city level. This paper presents the case of an Indian city wherein the transport sector climate change mitigation efforts are assessed against selected SDGs and their respective targets and argues for orienting low-carbon urban transport options to achieve the SDG targets.

Even at a low level of urbanization (34.03%[3]), India's urban landscape is highly unequal. India is expected to reach 50% urbanization level by 2050 with an addition of 416 million urban dwellers, nearly doubling the size of its urban population between 2018 and 2050[4]. India's urbanization is characterized by chronic poverty, gender inequality, and high informalities in employment, housing, transportation, and service provisioning. This often manifests as low levels of education, work participation rates, and low physical, social, and economic mobility among women, the urban poor, and other vulnerable groups[5,6]. Fragmented transport networks and lack of holistic planning tend to exacerbate poverty by curbing access to economic opportunities[7,8] as well as education and health[6], particularly in the case of women[6]. These linkages are expanded in Section "TRANSPORT-SDG INTERACTIONS" of the paper. India's urbanization future impinges on the progress of SDGs in her cities while addressing the climate change mitigation agenda, presenting complex challenges ahead.

The transport sector is India's second highest GHG emitting sector; passenger transport alone contributes to over 60% of transport-sector emissions[9]. The demand for passenger transport under the business-as-usual scenario would increase over four times from around 7,000 billion passenger-km in 2010 to 30,517 by 2050[10]. In India, like most countries of the global South, urbanization is unaccompanied by investment in active and public transport networks (PT), resulting in rapid motorization. India's increasing dependence on 2- & 3-wheelers has resulted in a 260% increase in CO_2 emissions since the last decade[2]. Increased intensity of economic activity will further increase transport demand, creating an urgent need to decarbonize transport[10]. At the national level, the policy reforms focus on vehicle & fuel efficiency standards[11] and the adoption of alternative fuels and technologies - biofuels, Electric Vehicles (EVs), *etc*. At the city level, reducing emissions from transport translates broadly into four types of actions: (i) a modal shift to public transport while reducing reliance on private motorized modes; (ii) retaining and promoting non-motorized transport (NMT - walking, cycling, cycle-rickshaws, *etc*.) through large-scale infrastructure improvement; (iii) promotion and setting up of infrastructure for EVs (for private, public and Intermediate Public Transport (IPT) vehicles); and (iv) land-use & transport integration through transit-oriented development (TOD), and compact, self-sufficient neighborhoods transport[12-14].

Existing literature shows evidence of synergies between adaptation and mitigation actions[15] and co-benefits of mitigation actions[16]. Systematic reviews have focused on global studies linking mitigation and SDGs[15,17]. Urban transport studies in the Indian context have focused on individual interventions[18,19] or policy gaps[20]. Future low-carbon scenarios at the city level have not been studied in the Indian context. This paper does an in-depth assessment of urban transport scenarios in the city of Surat to (i) assess whether these interventions enable deep emissions reductions; and (ii) assess the implication on emissions in an endeavor to deliver sustainable development goals (SDGs). A unique contribution of this study is that scenario development is place-based and informed by detailed stakeholder surveys. It also lays out the approach of SDG-aligned low-carbon transport and methodology to mainstream inclusive dimensions in the low-carbon transport options. It also argues that no two cities are equal, and hence, there is a need to prepare individual city assessments of low-carbon transport options and their SDG linkages. The results can thus provide robust and context-specific recommendations for informing sub-national and national policy on one hand and motivate individual cities to prepare their transport proposals.

This paper discusses three future scenarios- Scenario I, a mitigation scenario based on the existing low-carbon mobility plan; Scenario II, a deep decarbonization scenario informed by the global 1.5 °C target involving ambitious implementation of technological and demand interventions[21] and Scenario III, an SDG-aligned deep decarbonization scenario to deliver sustainable outcomes based on six relevant SDGs (SDG 1, 3, 5, 8, 11 & 13) at the target level. The study focuses on intra-city passenger transport. Section "TRANSPORT SCENARIO IN SURAT" presents Surat's existing transport landscape, Section "METHODOLOGY" details project methodology, Section "RESULTS" presents and discusses scenario-wise results, and Section "CONCLUSION" concludes with policy implications.

TRANSPORT-SDG INTERACTIONS

Urban transport has a robust and multifaceted relationship with most of the SDGs; six of these have been selected in this paper as context-specific for detailed interaction with urban transport. The transport options, which are low-carbon, affordable, safe, and convenient, have strong synergies with the SDGs and directly contribute to achieving several targets under these SDGs. Conversely, private vehicle-based transport options have negative implications for the SDGs. Some of these interactions are complex, and the following section discusses the SDG synergies and trade-offs of transport actions as evidenced in India. The SDG target-transport interactions are assessed as generating a trade-off in case of conflicts, synergy, or a mixed effect.

SDG 1 (No poverty) and SDG 8 (economic development): Transport provides access to economic opportunities, leading to employment and economic growth, and vice versa, establishing a co-dependence between SDG8 & urban transport. Apart from access to employment [SDG8.1 (The figure in the brackets refers to SDG and its target. For example, SDG8.1 refers to Target 1 of SDG 8)] (Available from: https://sdgs.un.org/goals/goal8 [Last accessed on 30 Nov 2022]), efficient transport systems are fundamental for economic productivity (SDG8.2 & SDG8.5)[22], especially for women and the urban poor[7,23]. In some cases, transport is also a primary labor-intensive employment sector, for example, in India's auto-rickshaw industry, creating ample work opportunities for low-skilled labor and migrants (SDG8.10). In Delhi, 89% of e-rickshaw drivers witnessed an increase in daily income compared to their previous employment, and about 40% of them switched from physically demanding jobs (cycle-rickshaw, handcart, *etc.*) to unemployment[24]. Access to employment is an opportunity to reduce poverty (SDG1.1, SDG1.2) (Available from: https://sdgs.un.org/goals/goal1 [Last accessed on 30 Nov 2022]). However, the emphasis on promoting transport infrastructure that primarily supports private vehicles often disproportionately benefits wealthier residents while leaving poorer residents burdened by negative externalities like higher air pollution burden, higher susceptibility to road accidents, spatial mismatch (unaffordable transport options leading to exclusion from opportunities), and lower access to healthcare facilities, deepening their economic insecurity & poverty. Studies also show that constant exposure to environmental pollution in South Asian cities leads to lower life expectancy by 5 to 7 years in urban poor compared to their wealthier counterparts (SDG1.5, SDG1.4).

SDG 3 (health & well-being): Reliable and safe transport systems, especially better connectivity between peri-urban and urban areas in the global South through public transport and NMT are linked to improved health outcomes (SDG3.3, SDG 3.8) (Available from: https://sdgs.un.org/goals/goal3 [Last accessed on 30

Nov 2022]), and reduced perinatal, neonatal & maternal mortality (SDG 3.1, SDG 3.2) by improving local air quality and reducing healthcare and transport expenditures[25]. Budget savings could be redeployed to better nutrition of women and children in low-income families - and increase access to affordable healthcare. Safe transport also reduces road fatalities. Ambient air pollution (mainly from the transport sector) kills 4.2 million people around the world every year[26], about 90% of which occurs in developing countries (SDG3.9). Studies conducted in India's megacities indicated that gasoline and diesel vehicles alone contribute to 20%-50% of PM2.5 emissions[27]. Road fatalities result in 1.35 million deaths annually[28], over 90% of which occur in low- and middle-income countries (SDG3.6). Although India accounts for only 1% share of the world's vehicles, it is responsible for 11% of global road fatalities, and non-motorized transport (NMT) users represent the largest share. Lastly, shifting away from private transport to public and active transport increases physical activity and reduces mortality caused by cardiovascular diseases[29,30].

SDG 5 (gender equality): Transport is crucial to women's empowerment, helping them access opportunities, participate in public life and politics, and enhance social interaction. Especially in low-income households, women's mobility increases their family's chances of escaping poverty (SDG 5.2 and 5.5) (Available from: https://sdgs.un.org/goals/goal5 [Last accessed on 30 Nov 2022])[7,31]. In cities of the global South, women have a much higher dependence on PT and NMT than men. Hence, the poor state of NMT and PT infrastructure often leaves women more vulnerable to street harassment, stalking, and sexual assault in public spaces/streets, curbing their social/public life and economic opportunities. In Bhopal, India, 88% of the surveyed women reported facing harassment while using PT and IPT, and 40% reported experiencing harassment regularly[32]. Experiences of harassment and violence when using public transport affect women's mobility, leading to a curbed social/public life and economic opportunities. In Karachi, 31% of students, 23% of working women, and 20% of homemakers said they reduced the use of public transport post-harassment[33]. The availability of a safe, reliable, and affordable public transport system forms the backbone of women's mobility and empowerment. A mobility study of 11 Indian cities indicates that 62% of middle-income women and 75% of low-income women respondents stated a dire need for more affordable and more accessible PT[34].

SDG 11 (sustainable cities): SDG 11 promotes access to affordable housing and basic services through low-carbon transport modes like PT, vital for low-income communities, as it improves their access to the same and reduces their social exclusion in terms of time, power, and space (SDG11.1 & SDG 11.2) (Available from: https://sdgs.un.org/goals/goal11 [Last accessed on 30 Nov 2022]). Resilient transport systems also have the potential to mitigate extreme weather events, especially for vulnerable groups, who are often disproportionately affected by climate change and are captive users of PT and NMT (SDG11.5 & SDG11.B). Low-carbon transport interventions (mass-transit projects, *etc*.) often generate trade-offs with cultural and natural heritage in densely built Asian cities when routed through eco-sensitive or historic cores (SDG 11.3 & 11.4)[35]. For example, Kerala's Silver Line project - a railway line connecting north and south Kerala - cuts through 1,383 hectares of the eco-sensitive zone (wetlands, forest areas, and backwaters) and parts of the Madayipara Biodiversity Heritage Site[36]. Similarly, the Delhi Metro Corridor expansion caused the displacement and felling of about 7,000 trees from Delhi's eco-sensitive Ridge area- also known as Delhi's lungs[37].

SDG 13 (climate action): When rapid urbanization is not accompanied by a robust public and active transport network, it leads to rapid motorization and higher passenger transport demand. ASEAN (Association of Southeast Asia Nations) countries' increasing dependency on personal motorized vehicles and disinvestment of PT have increased their CO_2 emissions by 260% from 2000 to 2015 (SDG13.2, SDG13.3) (Available from: https://sdgs.un.org/goals/goal13 [Last accessed on 30 Nov 2022]). Studies show that investments in improving NMT and IPT can increase the share of public transport from 30%-50% by 2030 in small cities in India[38]. In the absence of reliable PT and NMT networks, increased transport demand (due to an increase in economic activity) would further motorize passenger demand and its related emissions. A landmark survey on walkability conditions in 13 Asian cities revealed that 67% of the respondents intended to shift to motorized transport modes should their walking environments fail to improve (SDG13.2)[39]. Electric vehicles powered with emissions electricity and improved electricity transmission and distribution efficiency can halve transport CO_2 emissions by 2050 compared to Business-as-usual[18].

