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Evidence-based passenger transportation energy service demand scenarios for South Asia in integrated assessment models

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Abstract

Integrated assessment models (IAMs) are instrumental in shaping climate change mitigation policies. However, these models typically lack direct measures of many socio-cultural, behavioral, and lifestyle phenomena. Further, detailed analysis of future transport needs for Global South countries is required, given the expected increase in population, economic activities and, therefore, mobility demand. This work seeks to address both shortcomings by improving the quantification of sustainable mobility scenarios in IAMs for the Global South, with a focus on South Asian countries. Utilizing transport data from South Asia, we develop a passenger mobility demand model. We develop scenario narratives based on alternate visions of mobility futures, consisting of various outcomes for sets of phenomena, and establish interactions to produce IAM parametrizations. This parameterization is done based on pre-exsisting literature, with priority given to evidence from Global South region. Through these methods, we link detailed transport data to IAM scenarios. The relative richness of the data set allows replacing top–down calculations often encountered in IAM scenarios. Since the developed scenarios are based on evidence and data specifically from South Asia, they better capture actual potential mitigation in the region. The results indicate a doubling of passenger mobility demand by 2050, emphasizing the need for a detailed analysis of future scenarios that can guide policy and investment decisions. The scenario outcomes also highlight the importance of expanding public transport infrastructure to meet climate targets and improve access to low-cost mobility. Additionally, literature review and data collection processes have highlighted the urgent need for measured data to refine empirical work and ensure that scenarios and other modeling efforts align with actual regional empiricism.

1. Introduction

The transport sector accounted for about 30% of total global final energy consumption in 2019 and is a bottleneck in meeting climate change mitigation targets (International Energy Agency 2023a). Greenhouse gas (GHG) emissions from the transportation sector have not shown any signs of decrease and are projected to rise steadily even if existing commitments to decarbonize transport are fully implemented (International Energy Agency 2023b). The electrification of the transport fleet is likely to reduce GHG emissions from this sector. However, the pace and scale of electrification needed to achieve net-zero targets will be difficult to achieve or sustain, given current trends (Gaur *et al* 2022). Even if net-zero targets are met, cumulative emissions from past and ongoing activities can still pose challenges to limiting global temperature rise. Further, the additional electricity demand arising from electrification will challenge the pace of grid decarbonization (Winkler *et al* 2023). Moreover, the growth in car-oriented mobility has negative consequences for health, air quality, and community connection (Miner *et al* 2024).

Policies and measures to reduce emissions from the transport sector have either proved ineffective or progressing at a pace insufficient to meet climate targets. A key contributing factor is the limited depth of exploration in understanding the drivers of demand within this sector (Lamb *et al* 2021). Further, as mobility patterns and transport technologies evolve, there is a mutual impact that may invalidate the extrapolation of historical mobility patterns (Daniels and Yeh 2022). It is therefore important to increase the sophistication of travel demand projections and include the impact of ongoing innovations, policy interventions, and feedback effects in transport sector decarbonization pathways (Daniels and Yeh 2022, Yeh *et al* 2022, Briand *et al* 2023).

Integrated assessment models (IAMs) and energy systems optimization models (ESOMs) are integral to informing climate change mitigation policies and exploring different emissions pathways. Bottom–up IAMs and ESOMs are developed to explicitly represent efficiency improvements and technology or fuel substitution endogenously, and so are well-suited to study these phenomena. While the evidence to support additional demand-focused measures in the transport system is strong, climate mitigation in IAMs and ESOMs is primarily achieved through reduced energy intensity and fuel switches. This indicates a need to improve modeling techniques to include the role of various phenomena that could impact mobility patterns, especially in urban areas (Edelenbosch *et al* 2017). There have been some improvements in the representation of consumer behavior and lifestyle patterns in IAMs and ESOMs, to simulate a broader vision of alternative mobility scenarios (McCollum *et al* 2017, Luh *et al* 2022). The most common approaches are: representing mobility behaviors endogenously within these models, coupling a behavioral model with an energy systems model, and developing exogenous narratives based on assumptions about socio-techological developments (Trutnevyte *et al* 2019, Luh *et al* 2022).

While there is a plethora of evidence on how to decarbonize (passenger) transportation sector in high income countries (see Kainuma *et al* 2017, Brand *et al* 2019, Gi *et al* 2020, Lefevre *et al* 2021), this is not true for low- and middle-income countries. In light of the need to improve the representation of mobility scenarios for Global South regions in large-scale IAMs, the aim of this research is twofold: Firstly, to improve the quantification of sustainable mobility scenarios in IAMs for the Global South to avoid biases arising from reliance on data, literature, and particular phenomena from the Global North. Secondly, to improve the representation of demand-side mitigation options and associated behavioral, lifestyle, and socio-cultural phenomena corresponding to the passenger transport sector within an IAM framework.

