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ORIGINAL RESEARCH ARTICLE

Including SDGs in low-carbon transport scenarios: A case of Udaipur

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ABSTRACT

Transportation is fundamental to shaping urban form and quality of life. The transport sector contributes to a quarter of global GHG emissions. It is integral to countries' Nationally Determined Contributions (NDCs) to mitigate global warming or control warming beyond 2 ℃ or 1.5 ℃ above the pre-industrial level. Climate change mitigation in the transport sector demands a tailored approach for cities of the global south—recently urbanizing with increased dependence on motorization—incorporating social aspects of sustainability. The study examines the delivery of climate change mitigation and Sustainable Development Goals (SDG) in Udaipur's passenger transport sector through six SDGs. Over and above the business-as-usual scenario, the two scenarios presented are the technology scenario, which recalibrates Udaipur's available low-carbon mobility plan, and the SDG scenario, which addresses social transformations by applying assumptions derived from the primary survey in the city. The socially sensitive SDG scenario prioritizes the mobility demands of those with low or no mobility. It also enhances mobility by retaining the share of non-motorized transport (NMT), intermediate public transport (IPT), and public transport (PT) and regulating excessive use of private motorized vehicles. However, the SDG scenario causes a 26% increase in the vehicle kilometer traveled (VKT), a 24% increase in CO_2 emissions, and a 29% decrease in other GHG emissions over the Technology Scenario.

Keywords: decarbonization; sustainable transport; low-carbon pathways; sustainable development goals; social sustainability

1. Introduction

Transportation is fundamental to shaping urban form[1,2]. Transport links are inextricably linked to socioeconomic development in both urban and rural contexts[3,4]. The rise of each transport mode fuels a new conceptualization of urban structure; with the introduction of railroads came early suburbanization[5], and with automobiles came the urban sprawl and car-centric city planning approach[6,7] .The popularity of mass-transit modes like rail-based city transport, popularly known as Metro or subway, Bus Rapid Transit System (BRTS), and Light Rail Transit System (LRTS), birthed the idea of Transit Oriented Development[8–10], and now, the popularity of biking and walking, especially during the pandemic, has enabled conversations around a self-sufficient neighborhood or '15-minute city'[11,12].

Along with directly shaping urban forms, the transport sector also indirectly affects the quality of life. Annually, the transport sector contributes to 25% of the total GHG emissions and 11.4% of the total PM2.5

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and ozone pollution fatalities[13]. Rapid motorization in ASEAN countries has increased road traffic congestion and fuel consumption, degrading air quality[14,15]. The outdoor air pollution levels in many Asian cities are far above WHO guidelines. The associated CO_2 emissions and air pollution create a dire need to shift towards a sustainable pathway for transport development[16]. Hence, urban transport forms an integral part of climate mitigation efforts in countries across the globe. Low-carbon transport becomes an integral part of countries' Nationally Determined Contributions (NDCs) to mitigate global warming or control warming beyond 2 °C or 1.5 °C above the pre-industrial level[17]. Low-carbon transport is often conceptualized as land-use transport integration that (i) reverses the need for travel via personal motorized transport, (ii) reduces share and frequency of longer trips, (iii) promotes alternative fuel vehicles, with emphasis on electrification of urban transport and biofuels, (iv) promotes energy-efficient vehicles and stringent emission norms, and (vi) promotes active transport to reap co-benefits like healthier communities[18–20].

Although the need to create low-carbon transport systems is universal, the pathways to achieve the same drastically vary across levels of economic development[20]. For example, the core principle of low-carbon transport—reducing travel demand—is well suited for populations of the Global North for whom mobility and accessibility are a lived experience through transport. But, for those who have curtailed mobility and accessibility, reducing travel demand is neither an option nor desirable. In the context of the cities of the global south, high levels of inequalities and injustice render unequal impacts on climate change mitigation strategies[21,22]. Hence, decreasing travel demand in a context where transport access is contested and often excludes the most vulnerable groups (urban poor, women, socially disadvantaged, differently abled, etc.) deepens inequities. Similarly, mega-transport projects (like mass-transit projects or transit-oriented development) that result in a multi-fold increase in transit ridership in the cities of the global north often adversely impact urban poor and vulnerable communities in the cities of the global south by causing large-scale displacements and evictions, loss of livelihoods, increased transportation expenditure, and curbed mobility[23–25]. Thus, climate change mitigation in the transport sector demands a rather nuanced and tailored approach for cities in the global south, incorporating social aspects of sustainability. And as the IPCC 1.5 °C report argues, the climate change mitigation efforts need to be assessed against the development goals, now measured through the Sustainable Development Goals (SDGs) and their targets. This same argument applies to low-carbon urban transport, which we illustrate in this article based on the data from one mid-sized city in India, Udaipur, in Rajasthan.