TRANSPORT SCENARIO IN SURAT

Surat (The study area is the Surat Urban Development Area (SUDA), which goes beyond the Surat Municipal Corporation (SMC) limits) is an industrial city located in the western part of India. It has an estimated population of 7.5 million (in 2021) (The 2021 population census has not been canvassed due to COVID-19. Available from: https://worldpopulationreview.com/world-cities/surat-population [Last accessed on 10 Aug 2022]), 5.9 million residents, an area of 326.5 sq km, and a population density of 13,680 persons per sq. km. Surat is expected to be one of the world's fastest-growing cities[40], with a growth rate of 4.5% per annum during 2011-21, which is projected to increase at 2.9% per annum during 2021-31 (Source: Available from: https://worldpopulationreview.com/world-cities/surat-population [Last accessed on 10 Aug 2022]). Compared with similar-sized cities worldwide, it is compact and polycentric in nature. The city's economic base consists of small and medium-scale industries located in the peripheral areas.

Private vehicles [66% two-wheelers (2Ws) and 13% four-wheelers (4Ws)] dominate the city's vehicle composition, followed by 15% auto-rickshaws [three-wheelers (3Ws)] referred to as IPT. Walking and cycling form a large part of the mode-share [Table 1]; 2 in 5 persons making a trip are pedestrians, another 1 in 3 use privately owned 2Ws, and one in 10 use IPT. The average trip length in Surat is 5 km [Table 1], and pedestrians have long trip lengths (often as long as 3 km). Surat's historic core, the walled city, routinely experiences heavy traffic congestion due to inconsistent road widths (varying from 12 to 18 m) and the concentration of economic activities.

The current state of walking and cycling infrastructure is poor; only 20% of the city roads have pedestrian walkways, and only 7.6% have dedicated cycle tracks. The public transport network, consisting of the city buses and the Bus Rapid Transit System (BRTS), which is funded partly by the national government and partly by the city government, is fragmented and limited [Figure 1]. While auto-rickshaws, which are privately owned, serve a larger area [Figure 2], these trips cost relatively more than buses. Auto-rickshaws also run on certain arterial roads and are used as shared vehicles, similar to public transport modes. Owing to its limited network and poor last-mile connectivity, the mode share of buses (city buses and the BRTS) is low at 1.4% [Table 1]. The city, therefore, requires improvement in the public transport network along with walking and cycling infrastructure.

Current transport-SDG interactions in Surat

Lack of connectivity to the city center, overcrowding, and incompatible land uses generate physical and mental well-being trade-offs (SDG3), environmental degradation (SDG11 & 13), time poverty, and loss of productivity (SDG1 & 8). An overwhelmingly high share of personal vehicles (75%), high Vehicle Kilometer Traveled (VKT), and massive investments in automobile-based transport solutions generate trade-offs with inclusive, sustainable mobility (SDG11), environmental conservation and emission reduction (SDG13), safe access to employment opportunities and valued paid work under "decent work environment" (SDG1, 5 & 8). High non-motorized transport mode share in Surat fosters a synergy with increased physical activity

Table 1. Passenger transport in Surat (2016)

Transport characteristics	Registered vehicles	4.1 million
	Annual growth in the number of registered vehicles	9%
	Trip rate	1.6
	Annual vehicle kilometers traveled	9.4 billion
	Mode share (as of 2016)	
	Pedestrian	40%
	Cycle	2%
	Public transport	1.4%
	Intermediate public transport (IPT)	10.3%
	Two-wheelers	35.6%
	Cars	2%
	Other	8%
Transport systems & infrastructure	Road network length (in km)	5,773
	Non-motorized transport infrastructure	
	Footpath coverage (in % share of the total road network)	20%
	Cycle-track coverage (in % share of the total road network)	8%
	Pedestrian crossing	38
	Public transport	
	City bus fleet	811
	City bus network (in km)	274
	City bus routes	29
	BRT bus fleet	116
	BRT network	102
	BRT routes	35
	Intermediate public transport (IPT)	
	Number of vehicles	38,000
	IPT routes	52

Source: Surat CMP, 2018[41].

(SDG3), reducing the risk of premature death from obesity, diabetes, and other non-communicable diseases. But unsafe non-motorized transport infrastructure and inadequate public transport network lead to captive users (SDG1 & 8), a distorted mode mix and unequal distribution of road space (SDG11), compromised personal and sexual safety (SDG3 & 5), and curbed access to employment or devaluation of paid work (SDG8). Since most non-motorized transport users in Surat are captive, they are likely to shift to motorized transport for last mile or whole trips with increased income[42], increasing GHG emissions and related adverse impacts (SDG13). Old IPT fleets cause higher emissions and air & noise pollution, generating a trade-off with SDG11 and 13 while dissuading users due to lack of comfort and subpar ride quality. Freight and regional passenger transport passing through the city create trade-offs, increasing the frequency and severity of road accidents and pollution (SDG3 and 13). When questioned about their expectations from the city's mobility interventions, over 50% of Surat's residents hoped this would improve transportation, access to local shopping areas, and employment and enhance the well-being of the vulnerable populations[43]. A user satisfaction survey of Surat's BRTS revealed a high level of satisfaction among users. Major issues with the ongoing system included overcrowding during peak hours, private vehicles encroaching into and obstructing BRT lanes, inadequate parking around BRT stations, and the absence of an effective feeder system[44].

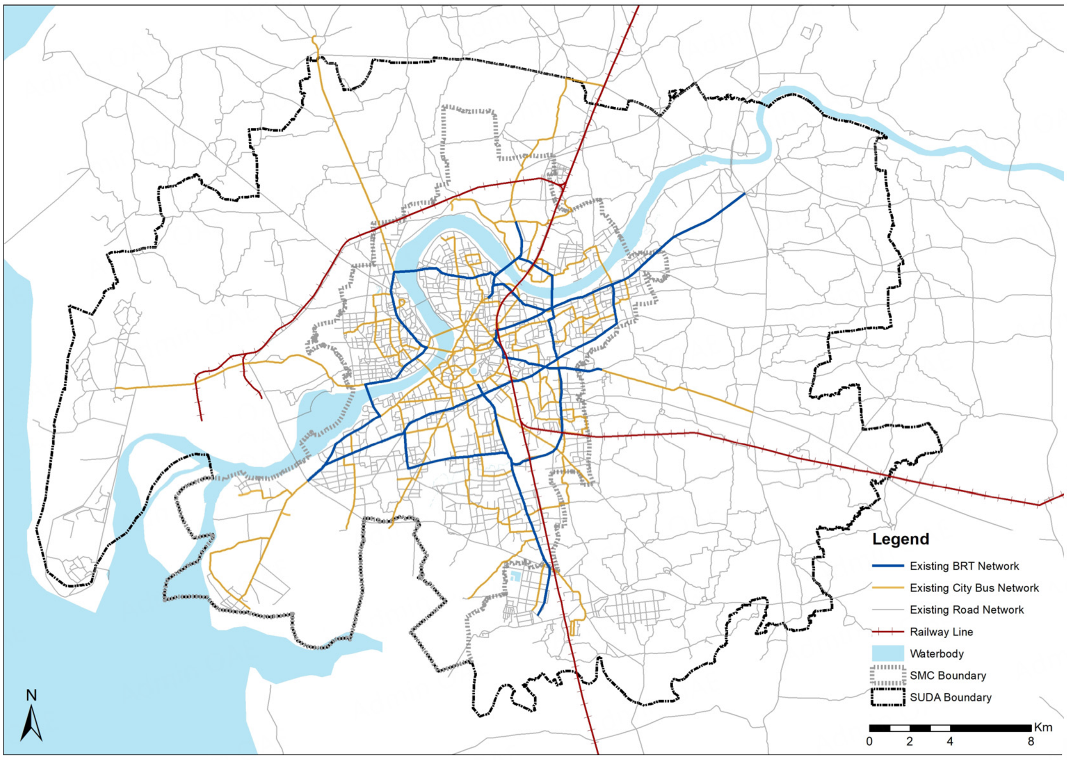

Figure 1. Existing PT network map.

Comprehensive mobility plan's low-carbon interventions

In 2018, Surat developed a comprehensive mobility plan (CMP) with a roadmap to achieve low-carbon mobility in Surat. Prepared to ensure "people-centric mobility", Surat's CMP emphasizes managing future travel demand through interventions that encourage a behavioral shift toward more sustainable transport choices. Surat CMP adopts a strategic planning approach, "Planning for Desirable Outcomes", which identifies the desired level of improvements in the quality of life, and works backward to build different sets of strategy mixes to achieve the same. Surat CMP's future scenarios are derived from extensive transport demand modeling, infrastructure cataloging, and GHG inventory. It estimates GHG emissions reduction to be 29% by 2046 and 16% by 2030 compared to base levels in 2016. Surat's CMP aims to increase the mobility of those not making trips using low-carbon modes and reduce emissions through the following strategies:

(i) Planned and well-managed urbanization: Includes (i) increase public-transit ridership through three types of transit-friendly streets: streets that can take Integrated Multimodal Transit network, streets that are Transit-Ready, and streets that can install Bus-Priority Lanes; and (ii) growth nodes connected to the city centers through rapid transit routes. The CMP projects a 43% decrease in traffic congestion from 2016 levels.

(ii) Reduction in vehicle-kilometer-traveled: CMP aims to cap the vehicle kilometers traveled to 45 million and reduce personal vehicle mode share by 22% by 2046.