Passenger mobility, encompassing factors like travel distance and mode choice, is influenced by a combination of factors, which we term 'phenomena'. These phenomena include socioeconomic conditions, behavioral and lifestyle choices, the availability and advancement of infrastructure and technologies, and policy measures. Representing the complex interactions between these phenomena in an IAM is challenging, in part because the phenomena driving demand in such models are aggregated and not distinctly represented.

In this study, we develop a framework to effectively represent various passenger mobility related phenomena using exogenous parameters of an IAM, as shown in figure 1. We first examine existing literature that explores causal relationships between various phenomena and passenger mobility patterns. Each identified phenomenon is systemically categorized and mapped to exogenous parameters of an IAM, MESSAGEix-Transport. This mapping allows the effects of each phenomenon on passenger mobility patterns to be captured and provides a method for representing these effects using an IAM.

Each phenomenon has the potential to influence multiple parameters of the IAM. To encapsulate all these influences, we individually include each phenomenon with all the parameters it is capable of influencing and parameterize them using empirical evidence from literature, with a priority given to evidence from the Global South. It is possible to define multiple trajectories for each phenomenon to visualize a range of potential mobility futures. In the next step, we utilize rich transport data (Indian Census 2011 and intercity travel) to develop and calibrate our model of passenger mobility demand for the whole of South Asia, considering the differences between other countries and India. This step establishes a link between region-specific data to a global IAM.

Finally, we develop four scenarios for passenger mobility based on alternate visions for mobility futures in South Asia. In each scenario, alternate outcomes for multiple phenomena influence the same IAM parameter. Hence, we establish interactions among these phenomena to produce IAM parameter data.

In summary, our primary contributions include: Firstly, we conduct a review of mobility-related phenomena, placing an emphasis on literature focusing on South Asia and the Global South. Secondly, we incorporate these phenomena into a novel mobility projection model designed to interface with an IAM. This is an innovative and adaptable framework that can be applied to other Global South regions and

IAMs. And, thirdly, we develop four distinct mobility scenarios using this model, each reflecting alternate visions for mobility based on explicit futures for these phenomena.

Section 2 discusses the current modeling gaps associated with IAMs and ESOMs. It also examines the unique challenges related to passenger mobility that South Asian countries face and elaborates on the significance of this region-specific analysis. The methodological framework and the process of developing sustainable mobility scenarios are discussed in section 3. The results are presented and discussed in section 4. Finally, the discussion and conclusions are outlined in section 5.

2. Gaps in literature and area background

2.1. The role of IAM & ESOM in transport decarbonization pathways and their shortcomings

IAMs and ESOMs are major tools used to explore different emissions and mitigation pathways for the transportation sector. However, these models have been critiqued for their techno-economic nature and limited representation of demand side mitigation options (Creutzig *et al* 2018, Stoddard *et al* 2021). In these models, energy systems decarbonization is often driven by technological changes, such as energy end-use electrification via renewables or efficiency improvements (Fragkos *et al* 2021). On the other hand, qualitative (societal, cultural, behavioral) and structural (infrastructure and economy) drivers of GHG emissions that are less easily quantifiable are not well represented (Stoddard *et al* 2021). In particular, exogenous parameters in these models generally do not include direct measures of many socio-cultural, behavioral, and lifestyle phenomena-even where such quantifications are well-established in the literature, and certainly where not (Yeh *et al* 2022). Consequently, modelers are limited to tuning the exogenous parameters that *are* captured, using different values across multiple scenarios to capture the assumed impact of such phenomena, even if only distantly related (van Soest *et al* 2019, van den Berg *et al* 2019, Creutzig *et al* 2022).

The default mobility trend in IAMs and ESOMs is typically based on measured causal relationships such as increasing passenger transport activity with rising incomes, while alternate futures in these models are usually represented through scenarios (Trutnevyte *et al* 2019). Examples include: 'low energy demand' scenario by Grubler *et al* (2018), implementation of the shared socioeconomic pathways (SSPs) by Bauer *et al* (2017) and a comprehensive exploration of such scenarios is available in the Intergovernmental Panel on Climate Change's Assessment Report 6 (Creutzig *et al* 2022, Jaramillo *et al* 2022).