The second section unpacks the SDG-transport interactions in Udaipur based on an extensive literature review and primary data. We present these interactions for six SDGs: SDG1-No Poverty, SDG3-Health & Well-Being, SDG5- Gender Equity, SDG8- Economic Growth and Decent Work, SDG11-Sustainable Cities and Communities, and SDG13- Climate Action for presenting our case. The third section presents the SDG-enabled low-carbon transport scenario methodology that mainstreams the SDGs within the climate mitigation scenarios. The methodological discussion is followed by a discussion of Udaipur's three transport scenarios: first, a Business-as-Usual Scenario (BAU) that portrays the city's transport landscape without any decarbonization intervention; second, a technology scenario that proposes severe emission reduction; and third, an SDG scenario that proposes enhanced mobility for a segment of the city's population. The concluding section summarizes our arguments and proposes policies to ensure SDG-enabled low-carbon pathways in countries such as India and, by extension, in the cities of the global South.

2. Unpacking SDG-transport interactions in cities through a case study of Udaipur, India

Udaipur is located in the western state of Rajasthan and has a population of 1.5 million. Udaipur is a model city for scenario building owing to its unique urbanization characteristics that speak to mid-sized cities in the Global South and the North. Like most mid-sized cities in the global south, Udaipur is on the brink of rapid urbanization and increased motorization, offering ample opportunity to reshape its urban transport landscape. And, like most cities in the Global North (especially Europe), Udaipur possesses the characteristics of smaller, compact cities with historic urban cores and a tourism-centric economic base. Moreover, Udaipur's population composition represents about 70% of Indian cities.

2.1. Travel patterns and transport systems in Udaipur[1]

Udaipur is known for its history, culture, and institutions. Along with a residential population of 1.5 million, Udaipur hosts a vast floating population of students and tourists. Traditionally a compact city (a 12-minute city) with a ring-radial road network, Udaipur is rapidly expanding along two highways, creating high travel demand. Udaipur is surrounded by hillocks and lakes towards the west, restricting rapid expansion and creating conflicts with heritage and natural preservation whenever expanded. The walled city and its immediate surroundings are predominantly mixed-use, enabling 80% of non-work trips by non-motorized transport. Land-use becomes largely residential, moving towards the peripheral areas except the eastern ones, which are industrial.

Over time, the city has experienced a steep increase in motorization; the number of registered vehicles soared by 52% in 6–7 years. Private vehicles comprise 85% of the traffic composition, leading to a higher annual motorized VKT (1011.69 million) than other similar-sized cities. Udaipur's Respirable Suspended Particulate Matter (RSPM) and Suspended Particulate Matter (SPM) percentages are considerably higher than the permissible norms set by the Central Pollution Control Board (CPCB). Road space in the city is highly contested with heterogeneous road users: motorized vehicle users, pedestrians, cyclists, street vendors and their clientele, private bus operators and their clientele, pavement dwellers, etc. 39% of roads in Udaipur have illegal street parking, further reducing the traffic-carrying capacity of roads. More than 26% of roads have a volume/capacity (v/c) ratio of more than 1 (a proxy for severe and frequent traffic congestion).

About half of the total trips in Udaipur are on foot, that is, by Active Transport (AT). Yet, non-motorized transport infrastructure, including footpaths, cycle lanes/ tracks, pedestrian/ cycle crossings, and street lighting, is poorly designed and inadequate, leading to poor Level of Service (LoS)[2]. Less than 1% of the roads have cycling and footpath infrastructure. Udaipur has only 2% of its total trips on cycle, versus the national average of 20% for cities with 5–10 lakhs of population[27]. Autorickshaws (three-wheelers)—an Intermediate Public Transport (IPT) mode—operate under fixed routes and rates in the city, essentially serving as Public Transport (PT). There are 27 designated IPT routes and 87 IPT stands across the city, while city buses operate on only five routes. IPT mode share in Udaipur is 11%, surpassing the national recommended average of 3%. About 25% of total IPT trips and 33% of total 2-wheeler trips have a trip length of 5 km or more, making them ideal PT trips. However, due to the lack of a robust PT network, only 2% of the total trips are by city buses. Udaipur's AT and PT share decline with an increase in income, indicating captive users; about 60% of trips of low-income groups are on foot; and over 65% of all female trips are on foot. Low-income women in Udaipur have the lowest trip rate (a proxy for mobility).