(iii) Emphasis on non-motorized transport infrastructure: Proposals of new footpaths and bicycle lanes along at least 30% of the total road network in accident-prone zones, bike-sharing schemes with bike-docking points, and Intelligent Transport System (ITS). All arterial roads and multimodal transit routes

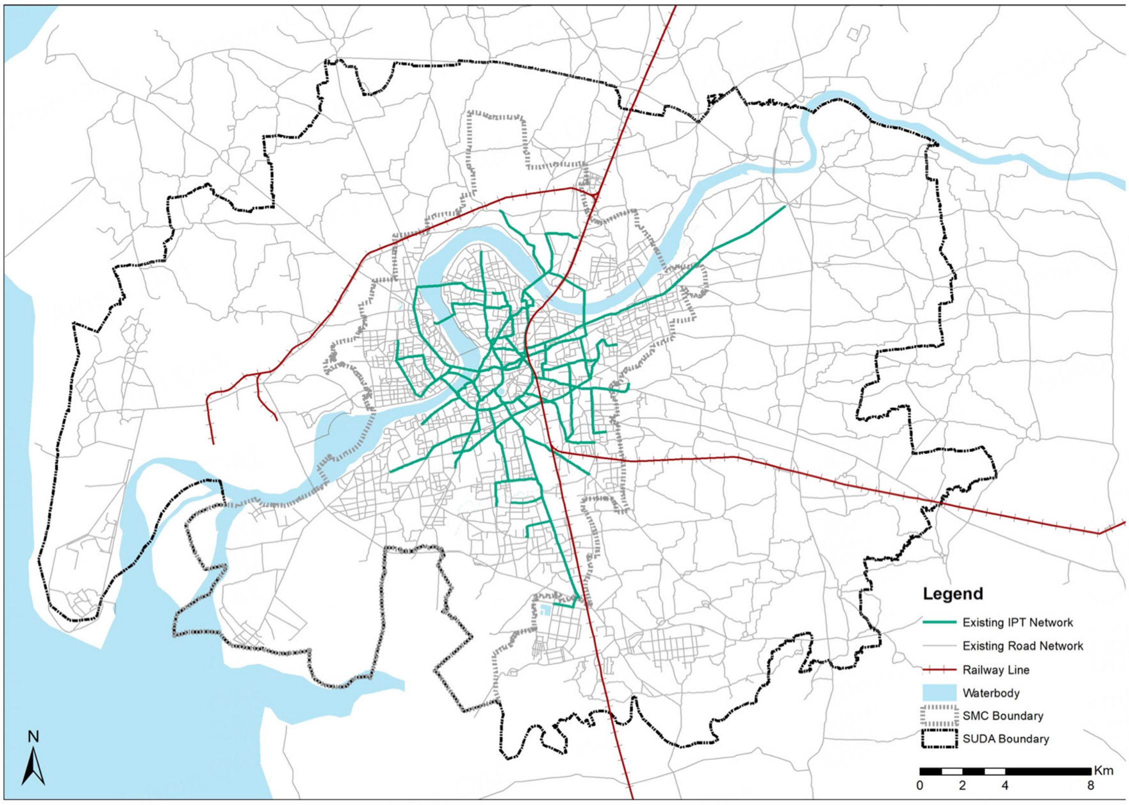

Figure 2. Existing IPT network map.

would be redesigned as per "Complete Streets" and Universal Street Design guidelines.

(iv) Investment in public transport: The modes proposed are the Bus Rapid Transit System (BRTS), regular public bus system, metro-rail, and ferry. The strategies discuss steps to increase the bus fleet, increase accessibility to public transport by 34%, and ensure 87% of households fall within 500m of public transit stations and multimodal fare integration.

METHODOLOGY

We present the project methodology [Figure 3] before detailing key methodological decisions and assumptions used for scenario development and GHG emissions modeling.

Scenario development

Based on past studies on Indian low-carbon scenarios[10,45], the paper assesses three scenarios for 2030. The first step is developing a qualitative scenario storyline[46,47], followed by quantitative assumptions for each scenario in the storyline. The narratives and assumptions used in scenario development are discussed below:

(i) The Base Scenario is constructed by projecting the travel demand from the base year (2016 [The city level CMPs are prepared every 20 years. These CMPs have extensive data base, which is hard to replicate in a short time span. Hence, we are using the 2016 survey as a base year. But, the understanding of transport systems and mobility related issues in the city are based on primary surveys undertaken in 2021]) to 2030 without considering any transport interventions proposed by Surat City's Comprehensive Mobility Plan. As

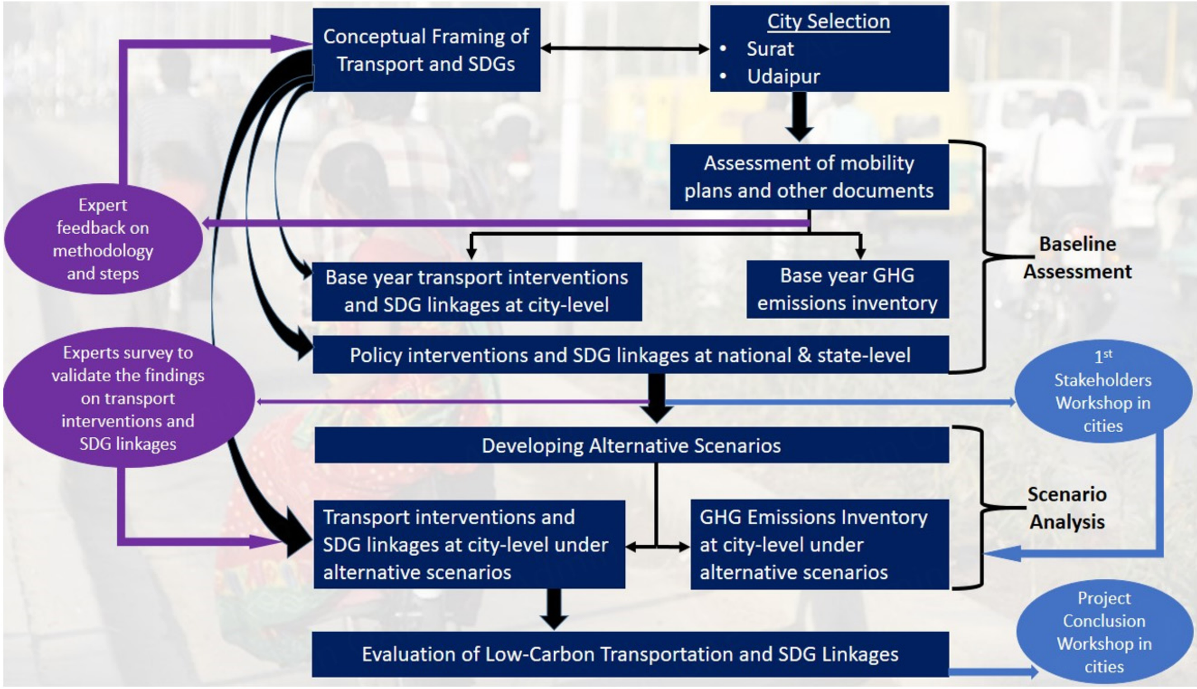

Figure 3. Project methodology.

the name suggests, this scenario is used as a reference case against which the impact of transport interventions on CO_2 emissions and SDGs for different scenarios are compared.

(ii) Scenario I is aligned with Surat CMP (as discussed in Section "Comprehensive mobility plan's low-carbon interventions"). The CMP projections are for 2046. Since the study's timeline is till 2030 (to assess impacts on SDGs), all other short- & medium-term interventions from the CMP are considered. However, significant land-use changes for 2046, e.g., segregation of residential and industrial land uses, are not considered as these are not expected to impact the immediate timeframe.

(iii) Scenario II is a Deep Decarbonization Scenario aligned with deep emission reduction necessary to achieve the global 1.5 °C temperature stabilization target. In addition to the interventions outlined in Surat's CMP (Scenario-I), this scenario assumes ambitious mitigation interventions implemented in the short term. These include technological improvements (vehicle & fuel efficiency, energy intensity, increased adoption of EVs) and sustainable behavioral changes (a greater shift to public transport, shared mobility, higher vehicle occupancy, and increased dependence on non-motorized transport for shorter trips).

(iv) Scenario III is an SDG-aligned Deep Decarbonization Scenario and builds on Scenario II. In addition to assumptions in Scenario II, this scenario also includes social and political transformation on account of ongoing processes of empowerment and democratization. It is rooted in social aspects of sustainability - like gender equality, education for all, equal opportunity, and sustainable mobility, mainly reflected by incorporating a higher Work Force Participation Rate (WFPR) (especially for women and poor) and higher school enrollments and, therefore, a higher number of trips for work and education, and thus increase in overall travel demand.

Travel demand projections

Surat's population in 2030 was estimated to be 9.2 million using a Compound Annual Growth Rate (CAGR) of 0.03% per annum[41]. Travel demand projections were calculated using 2030 assumptions about population growth rate, trip rate, trip length, and mode share for each trip purpose. For each scenario, these projections varied in line with the scenario storyline. The scenarios in the study assume progress on environmental (Scenarios I and II) and social and economic development (Scenario III), which significantly influence travel patterns.

These mobility assumptions are based on the contextual data derived from an in-depth qualitative survey and focused group discussions. Initially, the project aimed to capture trip diaries of approximately 0.05% of the total population in both cities through in-person surveys. Capturing detailed trip diaries (a detailed account of trip patterns collected over a fortnight) through in-person surveys for such a large sample size was challenging, especially given the ongoing pandemic. In keeping with the approaches used by researchers across the globe, mixed methods were deployed to overcome the hurdles of fieldwork during the COVID-19 pandemic. As a result, instead of detailed trip diaries, three types of surveys were used: a transport users' survey, a household survey, and a stakeholder's survey with a diverse body of stakeholders such as shop owners, street vendors, and others in the vicinity of a large-scale transport project. From October-December 2020, primary surveys (1,506 user & household surveys) (Detailed Questionnaire of the User Survey and Household Survey is attached as Supplementary Tables 1 and 2) and stakeholder surveys (115 surveys) (Sample size details disaggregated by stakeholders listed in Supplementary Table 3) were collected via random stratified sampling. Through this approach, demand-side trends, including travel patterns, mobility challenges, safety, affordability, resilience by mode, and the impacts of transport projects, were captured. This was supplemented with focus group discussions (3 focus group discussions with 30 participants) (Profile of Focus Group Discussion Participants listed in Supplementary Table 4). While the surveys focused on understanding the existing transport patterns in Surat city, they also included components eliciting feedback for future scenarios (e.g., the willingness to shift estimates, transport system improvements, *etc*.). The findings from the fieldwork (discussed in the results section) influence the travel demand projections and interpretation of proposed transport interventions on SDGs.