Further, the modeled scenarios are generally aggregated and lack spatial granularity or resolution below large regions. In the real world, technology uptake rates, policies to promote sustainable development, and the costs and benefits of energy transition are spatially uneven (Yenneti *et al* 2016, Golubchikov and O'Sullivan 2020, Schippl and Truffer 2020). Global- and national-level models and scenarios often do not-or can not-include regional disparities explicitly (Fragkos *et al* 2021). This limits the ability to model and analyze regional inequalities in access to energy services and infrastructure, region-specific policies, barriers, costs, etc, in an IAM or ESOM framework.

The introduction of new transformations in energy services (novel services, disruptive technology, etc) in these scenarios is typically not well connected to empirical evidence. Also, most of the narratives underlying these scenarios assume that a certain phenomenon or causal relationship established in a specific part of the world will have similar impacts across all regions. For instance, the Global North has followed a pattern of increasing private car ownership with rising incomes, and global scenarios such as Grubler *et al* (2018), Kuhnhenn *et al* (2020) assume that a similar phenomenon will occur in the Global South as well. Further, the narratives also lack a consideration of the short-run response versus the long-run lock-in effects of phenomena or disruptive technologies. For instance, services like app-based ride hailing may improve access to mobility in the short run, while in the long run lead to an increase in congestion and a shift away from non-motorized transport (NMT) and public transport (PT) (Tirachini 2020).

Efforts have been made to include demand side mitigation options and behaviors related to passenger transportation in large-scale IAMs. For example, van Sluisveld *et al* (2016) include measures intended to lower passenger activity (reduced vehicle use and shift to PT) in an IAM and conclude that structural changes in mobility could reduce emissions by 35% by 2050, compared to the 'Baseline'. McCollum *et al* (2017) incorporate vehicle purchase decision in a global IAM, MESSAGE-Transport, and find that this inclusion leads to significant changes in the portfolio of light duty vehicles (LDVs) and cumulative CO_2 emissions.

The majority of the limitations associated with modeling mobility within IAMs and ESOMs discussed above focus on the Global North context, where demand reduction is being recognized as a major decarbonization strategy (Grubler *et al* 2018, McGarry *et al* 2024). The Global South, on the other hand, continues to experience higher population and economic growth, leading to an expansion of its energy systems. Despite this growth, access to energy services remains disproportionately low in many of these regions. As a result, the relevance of low energy demand scenarios in these countries might seem paradoxical. Since more than 80% of the global population resides in Global South countries, these countries will play a pivotal role in shaping the future GHG emissions trajectory and determining the feasibility of achieving the Paris Agreement goals. However, currently, the representation of Global South countries in large-scale global IAMs is oversimplified, relying on stylized assumptions from observation in Global North as mentioned previously. Further, Creutzig *et al* (2024) highlight the dearth of studies focusing on Global South context that explore how access and service provision can be improved in these regions at lower emissions.

2.2. Why South Asia? (background)

South Asian countries (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka) account for approximately one-fourth of the global population; about 36.6% live in urban areas. Economic and population growth, along with increasing urbanization rates, have driven a continuous increase in demand for mobility (passenger and goods) in these countries. These drivers are likely to continue in the region, inevitably leading to an increase in demand for mobility and-without intervention-GHG emissions (ITF 2022). Since investment in infrastructure has long-term lock-in effects, choices made in the near term will determine energy service demands and, therefore, climate mitigation options and trajectories in the coming century. At this stage, South Asia *could* leverage green growth policies and technologies to leapfrog the car dependency and emission intensive mobility patterns often observed in the Global North, towards a more sustainable development pathway (Herman 2021). Currently, there is a lack of coherent data and detailed literature on the passenger transport sector of these countries, which leads to embedded assumptions within global models that the mobility patterns of Global North countries will play out in Global South countries (Herman 2021).

There are several challenges in achieving sustainable mobility development in South Asia. Firstly, cities are facing rising sprawl with a growing population (Jain and Sharma 2019, Kamble and Bahadure 2021). In most cases, lower income households are forced to live in suburban areas or peripheral settlements, further increasing travel distances (Chaudhry *et al* 2023, Hamiduddin 2023). The longer distances decrease access to employment, healthcare, education, etc, a challenge which is compounded by the inability to afford mobility services (IEA 2021). Secondly, rising income levels and the lack of PT infrastructure have led to increasing vehicle ownership rates (2-wheelers and private cars). This has not only caused a continuous increase in GHG emissions from the transport sector but has also led to poor air quality and congestion in urban areas (Badami and Haider 2013, Ellis and Roberts 2015). Finally, NMT modes are generally unsafe to use due to a lack of supporting infrastructure (IEA 2021).