2.2. Current SDG-transport interactions in Udaipur[3]

2.2.1. SDG1—No poverty

Transport networks reduce poverty by providing access to economic opportunities[28,29]. This creates a two-way relationship as it generates higher travel demand. Owing to its potential to reduce incidences of extreme poverty among peripheral and remote households, access to low-carbon transport modes like PT is considered a basic service (SDG 1.1, SDG 1.2)[24,30]. Like many cities in the global south, Udaipur's inaccessible and inconvenient public transport network forces the urban poor to either depend on non-motorized transport or experience curbed access to economic opportunities[31,32]. Over 40% of those who walk or cycle in Udaipur report curbed access to economic opportunities. Udaipur's vulnerable groups, dependent on AT and PT, experience disproportionately longer travel times than private vehicle users with similar trip lengths, resulting in time poverty. Most PT users reported dissatisfaction over long travel times and a willingness to quit commuting via PT with increased affordability.

2.2.2. SDG 3—Health & well-being

Urban transport planning has multiple direct implications for health and well-being: emission reduction from transport improves local air quality[17,33], affordable PT systems improve access to healthcare services[34], and safe networks for walking and cycling (Active Transport—AT) promote physical activity in individuals[35,36]. Like most South Asian cities, the prioritization of motorized traffic with negligence of infrastructure for AT and PT users in Udaipur translates into inadequate coverage of footpaths and under-prioritization of street design principles[37,38]. This creates a hostile environment for walkers and cyclists, increasing exposure to conflicts with motorized users and the risk of road accidents (SDG 3.6). Furthermore, the high average speed of motorized traffic, lack of pedestrian crossing in Udaipur, and encroachment on AT infrastructure result in frequent road accidents. These incidents disproportionately affect walkers and cyclists, as they make up over 50% of all road fatality victims. Increased dependence on motorized transport, especially in Udaipur's narrow lanes, creates frequent and severe traffic congestion; several streets in and around Udaipur's historic core experience an average speed of less than 10 kmph. Driving in such conditions causes several trade-offs with SDG 3: increased stress and anxiety, increased exposure to air pollution (SDG 3.4), and, in turn, a higher risk of developing cardiovascular and respiratory diseases and increased health costs (SDG 3.9). While Udaipur's wide network of open and recreational spaces has the potential to foster synergies with physical and mental health, the lack of connectivity to these spaces through PT or AT limits its benefits to vehicle owners. This generates health inequality in Udaipur (SDG 3.3, SDG 3.9).

2.2.3. SDG 5—Gender equity

Urban transport also has a direct, two-way relationship with SDG 5, as easy access to economic, social, and civic opportunities (via transport), in turn, creates additional travel demand and increases women's trip rates[39]. In cities with safe and affordable healthcare services, access to robust transport systems is also linked to improved health outcomes for women (SDG 5.6). Women, especially those from low-income groups, are forced to walk as they face greater cultural barriers (clothing and other) to cycling and often cannot afford public transport[40,41]. Since women's dependence on pedestrian infrastructure is greater than men's, the poor state of pedestrian infrastructure in cities of the global south causes women discomfort, increases their fear of violence (SDG targets 5.1 and 5.2), and curbs their mobility[42,43]. Udaipur's case reflects the same: low-income women have the lowest trip rate and the highest dependence on walking; only 7.5% of women rated the streets as safe to walk or cycle. Along with immobility, the unsafe infrastructure also adds to women's time poverty since their dependence on PT is far greater than that of men (SDGs 5.1 and 5.4). Women often forgo an opportunity to work outside their neighborhoods if they perceive transport fares and services to be expensive and unreliable[44]; 43% of female AT users in Udaipur reported frequently missing out on economic opportunities due to lack of access, compared to 24% of male AT users.

2.2.4. SDG 8—Economic growth & decent work

Along with enabling access to economic opportunities (SDG 8.1, SDG 8.3), the transport sector generates employment through a variety of jobs (SDG 8.10)[45,46]. Predominantly mixed-use developments (like

Udaipur's walled city area) foster synergies by enabling commerce, economic growth, and easy workplace access. Transport systems are also vital for worker productivity (SDG 8.2) and contribute to a 'decent work environment' for the informal sector, like street vendors (SDG 8.5, SDG 8.8). Udaipur's wide-spread IPT network and high mode share generate positive interactions by generating ample local jobs in the IPT system. Yet the lack of IPT fare revision, poor management, and gender bias among IPT drivers in Udaipur leave users overpaying for the trip and feeling unsafe.

Additionally, over 90% of street vendors and local shopkeepers caught in congested areas with vehicular and freight traffic reported experiencing risky and unregulated work environments, affecting their mental and physical health. Frequent and long traffic jams in Udaipur's contested streets, along with traffic flow mismanagement, impose a heavy burden on the economy as they affect workers' productivity. It forces workers to lose more time and stress in commuting, lose more fuel, generate more emissions, and increase their household expenditure on transport. This was widely reported by most personal-vehicle users.