Trip rate

The average trip rate and motorized trip rate for all scenarios except Scenario III are taken from the city's CMP[41]. For Scenario III, trip rate assumptions involve demographic projections and travel demand estimation aligned with SDGs. Trip rate is calculated for each of the seven demographic groups (working-age population-males, working-age population-females, children aged 0-6 years, children aged 6-15 years, early adults aged 15-29 years, older adults aged above 60 years, disabled population aged 15-65 years) by trip purpose (work, education, health, recreation, other). The demographic projections include improvement in development indicators like sex ratio, workforce participation rates (male and female), the share of school enrollments, and life expectancy based on the projections of countries with similar socio-economic characteristics. The SDG-aligned Scenario III assumes (i) improvement in women's empowerment indicated by improved sex ratio (898/1,000 from 758/1,000) and female workforce participation rate (33% from 18%), based on Sri-Lanka's indicators - highest in the Asian context[48], increasing their mobility for work and other purposes (SDG5 & 8); (ii) improvement in school enrollment (100% across all income groups), resulting in increased trip rate of children in age 6-15 years (SDG1 & 8); (iii) improvement in healthcare facilities and life expectancy, increasing the older adults population (13.7 from 12%) and their trip rates for health and recreation (SDG3); and (iv) higher workforce participation rates for males (89.2% from 80%) and females, increasing share of working men and women (62.8% from 53.6%) and work trip rates (SDG8). These assumptions lead to a larger calculated travel demand and result in a considerably higher total trip rate in Scenario III (3.07) compared to Base Scenario (1.6). The SDG-aligned Scenario III also assumes improved household access to public transport (100% from 83%), enabling captive users who commute to work via NMT to move to motorized modes. The assumption of public transport access for all results in 100% work trips, 50% health trips, 50% education trips, 15% recreation trips, and 15% other purpose trips are assumed to be taken by motorized modes (largely public transport), increasing the motorized trip rate (1.43 in Scenario III, compared to Base Scenario).

Mode share

Decreased dependency on private motorized vehicles forms the core of low carbon and sustainable mobility[49]. Hence, a gradual shift from private vehicles to public transport is assumed in Scenarios II and III. Base Scenario and Scenario I follow CMP assumptions. Compared to Scenario I, the 2W mode share is about 20% lower (to 31.2% from 52%) in Scenarios II & III. 4W mode share is about 2% lower in Scenario II and III compared to Scenario I (8.4% 4W mode share). Scenarios II and III assume interventions to improve walking and cycling infrastructure from Level of Service (LOS) (Quality of service of transport is measured by the Level of Service (LOS) benchmarks based on numerous parameters like level of comfort, fleet, average waiting time, average speeds, street light, intersection delay, and encroachment, *etc*. As per MoHUA's Service Level Benchmark (SLB) Handbook, the LOS is measured on a scale of 1 to 4, indicating highest to lowest QOS) 3 to 1, which results in 100% household access to public transport. As a result of a more robust public transport network and increased last-mile connectivity (via walking and cycling), public transport mode share is higher in Scenarios II and III (37.7%) compared to 18.6% in Scenario I. BRT's fleet and route expansion, along with significant last-mile access improvement, enables an 11% increase in BRT mode share from Scenario I to Scenarios II and III. Metro rail's mode share is almost doubled in Scenarios II and III (to 8.5% from 4.3%). This growth rate in Scenario II and III is aligned with the ambitious ridership projections in the Surat Metro Detailed Project Report (DPR).

Trip length

Trip lengths for 2W, 3W & 4W in all scenarios are extrapolated to 2030 using the CMP data[41]. In Scenarios II and III, improved household access to public transport and higher public transport demand (due to socio-environmentally sustainable behavior) results in longer trip lengths for public transport (to 14.1 km in Scenarios II and III from 10.3 km in Scenario I), as indicated in literature[50].

Vehicle occupancy

Vehicle occupancy for Scenario I is calculated by extrapolating the CMP data[41]. Higher vehicle occupancy is a vital part of the behavioral change in Scenarios II & III. Literature indicates that environmentally sustainable behavior in private vehicle users translates into more carpooling and shared mobility[51], resulting in higher vehicle occupancy in 2W (to 1.5 from 1.1) and 4W (to 2 from 1.2) in Scenarios II and III from Scenario I. The shared mobility proportion for 2W & 4W contributes about 35% of VKT[52]. With the integration and management of IPT, along with an improved fleet (EVs), the vehicle occupancy of 3Ws increases to 4 from 1.5 in Scenarios II and III from Scenario I, indicating a higher carrying capacity of the newer fleet and efficiency of IPT management. As a result of the increased efficiency of PT in Scenario II & III, vehicle occupancy of BRT and City Bus improves by 15% (to 63 from 52.5) to reach 90% of its carrying capacity.

Technology

All scenarios assume that the share of vehicles older than 2016 in the total on-road vehicle pool is negligible. The EV category will encompass all on-road electric vehicles by 2030. Although technological maturity is expected to reduce costs and increase vehicle efficiency and reliability, the operating emissions of EVs will be governed by emissions from the electricity source[53]. Base Scenario and Scenario I assume conservative sales of newer vehicles with no share of BSVII (Bharat Emission Standards (BS) are the standards set up by the Indian government which specify the amount of air pollutants from internal combustion engines, including those that vehicles can emit. Starting from BSI in year 2000, currently, Indian vehicles are required to comply with BSVI norms) for any mode. Scenarios II and III assume greater policy support[54] for purchasing newer, less polluting vehicles with an increased focus on shared mobility (3W, BRT).

In Scenario I, in line with Surat's Comprehensive Mobility Plan, the entire public transport fleet, including BRT and City Buses, needs to be electrified by 2030. In Scenario II, a substantial phasing-out of BSIII & BSIV vehicles to increased adoption of BSVI & BSVII is assumed across all modes. Electrification for BRT and Metrorail is available in all scenarios. Although Scenario II is rooted in technological advancement, based on SMC's EV procurement documents, authors assume a 40% EV fleet for City Bus in Scenario I instead of the 100% EV fleet listed in the CMP. The remaining 60% of the City Bus fleet has transitioned from diesel to CNG instead of EVs[55] due to affordability and adequate infrastructure provision. A higher EV share for private vehicles in Scenario II is based on sustainable behavior patterns among households with a higher dependency on private vehicles[56]. Detailed assumptions for fuel mix and vehicle engine standards are listed in Supplementary Table 5.

GHG emissions

GHG emissions were calculated for each scenario using a bottom-up, mode-based approach using the Activity-Structure-Intensity-Fuel (ASIF) (A × S × I × F, where A is total transport activity (in pkm); S is share of pkm by mode; I is fuel efficiency by mode; F is emissions per unit of fuel by mode and type of fuel) model for transport emissions[57] and assumptions from the CMP. The ASIF model is widely accepted in transport emissions modeling due to its simple use and its ability to explain complex changes[58]. Assumptions for emission standards are discussed below.

Emission standards

The emissions factors are derived from ARAI's BS-VI emissions regulation booklet[59]. EV emissions are based on calculations involving power generation mix, renewable energy intensity, and vehicle kilometers traveled on EV modes. The energy generation values for a six-year period (2015-16 to 2020-21) were projected to 2030 based on calculated growth rates and a projected shift to clean power generation sources. Additional demand for energy for both EVs and metro-rail operation (except stations) are considered, using passenger km data for the latter[60], and tons per capita per year emission is calculated for the use of energy in the transport sector (based on the emission factor in terms of ton CO_2/TJ for sustainable 2030 scenario following[61].

Mode-wise emission factors and emission deterioration factors

The 2030 projections of demand side and supply side emissions of EVs (Electric Vehicles) were calculated for each scenario (I, II & III) for Surat, using emission factors as shown in Table 2. This component was calculated from the actual generation data instead of installed capacity to ensure that results are indicative of ground reality[62,63]. The 2030 projections are based on two assumptions: (i) all thermal power plants run on coal/lignite; and (ii) all Renewable Energy Source (RES) plants with an incinerator utilize zero-emissions fuels.

Assessment of SDG interactions

SDG interactions with Surat's transport sector were assessed based on the existing situation and all four scenarios. SDG interactions are sector- and context-specific. Direct and indirect interactions between SDG and transport in the global South were derived from an extensive literature review of 9,000 papers. Upon that, the research team conducted a critical assessment of Surat's CMP[41] and other city-level planning

Table 2. Emission factors by mode

Emission factors	BS IV CO_2 (g/km)	BS VI CO_2 (g/km)	BS VII CO_2 (g/km)	EV (g CO_2 eq./km)
2W (Petrol)	45.36	39	27.94	[7.89-12.45]
3W (CNG)	69.96	60.36	43.4	[13.14-20.75]
4W (Petrol)	138.6	112.56	76.18	[41.27-65.16]
4W (Diesel)	162.91	132.33	97.72	-
Metro	0	0	0	[3,015.24-4,760.92]
BRT- Diesel	538.12	516.62	322.83	[220.80-348.64]
BRT- CNG	587.04	556.36	322.83	-
City- Bus Diesel	538.12	516.62	322.83	[297.03-469.00]
Other- Buses Diesel	538.12	516.62	322.83	[169.55-267.71]

Source: ARAI, 2021.

documents to contextualize the findings of the literature review for the city of Surat. The research team conducted detailed primary fieldwork to further update the findings from the CMP's critical assessment at a recent timeline. Transport modes (NMT, PT, *etc.*) were compared against national benchmarks (refer to Table 3) to analyze the adequacy and efficiency of each transport system element and supplemented with the findings from the fieldwork to assess whether the transport intervention generated a trade-off (-1), synergy (+1), or a mixed effect (+/- 1). The assignment of interaction scores, based on the framework by Nilsson *et al.* (2016)[64], is subjective, as the scores are assigned by the authors, who are field experts. We acknowledge that results may vary with different groups of people, a common limitation of any exercise involving the assignment of assessment scores[64-66].

RESULTS

Travel demand and willingness to shift

Fieldwork indicates that of all the private vehicle users (2W & 4W), 90% reported experiencing frequent traffic congestion, and 47% reported being in a road accident within the past 2 years. 76% of private vehicle users owned a 2W, and 57% reported an annual income of less than Rs. 300,000, putting them in the low-income group. Most (96%) of private vehicle users depend on their vehicles to access economic opportunities. Again, a large majority (over 95%) of private vehicle users were willing to shift to Public Transport Modes, especially Metrorail, provided Public Transport routes were accessible (53% of users) and affordable (26%). About a quarter of the users of non-motorized transport and public transport belonged to very low-income households (earning less than Rs. 60,000 annually), and the other half belonged to low-income households (earning between Rs. 60,000 - Rs. 300,000 annually). 47% of the very low-income households chose to use NMT due to the unavailability of PT. 32% of NMT users and 40% of PT users reported missing out on economic opportunities due to unreliable and inaccessible PT. Most NMT users recommended large-scale NMT infrastructure improvement (74% rate NMT infrastructure as poor, inadequate, and very unsafe). 83% of NMT users expressed willingness to shift to PT, given safe and convenient last-mile accessibility and broader PT coverage. In the lack of PT and NMT improvements, the majority of NMT and PT users would prefer to shift to 2Ws with an increase in income.