Previous studies have tried to address the above challenges in modeling frameworks. By developing a deep decarbonization scenario for passenger transport for emerging economies (Brazil, India, Indonesia, and South Africa), Briand *et al* (2023) find that reaching carbon neutrality would require more than 50% reductions in emissions per passenger distance traveled (PDT). This would require pursuing a wide range of mitigation options, including the use of NMT and integrated urban land-use development to curb car use and improve the provision of PT. Travel demand projection scenarios for India project a 200%–540% increase in CO_2 by 2050, highlighting that existing policy targets are likely to be insufficient to reduce, or even stabilize, emissions (Cazzola *et al* 2021). Both these studies also emphasize that a lack of data in developing countries limits detailed analysis of mobility patterns. In this study, we aim to address this deficit by developing sustainable mobility scenarios for South Asia by using data and evidence from the region, such that the developed scenarios align with actual potential mitigation in the region.

3. Methodological framework guiding model and scenario development

Figure 1 lays out the overall approach and steps involved in the process. In the subsequent subsections, we explain each major step separately.

3.1. Mobility related phenomena relevant to Global South

This section describes the phenomena captured in the literature review, grouped into several categories that are not mutually exclusive.

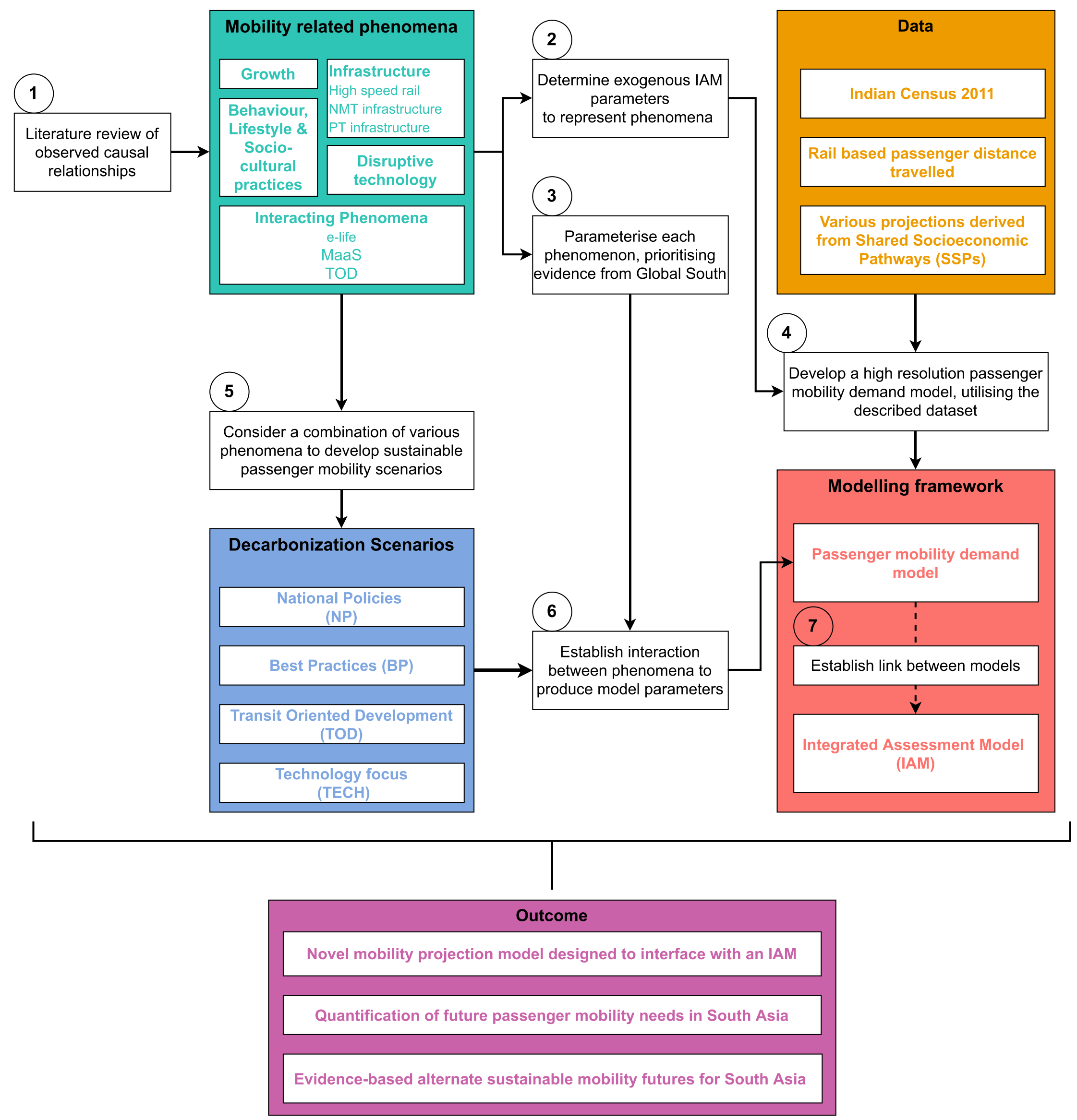


Figure 1. Overall workflow of approach describing various steps involved (dotted arrow line indicates future work- Step 7). E-life: Tele-'X'; TOD: transit oriented development; MaaS: mobility-as-a-service.

3.1.1. Growth and development

The main phenomena that influence growth associated with passenger mobility demand and emissions are population growth, economic growth, and urbanization. As discussed previously, population and economic growth are projected to continue in the Global South until mid-century, inevitably leading to the expansion of the transport, energy, and economic systems. However, a phenomenon like urbanization has different impacts in the short- versus long-run. In the short run, urbanization in developing countries leads to increased CO_2 emissions and road transport energy use (Poumanyvong *et al* 2012, Sikder *et al* 2022). This is due to an increase in higher income and greater access to technology and services. In the long run, however, higher urban density can reduce mobility demand due to lower travel distances: doubling density could reduce mobility demand by 10%–12% in India (Ahmad and de Oliveira 2016). Due to the lack of comprehensive data in the South