2.2.5. SDG 11—Sustainable cities and communities

Among all SDGs, SDG 11 has the most substantial relationship with urban transport. Transport plays a crucial role in enabling access and inclusion in two ways. First, by enabling access to affordable housing and basic services, especially for the urban poor residing in peripheral low-income housing (SDG 11.1)[47,48]. Second, through universal design and inclusive planning, urban transport systems improve accessibility, mobility, and, in turn, quality of life for all, especially vulnerable socio-economic groups (SDG 11.2)[49,46,20]. Although walking is the most preferred mode of transport (80% of intrazonal trips in Udaipur are on foot), Udaipur's 4% AT network coverage fairs poorly against the national average of 75% coverage. It causes a trade-off with most of the city's transport users. Udaipur's slim PT network, low frequency of buses, and lack of last-mile connectivity discourage the use of PT; of all PT users, only 5% actively choose PT, and only 8% of users find PT accessible in Udaipur. The AT infrastructure conditions create inaccessible streets for most users (other than personal vehicle users), creating a distorted mode mix and an unequal distribution of road space in Udaipur (SDG 11.2, 11.3, 11.5, and 11.7). The lack of effective integration of land use and transport leads to urban sprawl and increases a city's carbon footprint[20,50]. Like most cities in South Asia, Udaipur's rapid motorization and a multi-fold increase in passenger transport demand result in longer trip lengths, more frequent and more severe traffic congestions, longer travel times, higher fuel costs, increased emissions, and air pollution (SDG 11.6). Udaipur experiences about 4,500 tons of PM10 and 17 million tons of CO_2 annually, considerably higher RSPM and SPM percentages than Central Pollution Control Board (CPCB) standards.

2.2.6. SDG 13—Climate action

Decoupling transport sector emissions is strongly linked to enhanced climate action and resilience (SDG 13.2 and 13.3). Increased dependence on motorization in Udaipur adds pressure on the existing road infrastructure and causes high congestion and emissions[15,51]. Additionally, Udaipur's fleet composition across modes is highly unsustainable; over 23% of 2-wheelers (2Ws) in Udaipur are Bharat Standard-1 (BS1)[4], and another 55% are BS2, contributing to about 80% of the city's total carbon monoxide and 65% of the city's total carbon dioxide. 2-wheelers are also a leading source of NOx and other pollutants. 40% of Udaipur's IPT fleet is also older than 15 years, contributing to high levels of pollutants. The city's neglected and underperforming AT and PT systems pose a threat to SDG 13, as with increased income, the captive AT and PT users are more likely to shift to motorized transport for first-last mile or whole trips; over 55% of AT users and 62% of PT users expressed a willingness to shift to personal vehicles with increased income levels.

3. Developing a methodology for SDG-enabled low-carbon transport scenario

This section details key methodological decisions and assumptions. Based on past studies on Indian low-carbon scenarios[52,53], the paper assesses three scenarios for 2030. The first step is developing a qualitative scenario storyline[54,55], detailed in section 3.1, followed by quantitative assumptions for each scenario in the storyline in section 3.2.

Udaipur's scenario development is based on the city's Low Carbon Mobility Plan (LCMP) of Udaipur[27]. We consider 2041 to be the target year for scenario development for two reasons. First, it aligns with LCMP's target year, allowing the demand assumptions to be more robust. Second, it allows sufficient time to implement long-term strategies (like land-use changes) necessary to drive travel demand. Travel demand projections were calculated using assumptions about population growth rate, trip rate, trip length, and mode share for each trip purpose applied to the available LCMP. Travel demand assumptions from the BAU and technology scenarios stem from the LCMP. These assumptions in the SDG scenario are based on fieldwork (detailed in section 3.2).

3.1. Scenario development

The qualitative scenario narratives are discussed below:

i. The BAU scenario in Udaipur is rendered by rapid motorization and road-based solutions (road widening projects) due to the absence of transport demand management, active transport (AT) infrastructure, and public transport (PT) system improvements.
Scenario Strategies: (a) cater to the current travel demand, and (b) focus on road-based solutions.

ii. The technology scenario is borrowed from Udaipur's Low Carbon Mobility Plan[27], which considers a traditional low-carbon pathway that minimizes travel demand via land-use changes and promotes cleaner technologies.

Scenario Strategies: (a) increasing the intensity of mixed land-use and related intra-zonal trips; (b) increasing the density along PT corridors through infill development or green-field developments; (c) introducing and subsidizing energy-efficient vehicles; and (d) upgrading the PT and IPT fleets to meet better fuel norms.

iii. The SDG scenario builds on the technology scenario's interventions by including AT and PT infrastructure improvement, street redesign based on Universal Design and Complete Streets guidelines, and improved mobility for vulnerable groups. The SDG scenario alters basic assumptions for estimating travel demand, which assume an improved work participation rate, an improved trip rate for vulnerable groups, and reduced trip length due to land use change.