Fuel mix

Scenario II has the highest share of clean fuels compared to any other scenario (refer to Figure 4). Public Transport Modes have the highest EV share (BRT: 100% EV, City Bus: 40% EV, and 60% in BS-VI) across all modes in Scenario III, compared to 0% EV or BS-VI in the Base Scenario. Scenario II and III also witness a highly sustainable fuel mix for 3Ws (70% EV, 20% BS VI, and 10% BS-VIII) compared to the Base Scenario 0% EV or BS-VII. 2Ws and 4Ws continue to have a diverse fuel mix across scenarios, with an increasing

Table 3. Example of transport system indicators and their national benchmarks

Transport systems	System indicators*	National benchmark for LOS 1**	Direct/indirect interactions with SDGs***
Non-motorized transport (NMT)	NMT network coverage (%)	> 75%	1, 3, 5, 8, 11, 13
	NMT mode share****	36%	3, 11, 13
	Street lighting (Lux)	≥ 30%	3, 5, 11
	Encroachment on NMT paths by vehicular parking	< 10%	1, 8, 11
	Signalized intersections	> 75%	3, 11
Public transport (PT)	PT network coverage (%)	> 60%	1, 3, 5, 8, 11, 13
	PT mode share**	21%	1, 3, 5, 8, 11, 13
	Transit supply: buses/1,000 population	> 0.6	1, 5, 11
	Average waiting time for PT	< 4 min	1, 5, 11
	Level of comfort in PT (occupancy/carrying capacity)	< 1.5%	5, 11
	Transport affordability (% HH income expenditure)	< 15%	1, 5, 8, 11
	Average travel speed	> 20 KMPH	11, 13
	Transit access area (% built area within 500 m of transit stops)	> 80%	1, 3, 5, 8, 11, 13
	Transit friendly streets (% area exclusively used for transit)	≥ 30%	11, 13
	Mixed land-use along transit corridors	≥ 30%	3, 5, 8, 11
	Population density along transit corridors (people per hectare)	> 175	5, 11
Intermediate Public Transit (IPT)	IPT mode share**	3%	1, 5, 11
	Average travel speed	> 30 KMPH	11, 13
Roads and Motorized Transport	Road network coverage (% area under roads)	≥ 15%	1, 8, 11, 13
	Average travel speed (motorized vehicles)	> 30 KMPH	11, 13
	V/C ratio	< 1	8, 11, 13
	Road fatality rate per lakh population	< 2 People	1, 3, 11
	Road fatality rate for NMT users	< 20%	1, 3, 11

*This is not an exhaustive list; **values listed in this column refer to benchmarking for Level of Service (LOS) 1 (the highest level of service), based on the Service Level Benchmark for Urban Transport issued by the Ministry of Housing and Urban Affairs, 2013[67]; ***The interactions are derived from extensive literature reviews; ****mode share values differ with the population size and are derived from the Ministry of the Urban Development's (MoUD) Traffic & Transportation Policies and Strategies in Urban Areas in India[68].

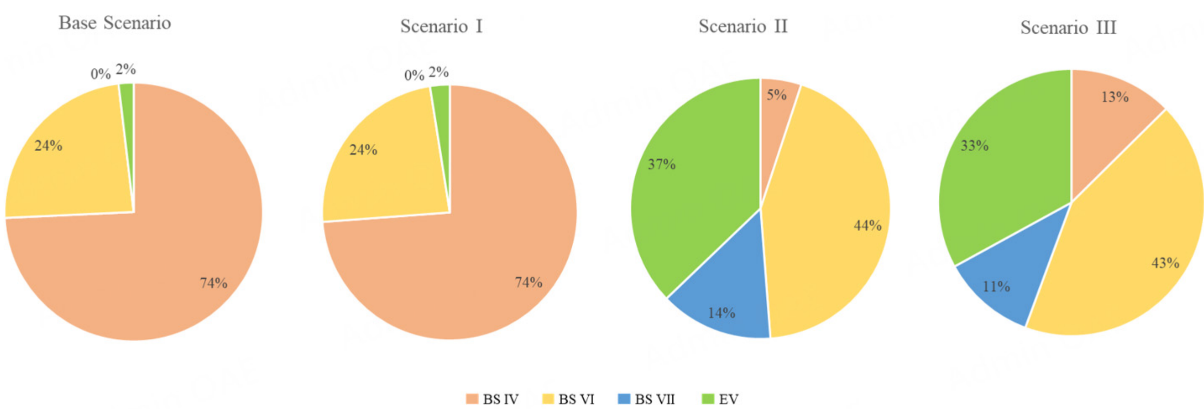

Figure 4. Fuel mix for different scenarios.

share of cleaner fuels; the share of BS-IV 2Ws drops from 78% in the Base Scenario to 5% in Scenario II and 10% in Scenario III. The share of EV 2Ws increased to 35% in Scenario II and 30% in Scenario III, from 2% in the Base Scenario. Similarly, in 4Ws, the share of BS-IV decreases from 65% in the Base Scenario to 12% in Scenario III, and the share of EV increases to 20% in Scenario III from 2% in the Base Scenario.

Motorized vehicle kilometer traveled

Two-wheelers contribute to the highest share of VKT, followed by four-wheelers [Figure 5]. Compared to the Base Scenario, Scenario II achieves the highest reduction in VKT (49%). Although Scenario III marks a 26% increase in VKT compared to Scenario II, it achieves a 23% decrease compared to Base Scenario and a 5% additional decrease than Scenario I. Scenarios II & III result in a higher VKT for 3Ws than the Base Scenario, owing to a higher IPT mode share in Scenario II & III. A higher trip rate in Scenario III results in a much higher (about double) VKT of public transport modes like Metro-rail, BRT, and City Bus compared to Scenario II. Covering almost double the VKT with the same PT fleet size (as in Scenario II) may pose a threat to the notion of "mobility for all" in Scenario III.

GHG emissions

Compared to the Base Scenario, Scenario I achieves a 16% decrease, Scenario II achieves a 59% decrease, and Scenario III achieves a 25% decrease [Figure 6]. Scenarios I, II, and III result in per-capita carbon emissions of 0.05, 0.02, and 0.04 tons per day, respectively. Considering modal emissions, two-wheelers demonstrate the greatest emissions reduction across all scenarios (73% and 53% reduction, respectively, in Scenario II and Scenario III from the Base Scenario). Public transport modes see a significant increase in Scenario III (286% for BRTS, 129% for City Buses). Scenario II shows a drastic decrease in both VKT and emissions, while Scenario III shows an 8% decrease in total VKT and an 11% decrease in total emissions compared to Scenario I.

SDG targets related progress

Scenario I: Many trade-offs in the Base scenario are either mitigated or transformed into synergies through non-motorized transport and public transport interventions. Multiple trade-offs are generated due to interventions such as Transit Oriented Development (TOD), Local Area Plans (LAP), Metro-rail, road network construction, and road widening projects. Studies in the global South indicate that creating TOD or high land-value capture zones can lead to gentrification, displacement, and increased poverty for the urban poor (SDG1.5, SDG1.A)[69]. Large-scale urban transport infrastructure projects often cause displacement, evictions, or loss of property and employment for adjoining residents, especially the urban poor (SDG1.1 & SDG8.5), encouraging the adoption of personal vehicles (SDG 11.2), thus contributing to traffic congestion, air/noise pollution, stress, and anxiety (SDG3.4, SDG3.9) and increased emissions (SDG13). Although the personal vehicle mode share reduces in Scenario I to 53%, it is considerably high for a sustainable mobility scenario, resulting in trade-offs with SDG11. The personal vehicle fuel mix in Scenario I illustrates a need for more strategies to transition to a more sustainable fleet, possibly underdelivering intended emissions reductions (SDG13.2). Non-motorized & public transport network expansion and infrastructure improvements result in 34% higher accessibility to low-carbon modes and achieve a 16% reduction in emissions (SDG11.1, SDG11.2, SDG13.2).

Scenario II: Sustainable fleet switch drives massive reduction in this scenario, resulting in synergy with SDG3.9 (air pollution), SDG13.2 (emission mitigation, adaptation and resilience), and SDG11.2 (affordable, safe, and inclusive transport). Along with the trade-offs of evictions and displacement (mentioned in Scenario I), limited transit access and lower trip rates, especially for women and urban poor, continue to cause "mixed" impacts with SDG1.1 & SDG1.4 (socio-economic mobility), SDG5.1 and SDG5.2 (gender-sensitive design), and SDG8.1 (economic development) in the medium term (2030).

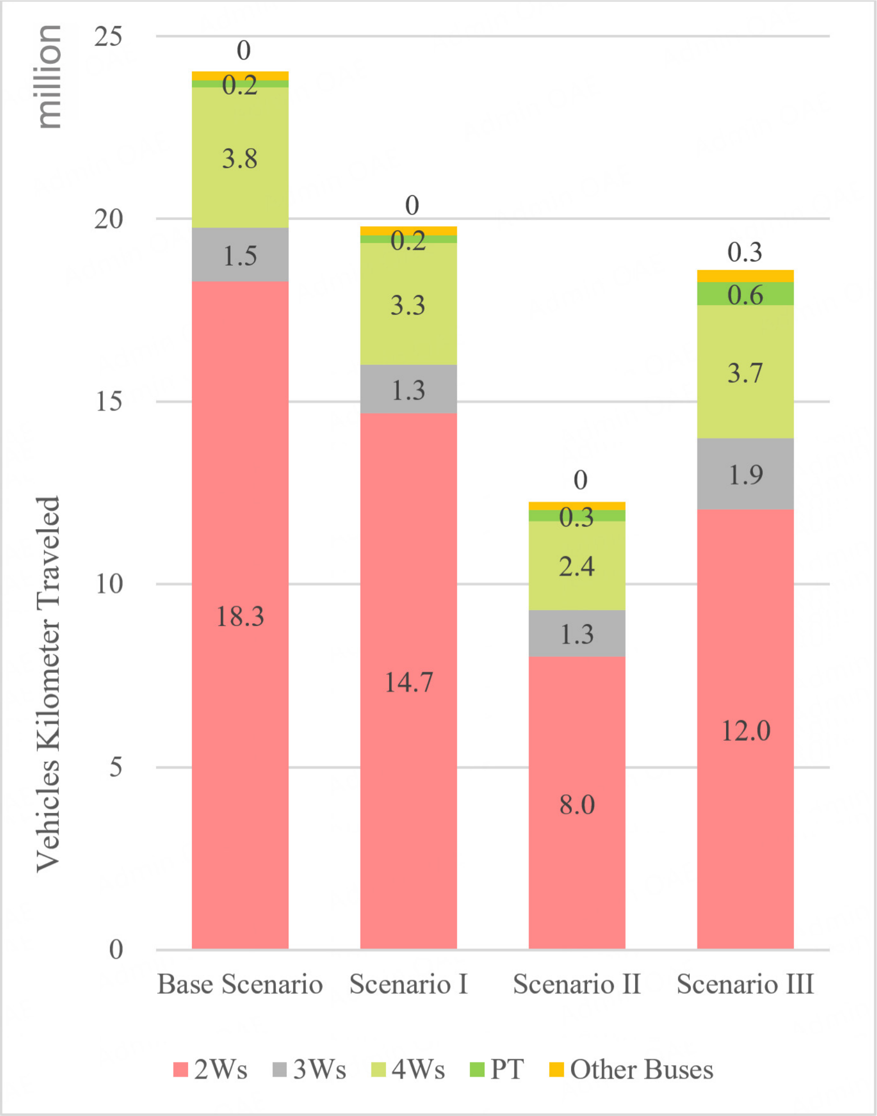

Figure 5. Scenario-wise vehicle kilometers traveled (VKT) by modes. Note: The "PT" category consists of Metro, BRT and city bus.