Asian region, we have defined two distinct trajectories for the distribution of urban population based on the urbanization trends observed in India. The Indian Census from 2001 and 2011 indicate a concentrated growth of population in large cities (Trajectory 1) (GoI 2011a). However, we also explore an alternate path (Trajectory 2) that envisions a more balanced growth, owing to rising pressures for resources in large cities, making them less attractive in the long term. A more detailed analysis of the impact of the nature of urbanization on mobility patterns is possible, and our modeling framework can accommodate multiple definitions of such trajectories. For the current study, we have defined two trajectories as follows:

- Concentrated growth (Trajectory 1): Share of urban population in large cities is assumed to increase by 10% points in 2030 and 7% points in 2050. Conversely, the share in cities and towns is assumed to decrease by 5% points each in 2030 and 3.5% points each in 2050.
- Balanced growth (Trajectory 2): Share of urban population in large cities is assumed to increase by 5% points in 2030 and 2% points in 2050. Conversely, the share in cities and towns is assumed to decrease by 2.5% points each in 2030 and 1% point each in 2050.

3.1.2. Transportation Infrastructure development

Infrastructure development, whether PT or spatial settlement patterns, has significant lock-in effects. The Global South is yet to build a major part of its infrastructure and hence has a wide range of possibilities to ensure development is sustainable. For example, Vasudevan *et al* (2021) find that high quality public transit system development could decrease two-wheeler ownership in India. Similarly, it is estimated that 35%–45% of trips shorter than 5 km can be made by NMT modes, which are otherwise made by motorized vehicles (not including cars), when appropriate infrastructure is developed in a large Indian city like Pune (Jain *et al* 2010). Further, improving NMT infrastructure is crucial for maintaining the current mode shares of NMT and PT in Indian cities (Tiwari *et al* 2016). A case study of two medium-sized Indian cities shows that maximum CO_2 emissions reduction can be achieved when both NMT and PT infrastructure are developed (Tiwari *et al* 2016).

3.1.3. Disruptive technology: digitization and automation

Digitization is one of the megatrends driving changes in multiple aspects of human life (Creutzig *et al* 2022). Digital technologies are expected to significantly alter mobility patterns, associated transport energy demand, GHG emission trajectories, and climate change mitigation options (Creutzig *et al* 2019, Noussan and Tagliapietra 2020). There are many related sub-phenomena, each with distinct and sometimes countervailing impacts.