Scenario Strategies: (a) increased intra-zonal trips (64% from 16% in BAU); (b) large-scale AT infrastructure improvements leading to 100% household access to PT and IPT; (c) aggressive adoptions of EV, especially for personal vehicles; (d) integrating mini-buses, city buses, and IPT for enhanced access for all; and (e) an increase in AT mode share and trip lengths.

3.2. Travel demand projections for 2041

Mobility assumptions for the BAU and technology scenarios are based on the LCMP. For the SDG scenario, these are based on contextual data from in-depth qualitative surveys and focused group discussions. Initially, the project aimed to capture the trip diaries of approximately 0.05% of the total population in the city through in-person surveys. However, due to the ongoing pandemic and learning from 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 canvassed: 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 to December 2020, primary surveys (449 user and household surveys) and stakeholder surveys (111 surveys) were collected via random stratified sampling. This approach captured demand-side trends, including travel patterns, mobility challenges, safety, affordability, resilience by mode, and the impacts of transport projects. This was supplemented with focus group discussions (3 focus group discussions with 30 participants). While the surveys focused on understanding the existing transport patterns in Udaipur, they also included components eliciting feedback for future scenarios (e.g., the willingness to shift estimates, transport system improvements, etc.). Unlike most studies on low-carbon transport, this study emphasizes the equitable representation of the vulnerable groups: 50% of survey respondents belong to socially disadvantaged (i.e., caste, religion) groups, and about 70% of survey respondents belong to economically disadvantaged (i.e., low-income and very low-income) groups. The findings from the fieldwork (discussed in the results section) influence the travel demand projections and interpretation of proposed transport interventions on SDGs.

3.2.1. Trip rate

Trips across all user groups are calculated by purpose (work, education, healthcare, recreation, and other purposes) and by extent from the trip's origin (inter-zonal: across Traffic Analysis Zones, intra-zonal: within the Traffic Analysis Zones). The total trip rate (inter-zonal and intra-zonal) for the BAU scenario and the technology scenario are adopted from Udaipur's LCMP[27], as mentioned in **Table 1**. For the SDG-enabled scenario, trip rate calculations reflect social and political transformation on account of ongoing processes of empowerment and democratization, accounted for via demographic projections (population distribution by age and sex).

Table 1. A snapshot of transport system parameters by scenarios.

Transport systems parameters		BAU scenario	Technology scenario	SDG scenario
Trip rate	Total trip-rate*	1.15	1.15	1.78
	Inter-zonal trip- rate**	1.12	1.12	1.17***
Mode share (%)	Walk	20.00	28.00	38.00
	Cycle	2.00	9.00	9.00
	2W	51.00	20.00	15.00
	3W	21.00	10.00	8.00
	4W	4.00	1.00	1.00
	Buses	2.00	32.00	30.00
Accessibility	% HH within walking distance of PT/IPT stops	60	83	100
	LOS of PT	4	2	1
Perception of safety while using AT	Walking	8%	83%	100%
	Cycling	7%	83%	100%
	LOS of AT	4	2	1
Vehicle kilometers travelled	Annual motorized VKT	2,559,907	1,335,210	2,003,526
Emissions levels (tons annually)	NO_2	61,261	36,066	20,298
	CO_2 (million)	33	24	32
	PM10	18,000	10,484	5721
	SO2	803	591	235
	CO	695,935	454,591	211,599

Table 1. (*Continued*).

Transport systems parameters		BAU scenario	Technology scenario	SDG scenario
Mitigation results	% VKT reduction	n/a	48%	22%
	% Emission reduction (CO_2)	-	27%	3%
	% Emission reduction (other GHGs)	-	35%	64%
SDG interactions****	SDG 1 (No poverty)			
	SDG 3 (Health & well-being)			
	SDG 5 (Gender equality)			
	SDG 8 (Economic development)			
	SDG 11(Sustainable cities)			
	SDG 13 (Climate action)			

*Total trip rate comprises inter-zonal trip rate and inter-zonal trip rates. Zones refer to TAZs (refer to footnote #5 for details of TAZs). The inter-zonal and intra-zonal trip rates are further disaggregated as motorized and non-motorized trip rates.
**Scenario calculations are based only on inter-zonal trip rates, as intra-zonal trips are often too short to accommodate in GHG emissions modeling. This is a common practice followed in the majority of decarbonization scenario-building studies.
***The SDG scenario accounts for a total trip rate of 1.78; due to high intra-zonal trips for user groups like elderly, women, children, and youth, the inter-zonal trip rate is 1.17.
****Red indicates a trade-off with SDGs, green indicates a synergy, and yellow indicates mixed impacts.