Scenario III: In this scenario, public transport and IPT interventions deliver multiple sustainable outcomes including last mile connectivity, affordability, employment of the poor, improving road safety, resilience during COVID-19, and gender equity. 100% public transport and non-motorized transport network coverage of affordable and peripheral housing and employment locations with affordable services, mitigates the "mixed" impacts mentioned in Scenario II and generates maximum synergies with all SDGs (Table 4 below).

Discussion

The paper proposes three approaches to the future transport scenario for Surat, a fast-growing metropolitan city: Scenario I, a regular low-carbon scenario based on a city-specific low-carbon mobility plan; Scenario II, a deep decarbonization scenario that relies on the ambitious implementation of technological and environmentally sustainable interventions toward achieving a 1.5 °C temperature stabilization, and Scenario III, an SDG-aligned deep decarbonization scenario to deliver sustainable outcomes.

Table 4. SDG interactions across the scenarios

Interaction	SDG 1	SDG 3	SDG 5	SDG 8	SDG 11	SDG 13
Scenario I						
Summary	(-1)	(+/-1)	(+1)	(+/-1)	(+/-1)	(+/-1)
Trade-off	Road-based transport solutions result in displacement, evictions, or loss of property & employment for the urban poor. High-value capture zones, like TOD, result in gentrification in adjoining areas	Increased dependence on motorized transport and subsequent traffic congestion, negatively impacting human health via increased exposure to air/noise pollution, road accidents, stress, and anxiety (from driving in congestion)		Land-acquisitions for road-based transport solutions result in loss of livelihood and property in and around the intervention area	Road-based transport solutions promote inequitable road-space distribution, and encourage adoption of private motorized vehicles	Dependence on motorized vehicles and lack of strategies to phase out to a more sustainable fleet, under-delivers intended emissions reductions
Synergy			NMT infrastructure improvement and PT expansion increase safety and mobility of women	NMT infrastructure improvement enables a "decent work" condition for urban poor who either walk to work or are employed on the streets	Transit-oriented Development, and feeder bus services increase public transit coverage	A relatively more sustainability fleet and mode share than the Base Scenario results in emission reduction
Scenario II						
Summary	(+/-1)	(+1)	(+1)	(+/-1)	(+/-1)	(+1)
Trade-off	Lack of interventions that counter road-based solutions, continues to result in the same trade-offs as Scenario I				Trade-offs caused by inequitable road-space distribution continue to violate sustainable mobility and neighborhoods	
Synergy (adding onto the synergies in Scenario I)	Subsidies for E-rickshaws decrease entry-level barriers for urban poor and improve economic outcomes by providing employment to unemployed and under-employed workers	Sustainable fleet substantially improves air quality and sustainable behavioral choices promote increased physical activity	Increased dependence on NMT for shorter trips by all groups, improves safety (via increased activity generation) for women and girls that are largely dependent on NMT	A more aggressive adoption of EVs, especially for the IPT sector, creates more employment opportunities for many other NMT providers (cycle-rickshaw, handcarts) and improves incomes for E-Rickshaw drivers	Sustainable behavior choices and fleet enables a low-carbon transport system, and forwards sustainability goals	Sustainable fleet switch (increased fuel and engine efficiency) drives massive emission reduction compared to Base Scenario
Scenario III						
Summary	(+1)	(+1)	(+1)	(+1)	(+1)	(+/-1)
Trade-off						Increased travel demand, especially motorized travel demand, increases emissions
Synergy (adding onto the synergies	Expanding the NMT and PT network coverage, especially into	Street design improvements using Universal Design and	NMT infrastructure improvement through Universal Design Guidelines and Complete Streets,	Mainstreaming IPT creates more employment opportunities in the transport sector, while improving	NMT improvement (including street design improvements), along with increased household access to	Although motorized VKT and emissions increased compared to Scenario II,

in Scenario II)	neighborhoods with informal or low-income housing, increases access to economic opportunities, especially for the mobility-deprived	Complete Streets guidelines decrease incidences of road accidents	increases personal and sexual safety for women. PT system improvements (network, frequency and infrastructure), along with improved last-mile, improve women's mobility and increase their access to civic and economic opportunities	NMT infrastructure through Universal Design Guidelines and Complete Streets strategies creates 'decent work' conditions for all and enhanced productivity. PT expansion and improved last-mile access improve economic outcomes of the captive NMT users and the mobility-deprived	PT and improved last-mile (through feeder buses), improves access to basic services and mobility for vulnerable groups. NMT and PT improvement also increases resilience during extreme weather events, especially for the urban poor	the sustainable behavioral choices reflected in a higher NMT and PT mode share, continue to deliver emission reductions compared to the Base Scenario

Key: synergy (+1), trade-off (-1), Neutral (0), and both synergy and trade-off (+,-).

As expected, Scenario II achieves the greatest emission reduction (almost 60%) compared to Base Scenario owing to strategies that promote environmentally conscious behavior and aggressive adoption of a sustainable fuel mix. Scenario III is based on social aspects of sustainability and achieves a 25% emission reduction compared to the Base Scenario. Increased mobility of disadvantaged groups in Scenario III results in higher vehicle kilometers traveled and, hence, higher emissions than in Scenario II. Modal shifts from private vehicles to public transport in Scenarios II & III primarily drive the emission reduction. The reduction in private two-wheelers can be attributed to anticipated behavioral changes like higher vehicle occupancy, decreased private motorized mode preference, and technological advancements like a higher number of cleaner and more fuel-efficient public transport fleets. The significant increase in emissions from public transport modes in Scenario III stems from a 19% increase in its mode share and over 200% increase in its demand. A larger share of fuel-efficient public transport fleet and higher vehicle occupancy of three-wheelers in Scenario II results in an emission reduction of 65% from the base scenario despite only a 9% change in mode share. Scenario II has the lowest total and per-capita CO_2 emission, yet results in "mixed" interactions with three of the six SDGs. Scenario III has maximum synergies with the SDGs compared to any other scenario and has the second-lowest total and per-capita GHG emissions, making it the most suitable scenario for Surat's sustainable future.

Initial urban transport studies investigated urban pollution[70], accessibility[71], NMT infrastructure and mobility[72], and safety[73]. The next set of urban transport studies examined how the transport sector can contribute to climate change mitigation[10,58,74]. Advancing these, research needs to look at social inclusion and other development indicators, especially in terms of universal access, climate change adaptation and resilience, and socio-economic mobility[75]. IPCC's Special Report on the Global Warming of 1.5 °C highlights deep and ambitious reductions across sectors and systems and emphasizes the importance of aligning these with sustainable development[1]. IPCC's Sixth Assessment Report shows that transport actions such as a shift to public transport, demand reduction measures, and electrification can deliver synergies with SDGs. This study illustrates that for cities in the global South grappling with simultaneous challenges of poverty, inequality, and climate change, addressing various deprivations, such as low mobility and reduced access to opportunities, is essential to achieving SDGs. However, this comes at the cost of increased emissions. Nevertheless, this study illustrates that this increase is marginal, a 34% increase than the deep decarbonized scenario, but gains in the SDGs are significant and justifiably high. Such trade-offs of extreme climate mitigation actions and SDG-enhancing actions would be essential for sustainable climate change mitigation, which we call SDG-aligned climate change mitigation efforts in developing countries.

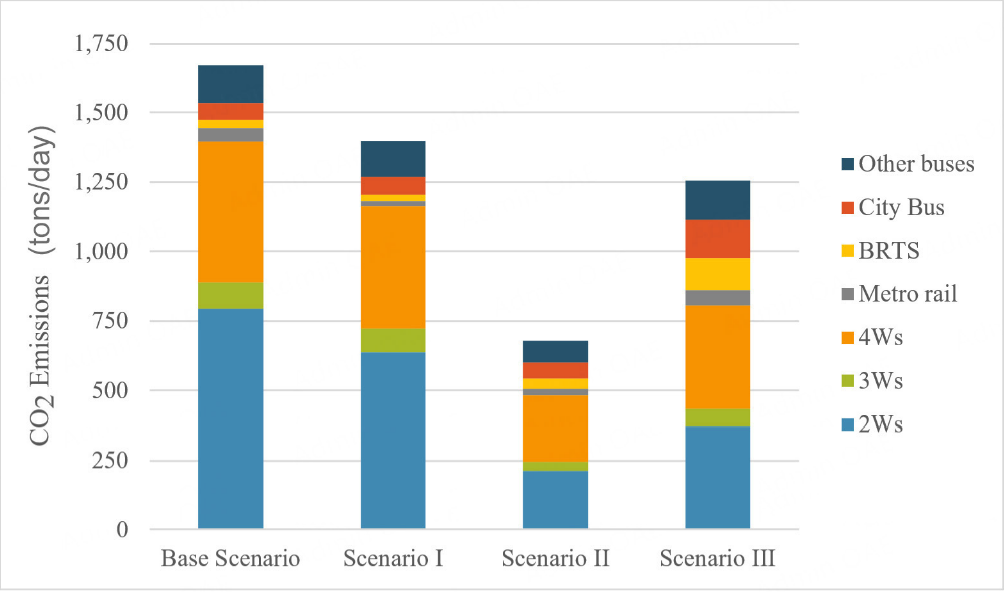

Figure 6. CO_2 emissions (tons/day) by mode and scenarios.