Tele-X or e-life: The evidence on the impact of remote working and online shopping on passenger transport is mixed (Le *et al* 2022). Tan *et al* (2023) find that with remote work policies in place, workers tend to move to low density suburbs, leading to longer commutes and a shift to private cars, thereby increasing vehicle distance traveled (VDT) in the future. However, online delivery services can curb some of the rebound effects of remote working (Tan *et al* 2023). Zhang and Zhang (2021) and Hossain *et al* (2023) conclude that with appropriate policies in place, remote work can contribute to a reduction in travel demand and emissions in China and Bangladesh, respectively. There is some evidence that online shopping substitutes for shopping trips (Le *et al* 2022), and e-commerce is likely to expand in Asian markets in the coming decade (Kinda 2019). With this context, we include the best-case scenario for e-life in this study, assuming that e-life will lead to a reduction in transport demand.

Ride hailing and sharing: On-demand mobility services like ride hailing are found to increase VDT, have lower occupancy in general, and lead to greater traffic congestion in big cities (Henao and Marshall 2019, Bekka *et al* 2020, Tirachini and Gomez-Lobo 2020). Such services have led to a shift away from NMT and PT, and can induce car-based travel (de Souza Silva *et al* 2018, Cazzola *et al* 2021). Ride sharing can, however, reduce VDT and traffic externalities like congestion and pollution, and bring environmental benefits (Caulfield 2009, Cai *et al* 2019, Chen *et al* 2021). Ride sharing is expected to decrease CO_2 emissions in the short-term, but substantial rebound mechanisms can be expected in the long run, through mode switch to cars, and increased travel distances as improved access to mobility service could encourage relocation to suburbs, etc (Yin *et al* 2018).

Autonomous vehicles (AVs) have been highlighted for their potential to revolutionize the transport system (Meyer *et al* 2017, Bösch *et al* 2018, Millard-Ball 2019). Under some scenarios of deployment, they could increase access to mobility for some (children, elderly, disabled, etc), reduce private car ownership, and increase opportunities to pedestrianize urban centers. Alternatively, it is also possible that AVs may lead to an increase in VDT, urban sprawl, and a shift away from PT.

Mobility as a service (MaaS) is a novel mobility solution that can provide high accessibility by combining shared mobility services (car-sharing, bike sharing, etc, in combination with PT) and developments in information and communication technologies (Kamargianni *et al* 2016). The willingness to use MaaS and increase the use of PT was high in a survey conducted by Hasselwander *et al* (2022) in Metro Manila, Philippines. However, implementation of MaaS at a large scale in Global South cities would require a different approach than those adopted in developed countries, such as offline access to MaaS platforms, integration of intermediate PT (IPT) modes, and more (Hasselwander and Bigotte 2023).

3.1.4. Behavioral, lifestyle & socio-cultural practices

Behavioral, lifestyle, and socio-cultural practices significantly impact the choices individuals make regarding how they travel. In literature, behavioral changes are categorized as short-term travel decisions, whereas lifestyle changes are typically broader and more permanent decisions (Van Acker *et al* 2016). The evolution of these elements in the future can affect various elements of the transport energy system, urban planning, infrastructure development, and emissions.

Environmental awareness can significantly impact travel behavior (Mandić *et al* 2023). For a case study in Delhi, Gupta and Sinha (2022) find that people with a pro-environmental attitude are likely to use shared mobility and PT for their travel needs, and are willing to reduce private car dependency. Soto *et al* (2021) recommend the use of marketing campaigns and financial incentives to encourage people with environmental concerns to shift to sustainable modes.

Socio-cultural norms such as viewing private vehicle ownership as a status symbol is prevalent in Global South countries (Pojani and Stead 2018, Chaudhry *et al* 2023). While strategies aimed at increasing environmental awareness have been successful in reducing car ownership, the existing evidence primarily pertains to developed countries where such ownership is at or near saturation (Pojani and Stead 2018). A shift to low-carbon modes in Global South cities would require addressing safety concerns, enhancing social influence, and raising the symbolic profile of PT, along with developing appropriate infrastructure (Ashmore *et al* 2019, Javaid *et al* 2020). Embracing changes in lifestyle patterns like work-from-home and online shopping ('Tele-X') can be used to further manage transport demand in large Global South cities (Jamal and Khan 2021).

3.1.5. Urban development paradigms: transit oriented development (TOD)

TOD is increasingly becoming a part of sustainable urban development plans at a global scale (Ibraeva *et al* 2020, Knowles *et al* 2020). It combines mixed-use land development and urban design with transport planning (Ibraeva *et al* 2020). In Asian cities with well-established metro rail transit, TOD can reduce VDT and traffic congestion, and promote PT and NMT modes (Kumar *et al* 2020). Li *et al* (2022) further confirm, for a case study in China, that residents in TOD areas are more likely to choose NMT or PT modes. Findings from Nakshi and Debnath (2021) suggest that mixed land-use policies, shorter distances to bus stops, and higher density are needed in a city like Dhaka to increase PT accessibility.