The SDG-enabled scenario assumes:

1) Improvement in women's empowerment (accounted for by increasing the female workforce participation rate to 33.7% from 19.6% in the BAU scenario), increasing their mobility for work and other purposes (SDGs 5 and 8),
2) Improvement in access to and availability of economic opportunities, resulting in a higher workforce participation rate of 80.8% in the SDG-enabled scenario compared to 65.8% in the BAU scenario,
3) Improvement in school enrollment across all income groups (accounted for by assuming 100% school enrollment among children aged 3 to 17 years) (SDGs 1 and 8),
4) Improvement in access and availability of healthcare facilities (SDG 3), increasing healthcare trips for specific groups like the elderly, children, and specially-abled people.
5) Improvement in AT infrastructure (LoS 1 in the SDG-enabled scenario from LoS 4 in the BAU) and safety (100% in the SDG-enabled scenario from 8% in the BAU) increases intra-zonal trips, especially for 'recreational', 'healthcare', and 'other' purpose trips among women.

This results in increased trip rates in the SDG-enabled scenario for the following user groups (see **Table 1**):

1) Women—increased work trips (2 inter-zonal trips a day), increased recreational trips (2 inter-zonal trips a week), increased healthcare trips (2 intra-zonal trips a month), and other purpose trips (2 intra-zonal trips a week), resulting in a total trip rate of 1.04 in the SDG-enabled from 0.67 in the BAU scenario.
2) Elderly—increased recreational trips (2 intra-zonal trips twice a week), increased healthcare trips (2 intra-zonal trips twice a week), and other purpose trips (2 intra-zonal trips a week),
3) Children (age 3 to 15)—increased educational trips (2 inter-zonal trips a day), increased recreational trips (2 inter-zonal trips every other day), and increased healthcare trips (2 intra-zonal trips a month)
4) Early Adults/ Youth (ages 15 to 29) —increased educational trips (2 inter-zonal trips a day), increased recreational trips (2 inter-zonal trips every other day), increased healthcare trips (2 intra-zonal trips a month), and other purpose trips (2 intra-zonal trips a week),
5) Specially-abled—work and education trips accounted for in respective age groups; increased healthcare trips accompanied by a caregiver (2 inter-zonal trips a week).

The SDG scenario's total trip rate of 1.78 is considerably higher than the BAU and the technology scenario, yet for GHG emissions modeling, the authors only consider the inter-zonal trip rate (refer to the notes in **Table 1** for details). The work trip rate for inter-zonal trips increases to 0.72 in the SDG-enabled scenario from 0.37 in the BAU scenario, indicating a drastic increase in work trips (**Table 1**). The SDG scenario also accounts for a higher recreation and health trip rate compared to the BAU and technology scenarios.

3.2.2. Mode share

The SDG-enabled scenario assumes that improving walking and cycling infrastructure (to LoS of 1 from 4 in the BAU scenario) and increased safety will increase the AT mode share to 47% from 22% in BAU. Increased household accessibility to and modal integration of all PT and IPT modes (city buses, mini-buses, shared autos, auto-rickshaws) encourages a shift to PT and IPT from personal vehicles; 2Ws and 4Ws mode shares decrease by 37% and 3%, respectively; PT mode share increases by 28%. Upon modal integration and route regularization, IPT is assumed to primarily function as a last-mile option for PT, decreasing its modal share to 8% from 21% in the BAU scenario.

3.2.3. Trip length

Trip lengths for motorized modes are assumed to be the same across all scenarios. Although increased trip lengths often follow PT and IPT improvements, they remain unchanged for a small city like Udaipur. However, large-scale improvements in AT infrastructure increase trip lengths for inter-zonal trips via walking and cycling, which is likely to function as the most reliable mode for cultural and built-heritage tourism.

3.2.4. Fuel and engine mix

All scenarios assume the share of vehicles older than 2016 in the total on-road vehicle pool to be negligible. Increased government subsidies and aggressive promotion of Electric Vehicles (EVs) by the state result in a more aggressive adoption of EVs across all modes than in the BAU scenario. The SDG-enabled scenario assumes that 100% of the PT and IPT fleets will transition to EVs. Mandating Vehicle Scrappage Policy 2021 and strict implementation of BS for any new purchase of personal vehicles ensures a negligible share of vehicles older than BS6; hence, the 2Ws fuel mix consists of 30% BS6, 20% BS7, and 50% EVs. Similarly, diesel 4Ws will be phased out, resulting in 40% BS6, 20% BS7, and 40% EVs. For the non-resident population and tourists, a higher share of shared mobility and Mobility as a Service (MaaS) (over 90%) results in a largely EV fuel mix.