CONCLUSION

The most important conclusion of this paper is that for the regions with high socio-economic inequity and curbed mobility, scenarios that account for sustainability often involve higher emissions than an aggressive deep decarbonization scenario. Put another way, deep decarbonization of urban transport cannot be at the cost of the continuance of low mobility of the vulnerable urban groups in highly unequal cities. Thus, cities such as Surat, a fast-growing metropolis in the Global South, need to enhance the mobility of their current and future vulnerable populations. This can be achieved by prioritizing public transport and NMT infrastructure in the cities, rather than road-based solutions like widening roads, constructing city-level elevated highways, and road network expansions. Redeploying funds for public transport and NMT is crucial to delivering Socially Sustainable Low-Carbon Transport in cities of the Global South.

Another important finding that aligns with previous studies[19] is the share of IPT as a key option in delivering sustainable mobility. It enhances the use of public transport, manages private motorization, and delivers emission reductions compared to private vehicle trips. However, shared last-mile connectivity options like the auto-rickshaw sector are still semi-formal and require more governance attention in sustainable transport policy. Transport modes like IPT also support employment in the cities of the global South[24], and hence need to be technologically upgraded, formalized, and integrated with the city's public transport systems through innovative governance mechanisms. Initiatives like Pink Autos of Ranchi and Surat (in India) - auto services for women by women- serve as an interesting example of formalizing and upscaling the IPT sector. In 2017, SMC provided training, licensing, and subsidies (on the purchase of IPT vehicles) to 70 female auto-rickshaw drivers. SMC aimed to increase women's workforce participation rate in the city's transport sector, along with providing safe transport options for women.

The transport sector policies require a paradigmatic shift from focusing on designing active transport systems that enhance the latent mobility needs of vulnerable populations with technological and governance improvements. Mainstreaming these into the conventional transportation planning documents is vital to realize this paradigm shift. One such tool - the Comprehensive Mobility Plans (CMPs) preparation - serves as an apt mechanism to advance multiple simultaneous goals such as emission reduction, climate-resilient transport systems, improved public health and SDG delivery. When CMPs embed both social sector targets related to poverty reduction, employment generation, improvement in education and health, and climate actions in gender-equitous ways, a socially sustainable low-carbon future can be unlocked.

DECLARATIONS

Acknowledgment

The study was part of a large-scale research project- OPTIMISM (Opportunities of climate change mitigation and Sustainable Development), with partners from four countries. This research is funded by the Department of Biotechnology (DBT), Ministry of Science & Technology, Government of India. The authors would like to express gratitude to the Resilience Strata team for conducting fieldwork and to Bandish Patel for coordinating the primary surveys in Surat. The authors also thank Disable India, Jeevanam Astey, Institute of Transport and Development Policy (ITDP), Space Kreators, and Mahila Housing Trust (MHT) for participating in the Focus Group Discussions. All maps presented in the paper are prepared by Kanika Gounder.

Authors' contributions

Conceptualizing, framing, and methodology development: Mahadevia, D.; Pathak, M.
Literature review: Lathia, S.; Mukhopadhyay, C.; Pathak, M.
Calculations: Lathia, S.; Rawal, S.; Pathak, M.; Mahadevia, D.; Mukhopadhyay, C.
Results interpretation: Lathia, S.; Pathak, M.
Final text: Mahadevia, D.; Pathak, M.; Lathia, S.

Availability of data and materials

Some results supporting the study are presented in the Supplementary Materials. Other raw data that support the findings of this study are available from the corresponding author upon reasonable request.

Financial support and sponsorship

This work was supported by the Department of Bio-Technology, Ministry of Science & Technology, Government of India [BT/IN/TaSE/74/MP/2018-19; Date: 14/10/2019].

Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Copyright

REFERENCES

1. Allen, M. R.; Dube, O. P.; Solecki, W.; et al. Framing and context. 2018. Available from: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/10/SR15_1SM_Low_Res.pdf [Last accessed on 23 Apr 2025].
2. IPCC. Climate change 2022 - impacts, adaptation and vulnerability: working group II contribution to the sixth assessment report of the intergovernmental panel on climate change. Cambridge, England: Cambridge University Press; 2023, p. 3056. DOI
3. NITI Aayog. Reforms in urban planning capacity in India. New Delhi: NITI Aayog; 2021. Available from: https://www.niti.gov.in/sites/default/files/2021-09/UrbanPlanningCapacity-in-India-16092021.pdf [Last accessed on 23 Apr 2025].

4. United Nations. World Urbanization prospects: the 2018 revision. New York: United Nations; 2019. Available from: https://population.un.org/wup/assets/WUP2018-Report.pdf [Last accessed on 23 Apr 2025].
5. Mahadevia, D.; Advani, D. Gender differentials in travel pattern - the case of a mid-sized city, Rajkot, India. *Transp. Res. Part. D.* **2016**, *44*, 292-302. DOI
6. UNDP. Addressing Gender Concerns in India's Urban Renewal Mission. New Delhi: United Nations Development Programme; 2009. Available from: https://www.undp.org/sites/g/files/zskgke326/files/migration/in/addressinggenderconcerns.pdf [Last accessed on 23 Apr 2025].
7. Anand, A.; Tiwari, G. A gendered perspective of the shelter-transport-livelihood link: the case of poor women in Delhi. *Transp. Rev.* **2006**, *26*, 63-80. DOI
8. World Bank. Global economic prospects 2005: trade, regionalism and development. Washington, DC: World Bank; 2005. Available from: https://openknowledge.worldbank.org/entities/publication/cf5511b6-919a-5cbf-9948-e7d70ea60853 [Last accessed on 23 Apr 2025].
9. International Energy Agency. CO2 Emissions from Fuel Combustion (2019 Edition). IEA; 2019. DOI
10. Dhar, S.; Pathak, M.; Shukla, P. R. Transformation of India's transport sector under global warming of 2 °C and 1.5 °C scenario. *J. Clean. Prod.* **2018**, *172*, 417-27. DOI
11. Godínez-Zamora, G.; Victor-Gallardo, L.; Angulo-Paniagua, J.; et al. Decarbonising the transport and energy sectors: technical feasibility and socioeconomic impacts in Costa Rica. *Energy. Strategy. Rev.* **2020**, *32*, 100573. DOI
12. NITI Aayog. Comparison of decarbonisation strategies for India's land transport sector: an inter model assessment. New Delhi: TERI; 2019. Available from: https://shaktifoundation.in/wp-content/uploads/2019/11/Intermodel-Study_Final-Report.pdf [Last accessed on 23 Apr 2025].
13. Munshi, T.; Shah, K.; Vaid, A.; et al. Promoting low carbon development in India, low-carbon comprehensive mobility plan: Rajkot. 2015. DOI
14. Department for Transport. Decarbonising transport: a better, greener Britain. London; 2021. Available from: https://assets.publishing.service.gov.uk/media/610d63ffe90e0706d92fa282/decarbonising-transport-a-better-greener-britain.pdf [Last accessed on 23 Apr 2025].
15. Sharifi, A. Co-benefits and synergies between urban climate change mitigation and adaptation measures: a literature review. *Sci. Total. Environ.* **2021**, *750*, 141642. DOI
16. Boyd, D.; Pathak, M.; Van Diemen, R.; Skea, J. Mitigation co-benefits of climate change adaptation: a case-study analysis of eight cities. *Sustain. Cities. Soc.* **2022**, *77*, 103563. DOI
17. Roy, J.; Some, S.; Das, N.; Pathak, M. Demand side climate change mitigation actions and SDGs: literature review with systematic evidence search. *Environ. Res. Lett.* **2021**, *16*, 043003. DOI
18. Das, D.; Kalbar, P. P.; Velaga, N. R. Pathways to decarbonize passenger transportation: implications to India's climate budget. *J. Clean. Prod.* **2021**, *295*, 126321. DOI
19. Mani, A.; Pai, M.; Aggarwal, R. Sustainable urban transport policy in India: focus on autorickshaw sector. *Transp. Res. Rec.* **2012**, *2317*, 104-10. DOI
20. Verma, A.; Harsha, V.; Subramanian, G. H. Evolution of urban transportation policies in India: a review and analysis. *Transp. Dev. Econ.* **2021**, *7*, 136. DOI
21. Hickman, R.; Hall, P.; Banister, D. Planning more for sustainable mobility. *J. Transp. Geogr.* **2013**, *33*, 210-9. DOI
22. Buckle, S.; Mirabile, M.; Jaber, A.; et al. Integrated policies for climate, air, ecosystems, energy and transport. In: Systemic thinking for policy making: the potential of systems analysis for addressing global policy challenges in the 21st century. OECD; 2020, pp. 44-53. DOI
23. World Bank Group. Closing the gap: gender, transport, and employment in Mumbai; 2021. Available from: https://openknowledge.worldbank.org/bitstream/handle/10986/35248/Closing-the-Gap-Gender-Transport-and-Employment-in-Mumbai.pdf?sequence=1&isAllowed=y [Last accessed on 23 Apr 2025].
24. Singh, D. R.; Mishra, S.; Tripathi, K. Analysing acceptability of E-rickshaw as a public transport innovation in Delhi: a responsible innovation perspective. *Technol. Forecast. Soc. Chang.* **2021**, *170*, 120908. DOI
25. Wismans, J.; Grahn, M.; Denbratt, I. Low-carbon transport - health and climate benefits. 2016. Available from: https://publications.lib.chalmers.se/records/fulltext/233671/233671.pdf [Last accessed on 23 Apr 2025].
26. World Health Organization (WHO). Ambient (outdoor) air pollution; 2022. Available from: https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health [Last accessed on 23 Apr 2025].
27. IQAir. 2019 world air quality report: region & city PM2.5 ranking; 2019. Available from: https://www.iqair.com/dl/pdf-reports/2019-World-Air-Report-V8-20200318.pdf [Last accessed on 23 Apr 2025].
28. World Health Organization (WHO). Global status report on road safety 2018. World Health Organization; 2018. Available from: https://www.who.int/publications-detail-redirect/9789241565684 [Last accessed on 23 Apr 2025].
29. Macmillan, A.; Smith, M.; Witten, K.; et al. Suburb-level changes for active transport to meet the SDGs: causal theory and a New Zealand case study. *Sci. Total. Environ.* **2020**, *714*, 136678. DOI
30. Ramirez-Rubio, O.; Daher, C.; Fanjul, G.; et al. Urban health: an example of a "health in all policies" approach in the context of SDGs implementation. *Global. Health.* **2019**, *15*, 87. DOI
31. Mahadevia, D. Gender sensitive transport planning for cities in India; 2015. DOI