3.2. Representing phenomena in an IAM

This section describes the process of representing each phenomenon within an IAM framework. It is important to emphasize here that our approach does not involve making structural changes to the IAM itself. Instead, we develop a methodology to improve the translation and quantification of passenger mobility related phenomena into exogenous parameters of the IAM.

3.2.1. IAM

IAMs are valuable tools that provide insights into techno-economic feasibility of climate targets and the impact of policy interventions. MESSAGEix-GLOBIOM is one family of such models that consists of a combination of energy, economy, land-use, climate, and air-pollution models at the global level (Krey *et al* 2020). The representation of the transport sector in the global model is stylized. However, a technology-rich representation of the transport sector is possible, and the resultant model is referred to as MESSAGEix-Transport.

3.2.2. Translating phenomena to IAM parameters

Following the comprehensive literature review that explores the causal relationships between each phenomenon and passenger mobility patterns, we now link each phenomenon to the exogenous parameters of MESSAGEix-Transport. This enables effective and distinct representation of each phenomenon in the modeling framework. The exogenous parameters of the IAM tuned in this study are: PDT, mode share, vehicle occupancy, vehicle ownership (private car and 2-wheelers), and LDV technology type. PDT, in turn, is driven by *trip rate* and *trip share* by distance category, which are parameters of the estimated demand model presented in the next section. Table 1 summarizes how each phenomenon can be translated into IAM parameters based on evidence from the literature review above.

3.2.3. Parameterization strategy

We parameterize each phenomenon based on a comprehensive literature review. In doing so, we adopt a specific order of precedence: first, evidence from South Asia is prioritized. If this is not available, then evidence from Global South countries outside of South Asia is used. As a last resort, we use evidence

Table 1. Representation of phenomenon in MESSAGEix-Transport.

Category	Phenomenon	Measurement	Parameter(s) in MESSAGEix-Transport
Growth	Urbanization	Share of total population	PDT
Disruptive technology	Autonomous vehicle	Mode share	PDT, vehicle ownership, share of PT
	Ride hailing	Share of *t*axis	PDT, share of PT and NMT, LDV occupancy
	Ride sharing	% of trips	Occupancy of LDVs (taxi)
Infrastructure	High speed rail	Share of rail	Share of rail in intercity travel
	NMT infrastructure		Mode share of NMT
	PT infrastructure		Mode share of PT, occupancy
Behavior, Lifestyle & Socio-cultural practices	Comfort, reliability, safety		Vehicle ownership and mode shares
	Environmental awareness		Vehicle ownership, Share of LDVs, PT and NMT
	Higher standard of living		LDV ownership and use
Complex	e-life	Trip rate	PDT
	MaaS	Share of various modes	Mode share of LDVs, PT and NMT
	Transit oriented development		PDT (trip share), vehicle ownership, share of PT and NMT

from the Global North. This novel strategy is conceived to mitigate the prevalence of wealthy, data-rich, and heavily-studied areas in the literature by not allowing such over-representation to skew the future outcomes envisioned and modeled for the Global South.

For each specific phenomenon, evidence for both the short-term and long-term effects is compiled. This encompasses a range of values spanning from low to high for each parameter. Table 2 shows how each phenomenon is parameterized, prioritizing evidence from Global South. The detailed description of the modeling approach for each of these phenomena is outlined in table A.1 in the appendix A.

Notably, phenomena such as AVs and MaaS exhibit novelty even in developed countries, posing challenges in measuring their impacts or observing distinct outcomes in diverse settings. To address this, we extrapolated outcomes deemed plausible within the South Asian context.

The literature also indicates the contextual nature of factors such as comfort, reliability, and safety. The relationship between infrastructure and individual choices becomes apparent-for example, the development of a robust PT network fosters a sense of safety and reliability, thereby encouraging its utilization. However, the lack of it may drive individuals towards private vehicle ownership. Another illustrative example involves ride sharing with strangers-which in the Global South context can be perceived as more comfortable than other modes of transport but can also be less preferred, particularly for women (Vanderschuren and Baufeldt 2018). Consequently, they may prefer the alternative of ride hailing. However, if the option to travel with other women as co-passengers or a panic button is provided to increase the sense of safety, ride sharing could be widely adopted (Meshram *et al* 2020, Mitropoulos *et al* 2021). Hence, the outcome of this behavioral response is highly dependent on other phenomena (and their outcome) that are considered in tandem.