3.2.5. Emission standards

GHG emissions were calculated for each scenario using a bottom-up, mode-based approach using the ASIF[6] methodology[57]. The emissions factors are also derived from ARAI's BS4 emissions regulation booklet[58]. All EV vehicle kilometers traveled are assumed to have zero emissions.

3.3. Assessment of SDG interactions

We are assessing each transport scenario from the SDG lens, that is, each scenario's interaction with the selected SDGs. We have given an interaction score based on our subjective interaction assessment. We use a three-point scale: synergy (+1), trade-off (−1), neutral (0), and both (+, −). We ask the question, "If intervention A is made, how does this influence progress on SDG target x?"[20] Each transport intervention is critically assessed against six selected SDGs based on Service Level Benchmarks[59]. The interaction scores are assigned by the authors, who are field experts. We acknowledged that results may vary with different groups of people, a standard limitation of any exercise involving assessing assessment scores[60,61].

4. Udaipur's future scenarios: Results and discussion

BAU Scenario: As discussed in Section 3, this scenario draws from prevailing transport trends and minimal transport planning intervention. The city's growth patterns and urbanization (as directed in Udaipur's Master Plan 2031) lead to sprawl, trip lengths, and dependence on motorized transport. Several road widening and new road projects (4 projects of 60 m, eight projects of 36 m, and nine projects of 30 m) proposed in the Master Plan rupture through the city's densely built heritage, causing a significant trade-off with SDG11. AT and PT users continue to face severe challenges, as neither the Master Plan nor any other city development document states AT or PT improvement as a priority. Further, 80 acres of green and public space are converted to land reserved for freight and parking. As a result, in comparison to 2016, mixed land use (vital for shorter trips) decreased to 16%, motorized mode share increased by 5%, household access to PT decreased by 9%, and PT mode share further dropped to 2% (refer to **Table 1**). Based on a comparison to 2016, emission levels increased by approximately 64% due to the city's high dependence on personal motorized vehicles and the chaotic transport landscape. As discussed in Sections 2 and 3, this scenario continues to cause trade-offs with most SDGs (refer to **Table 1**).

Technology Scenario: This scenario is based on LCMP's low-carbon proposals. To mitigate the sprawling land use proposed in the Master Plan that increased the average trip length in the BAU scenario, this scenario includes land-use pattern proposals conducive to smaller trips and shorter travel distances. The scenario aims to reverse the travel demand in the BAU scenario by ensuring better connectivity to PT/ IPT and using serviced land efficiently to create a more compact urban form; the intensity of mixed land-use increases by 40%, resulting in increased intra-zonal trips; increasing PT and IPT coverage by 20% and 16%, respectively, resulting in enhanced household access to PT and IPT by 23% (reaching 83%) (refer to **Table 1**). This scenario also includes improvements in the LoS of AT and PT, leading to an increased perception of safety by ~75%. Even with the same trip rate as the BAU scenario, this scenario delivers a 48% decrease in VKT, owing to a massive reduction in personal vehicle mode share (34%) and wider adoption of EVs. The massive VKT and emission reduction, as well as improved air quality and physical health, enable this scenario to generate ample synergies with SDGs 3 and 13. Considerable reductions in traffic congestion and improved LoS for AT deliver synergies with SDG8, especially for targets of a 'decent work environment' and worker productivity. Yet, low trip rates for vulnerable groups, translating to curtailed mobility and access to civic and economic opportunities, deliver mixed interactions with SDGs 1, 5, and 11 (refer to **Table 1**).

SDG Scenario: As discussed in Section 3, this scenario builds on the technology scenario interventions to include a higher travel demand for vulnerable groups. This scenario accounts for a total trip rate of 1.78 (considerably higher than the BAU & Technology scenario). However, the gross trip rate incorporated for VKT is 1.17, as the remaining is considered intra-zonal trips for user groups like the elderly, women, children, and youth (refer to **Table 1**). With 100% coverage of AT infrastructure and large-scale improvement in AT LoS (from 4 in BAU to 1 in the SDG scenario), this scenario drives an 18% increase in walking mode share and 100% household access to PT and IPT. Personal vehicle mode share drops by 39% compared to BAU and 5% compared to the technology scenario. Hence, even with increased travel demand, this scenario delivers a VKT reduction of 22% compared to BAU. Along with reversing the 'unsustainable' travel demand in the BAU, this scenario also alters the curtailed mobility of the vulnerable groups (urban poor, women, elderly, and specially-abled) in the BAU, as well as the technology scenario, delivering maximum synergies with the SDGs (refer to **Table 1**). AT and PT's drastic LoS improvement reverses the inequitable road space distribution in the BAU and enables a modal shift from personal vehicles (2-wheeler mode share decreases from 51% in the BAU scenario to 15% in the SDG-enabled scenario) to AT and PT, delivering several synergies with SDGs 11 and 13. The increased intra-zonal trip rate (mainly via AT) in the SDG scenario drives the decrease in NO2, SO2, CO, and PM10, drastically improving air quality and delivering synergies with SDGs 3 and 11 (refer to **Figure 1**).