32. Bhatt, A.; Menon, R.; Khan, A. Women's safety in public transport: a pilot initiative in Bhopal. The WRI Ross Center for Sustainable Cities; 2015. Available from: https://www.wricitiesindia.org/sites/default/files/Women%27s%20Safety.pdf [Last accessed on 23 Apr 2025].
33. SUTP. SUTP module 7a - approaches for gender responsive urban mobility: gender and urban transport - smart and affordable. GIZ-SUTP; 2018. Available from: https://sutp.org/publications/approaches-for-gender-responsive-urban-mobility-gender-and-urban-transport-smart-and-affordable/ [Last accessed on 23 Apr 2025].
34. Shah, S.; Raman, A. What do women and girls want from urban mobility systems. OLA Mobility Institute; 2019. Available from: https://olawebcdn.com/ola-institute/ola_women_and_mobility.pdf [Last accessed on 27 Apr 2025]
35. Petti, L.; Trillo, C.; Makore, B. N. Cultural heritage and sustainable development targets: a possible harmonisation? Insights from the European perspective. *Sustainability* **2020**, *12*, 926. DOI
36. Shaji, K. A. Why Kerala's silver line project is a budding environmental disaster. science - the wire; 2021. Available from: https://science.thewire.in/politics/government/why-keralas-silver-line-project-is-a-budding-environmental-disaster/ [Last accessed on 23 Apr 2025].
37. Barman, S. R. 6,961 trees to make way for Delhi Metro corridor, proposal gets SC panel nod. The Indian Express; 2021. Available from: https://indianexpress.com/article/cities/delhi/6961-trees-to-make-way-for-delhi-metro-corridor-proposal-gets-sc-panel-nod-7451228/ [Last accessed on 23 Apr 2025].
38. Tiwari, G.; Phillip, C. Development of public transport systems in small cities: a roadmap for achieving sustainable development goal indicator 11.2. *IATSS. Res.* **2021**, *45*, 31-8. DOI
39. Leather, J.; Fabian, H.; Gota, S.; Mejia, A. Walkability and pedestrian facilities in Asian cities - state and issues. ADB Sustainable Development Working Paper Series; 2011. Available from: https://www.adb.org/sites/default/files/publication/28679/adb-wp17-walkability-pedestrian-facilities-asian-cities.pdf [Last accessed on 23 Apr 2025].
40. Economic Times. Surat to be world's fastest growing city during 2019-35: report; 2018. Available from: https://economictimes.indiatimes.com/news/politics-and-nation/surat-to-be-worlds-fastest-growing-city-during-2019-35-report/articleshow/66991793.cms?from=mdr [Last accessed on 23 Apr 2025].
41. CRDF. Comprehensive mobility plan for Surat. Surat Municipal Corporation; 2018. Available from: https://crdf.org.in/project/comprehensive-mobility-plan-for-surat [Last accessed on 23 Apr 2025].
42. Jain, D.; Tiwari, G. Promoting low carbon transport in India - NMT infrastructure in India: investment, policy and design; 2013. Available from: https://www.uncclearn.org/resources/library/promoting-low-carbon-transport-in-india-nmt-infrastructure-in-india-investment-policy-and-design/ [Last accessed on 23 Apr 2025].
43. Sharma, S.; Gandhi, P.; Roy, A. K. Lean management based sustainable transport system for Surat metropolitan area in the context of industrial development. *JTTE.* **2017**, *5*, 147-56. DOI
44. Agarbattiwala, T.; Bhatt, B. Performance analysis of BRT system Surat. *Int. J. Eng. Res.* **2016**, *5*, 519-23. DOI
45. United Nations Environment Programme (UNEP). The emissions gap report 2015. Accessible from: https://wedocs.unep.org/bitstream/handle/20.500.11822/32070/EGR15.pdf?sequence=1&isAllowed=y [Last accessed on 27 Apr 2025].
46. Schweizer, V. J.; Kriegler, E. Improving environmental change research with systematic techniques for qualitative scenarios. *Environ. Res. Lett.* **2012**, *7*, 044011. DOI
47. Waisman, H.; Bataille, C.; Winkler, H.; et al. A pathway design framework for national low greenhouse gas emission development strategies. *Nat. Clim. Chang.* **2019**, *9*, 261-8. DOI
48. International Labour Organization. Labor force participation rate, female (% of female population ages 15+) (modeled ILO estimate) - Sri Lanka. 2022. Available from: https://data.worldbank.org/indicator/SL.TLF.CACT.FE.ZS?locations=LK [Last accessed on 23 Apr 2025].
49. Chakraborty, S.; Kumar, N. M.; Jayakumar, A.; Dash, S. K.; Elangovan, D. Selected aspects of sustainable mobility reveals implementable approaches and conceivable actions. *Sustainability* **2021**, *13*, 12918. DOI
50. Prabhu, A.; Pai, M. Buses as low-carbon mobility solutions for urban India: evidence from two cities. *Transp. Res. Rec.* **2012**, *2317*, 15-23. DOI
51. Bresciani, C.; Colorni, A.; Costa, F.; Luè, A.; Studer, L. Carpooling: facts and new trends. In: 2018 International Conference of Electrical and Electronic Technologies for Automotive. IEEE; 2018. p. 1-4. DOI
52. NITI Aayog. Moving forward together: enabling shared mobility in India; 2018. Available from: https://www.niti.gov.in/sites/default/files/2023-02/Shared-mobility.pdf [Last accessed on 23 Apr 2025].
53. Zubelzu, S.; Álvarez, R. A simplified method to assess the influence of the power generation mix in urban carbon emissions. *Energy* **2016**, *115*, 875-87. DOI
54. Gazette of India. Vehicle scrapping policy, CG-DL-E-18032021-225972, PART II -Section 3 - Sub-section (i); 2021. Available from: https://morth.nic.in/sites/default/files/notifications_document/RVSF%20Notification.pdf [Last accessed on 23 Apr 2025].
55. Hodge, C.; Jeffers, M. J.; Desai, J.; Miller, E.; Shah, V. Surat municipal corporation bus electrification assessment. Golden, CO: National Renewable Energy Laboratory; 2019. Available from: https://www.nrel.gov/docs/fy19osti/73600.pdf [Last accessed on 23 Apr 2025].
56. KPMG. Shifting gears: the evolving electric vehicle landscape in India; 2020. Available from: https://www.lightson.news/content/files/content/dam/kpmg/in/pdf/2020/10/electric-vehicle-mobility-ev-adoption.pdf [Last accessed on 23 Apr 2025].
57. UNFCCC, GIZ, ICCT. Compendium on greenhouse gas baselines and monitoring: passenger and freight transport; 2018. Available

from: https://unfccc.int/sites/default/files/resource/UNFCCC%20Compendium%20Transport%20Revised.pdf [Last accessed on 23 Apr 2025].

58. Zhang, S.; Zhao, J. Low-carbon futures for Shenzhen's urban passenger transport: a human-based approach. *Transp. Res. Part. D.* **2018**, *62*, 236-55. DOI
59. ARAI. Indian emissions regulations; 2021. Available from: https://www.araiindia.com/pdf/Indian_Emission_Regulation_Booklet.pdf [Last accessed on 23 Apr 2025].
60. Ghate, A. T.; Qamar, S. Carbon footprint of urban public transport systems in Indian cities. *Case. Stud. Transp. Policy.* **2020**, *8*, 245-51. DOI
61. Bataille, C.; Waisman, H.; Colombier, M.; Segafredo, L.; Williams, J. The deep decarbonization pathways project (DDPP): insights and emerging issues. *Clim. Policy.* **2016**, *16*, S1-6. DOI
62. Ministry of New and Renewable Energy. Annual report 2020-21. New Delhi: Ministry of New and Renewable Energy; 2021. Available from: https://mnre.gov.in/en/annual-reports-2020-21-2/ [Last accessed on 23 Apr 2025].
63. Ministry of Power. Annual report 2020-21. New Delhi: Ministry of Power; 2021. Available from: https://powermin.gov.in/sites/default/files/uploads/MOP_Annual_Report_Eng_2020-21.pdf [Last accessed on 23 Apr 2025].
64. Nilsson, M.; Griggs, D.; Visbeck, M. Policy: map the interactions between sustainable development goals. *Nature* **2016**, *534*, 320-2. DOI
65. Fader, M.; Cranmer, C.; Lawford, R.; Engel-Cox, J. Toward an understanding of synergies and trade-offs between water, energy, and food SDG targets. *Front. Environ. Sci.* **2018**, *6*, 112. DOI
66. Hernández-Orozco, E.; lobos-Alva, I.; Cardenas-Vélez, M.; Purkey, D.; Nilsson, M.; Martin, P. The application of soft systems thinking in SDG interaction studies: a comparison between SDG interactions at national and subnational levels in Colombia. *Environ. Dev. Sustain.* **2022**, *24*, 8930-64. DOI
67. Ministry of Housing and Urban Affairs (MOHUA). Service level benchmark in urban transport for Indian cities; 2013. Available from: https://mohua.gov.in/upload/uploadfiles/files/VoulmeI_Methodologyreport_final03.pdf [Last accessed on 23 Apr 2025].
68. Ministry of Urban Development (MoUD). Study on traffic and transportation policies and strategies in urban areas in India. New Delhi: Wilbur Smith Associates; 2008. Available from: https://mohua.gov.in/upload/uploadfiles/files/final_Report.pdf [Last accessed on 23 Apr 2025].
69. Padeiro, M.; Louro, A.; da, C. N. M. Transit-oriented development and gentrification: a systematic review. *Transp. Rev.* **2019**, *39*, 733-54. DOI
70. Reddy, B. S. Urban transportation in India: a tale of two cities. *Energy. Sustain. Dev.* **2000**, *4*, 65-76. DOI
71. Banerjee-Guha, S. Developing public transport in Indian cities: towards a sustainable future. In: Low N, Gleeson B, editors. Making urban transport sustainable. London: Palgrave Macmillan UK; 2003. pp. 165-83. DOI
72. Srinivasan, S.; Rogers, P. Travel behavior of low-income residents: studying two contrasting locations in the city of Chennai, India. *J. Transp. Geogr.* **2005**, *13*, 265-74. DOI
73. Tiwari, G. Urban transport priorities: meeting the challenge of socio-economic diversity in cities, a case study of Delhi, India. *Cities* **2002**, *19*, 95-103. DOI
74. Arioli, M.; Fulton, L.; Lah, O. Transportation strategies for a 1.5 °C world: a comparison of four countries. *Transp. Res. Part. D.* **2020**, *87*, 102526. DOI
75. Chen, L.; Tan, Y.; Lv, G.; Cai, W.; Gao, X.; Li, R. Uncovering the coupling effect with energy-related carbon emissions and human development variety in Chinese provinces. *J. Environ. Sci.* **2024**, *139*, 527-42. DOI