Like most Indian cities, the BAU scenario projects high emissions (33 million tons annually), an unequal distribution of road space, and a chaotic transport landscape. The technology scenario results in massive emission reductions (27% reduction than BAU; a total of 24 million tons annually). Although the technology scenario—consisting of interventions currently promoted by the national government (EVs, efficient fuel engine standards, etc.)—mitigates many trade-offs compared to BAU, it does not focus on improving mobility for the vulnerable population groups (i.e., poor, women, specially-abled, elderly, and children), causing trade-offs with many SDGs (refer to **Table 1**). The SDG scenario maximizes synergy with SDGs (especially SDGs 1 and 5) and a socially sustainable mobility landscape. However, GHG emission mitigation is compromised to maximize the synergy with the SDGs (32 million tons annually) compared to the technology scenario.

The SDG scenario is socially sensitive, prioritizes mobility demand of those with low or no mobility, leading to socio-economic mobility over generations, makes efforts to enhance mobility by retaining the share of AT, IPT, and PT that could be used by all, including the higher income groups, and regulates excessive use of private motorized vehicles, but by a 26% increase in the VKT, a 24% increase in CO_2 emissions, and a 29% decrease in other GHG emissions over the Technology Scenario. The SDG scenario particularly improves access to PT (40% increase over the BAU scenario and 17% increase over the technology scenario) and perception of safety while using AT (~92% increase over the BAU scenario and 17% increase over the technology scenario), fostering synergies with SDGs 1, 5, and 11. The SDG scenario considers the vulnerable groups' social mobility and meets their increased travel demand.

Figure 1. GhG Emissions & VKT by Scenarios (2041).

5. Conclusion

Although the SDG scenario has increased CO_2 emissions over the technology scenario, the delivery of SDGs is prioritized over GHG emission mitigation to achieve economic development in the long run with reduced inequality. Climate change and its impacts on the cities of the global south have to be seen as one of the development issues that are now envisaged through the SDGs, including SDG 13. Hence, cities in the Global South, especially in South Asia and Africa, where much of the future urbanization is to occur, follow a different pathway, as climate change mitigation cannot be prioritized at the cost of SDG improvement.

This case study highlights that (i) the delivery and maintenance of an efficient PT system, supported by AT infrastructure, is critical in enabling a shift from personal motorized vehicles to active transport; (ii) increased use of shared-mobility applications promoting ride-hailing services could potentially impact GHG emission reduction, (iii) provision of essential elements like AT crossings, traffic signals, and lights, raised medians, road signages contribute to a safe street environment, and also improve PT access, and (iv) improving coordination between tourism and transport policies improves mobility for the visitors to destinations, and secures the economic viability of local transport systems by servicing both residents and tourists. Particular emphasis must be given to transport modes/ networks accessed more by vulnerable groups, like the urban poor, disabled, older adults and children, women, etc. Regular safety audits of transport infrastructure, including NMT networks, metro stations, and bus stations, are needed to identify safe routes to school, work, etc. Regulatory support by the government for shared services (MaaS) may lead to the acceleration of innovation in technology through the involvement of the private sector in service delivery. Hence, for the cities in the global south, development, climate action, and SDG delivery will have to take place in synergy.

Author contributions

Conceptualization: DM, SL and CM; methodology: DM, SL, CM; software: SL; validation: DM, SL and CM; formal analysis: DM, SL and CM; investigation: DM, SL and CM; resources: SL and CM; data curation: SL and CM; writing—original draft preparation: SL; writing—review and editing: DM, CM and SL; visualization: SL; supervision: DM; project administration: DM and SL; funding acquisition: DM. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

Notes

1. This section is based on the critical assessment of Udaipur's Low-Carbon Mobility Plan[26].
2. 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. This section draws broader framework from literature review, and all city-specific data from either the critical assessment of the LCMP or primary data (indicated where necessary).
4. 'Bharat Emission Standards' 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 BS1 in 2000 year, currently, Indian vehicles are required to comply to BS6 norms.
5. Traffic analysis zones (TAZs) are universally used in travel demand modeling to represent the spatial distribution of trip origins and destinations and the population, employment, and other spatial attributes that generate or influence travel demand[56].
6. $A \times S \times I \times F$, where A is total transport activity (in km); S is share of km by mode; I is fuel efficiency by mode; F is emissions per unit of fuel by mode and type of fuel.

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