3.3. Passenger mobility demand model

This section describes the model constructed to generate IAM parameter data for passenger transport activity, based on the detailed quantities that are directly implicated in the causal relationships from the literature. The estimations of PDT and mode shares within the model are underpinned by projections of population growth, the pace and nature of urbanization, and GDP per capita. The projections of population growth, pace of urbanization and GDP are derived from the SSPs (IIASA and contributing

Table 2. Parameter values for each phenomena

Phenomenon	Parameter	Value	
		Short-run	Long-run
Urbanization	PDT	0.4% [1] to 2.3% [2]	0.2% [3] to 1.33% [4]
Autonomous vehicle (AV)	PDT Vehicle ownership PT share	} Dependent on scenario of deployment [33]**	
Ride hailing	VDT NMT share PT share Vehicle ownership	 −1% [22] −5.4% [21]** to −17% [20] 	83.5% [24]** −16% [30]** −3% [23]
Ride sharing	VDT	−8.21% [18] to −37% [19]	
High speed rail infrastructure	Share of rail in long-distance travel		52.7%[25]
NMT infrastructure	NMT share (trips <5 km)		Shift of 35% from 2-wheelers & 45% from bus[31]
PT infrastructure	PT share	Increase in share by 8% [27] to 10.6% [26]	Shift of 45% from 2-wheelers and 11.5% from cars [32]
Comfort, reliability, safety	Vehicle ownership Mode shares	} Context specific- dependent on other phenomena under consideration [34], [35]	
Environmental awareness	EV sale share	30%[37]	100%
Higher standard of living	LDV ownership		Increase in average ownership by 63% from current level [36]
e-life	Trip rate	−19%[28]	−5% [29]**

(Continued.)

Table 2. (Continued.)

Phenomenon	Parameter	Value	
		Short-run	Long-run
MaaS	LDV share NMT share PT share	} Dependent on scenario of deployment	
Transit oriented development[‡]	PDT	−0.24%[5] to −0.44%[6]	−20%[7] to −42.5%[8]**
	NMT share	0.3%[9]	17%[10]** to 30%[11]
	PT share	0.1%[12]**	12%[13] to 60%[14]**
	Vehicle ownership	No evidence of reduction in short-run[15]	−10%[16]** to −40%[17]**

**Global North. ‡In the short run, TOD is measured as increase in density- values correspond to 1% increase in density. [1]Lv and Wu (2019). [2]Hao *et al* (2014). [3]Wang *et al* (2019). [4]Poumanyvong *et al* (2012). [5]Ahmad and de Oliveira (2016). [6]Proque *et al* (2020). [7]Chen *et al* (2017). [8]Stiffler (2011). [9]Bautista-Hernández (2021). [10]Zamir *et al* (2014). [11]Zhang and Zhao (2017). [12]Mattson (2020).[13]Goel and Mohan (2020). [14]Mees (2014).[15]Tiwari *et al* (2016), Bansal *et al* (2018). [16]Dong (2021). [17]Nasri and Zhang (2014). [18]Zhu and Mo (2022). [19]Chen *et al* (2021). [20]Haddad *et al* (2019). [21]Ngo *et al* (2021). [22]Acheampong *et al* (2020). [23]Ward *et al* (2019). [24]Henao and Marshall (2019). [25]Ou *et al* (2022). [26]Maluf (2014). [27]Majid *et al* (2018). [28]Kanimozhee and Srikanth (2023). [29]Budnitz *et al* (2020). [30]Diao *et al* (2021). [31]Jain *et al* (2010). [32]Fatima and Kumar (2014). [33]Moreno *et al* (2018). [34]Gupta and Sinha (2022). [35]Jain *et al* (2014). [36]Assuming national average ownership to reach current level of large cities in South Asia (Abdul-Manan *et al* 2022). [37]Dixit and Singh (2022).

modeling teams 2024). Our framework is flexibly designed to incorporate data from any of the five SSPs. However, for the scope of the current study, we use SSP2. SSP2 represents middle-of-the-road development in terms of climate mitigation and adaptation challenges, and the social, economic, and technological trends follow historical patterns (Fricko *et al* 2017).

The development of future passenger mobility demand trajectories involves various steps. ***We estimate a daily travel passenger mobility demand model, calibrated to the Indian Census 2011*** (section 3.3.1). This model is disaggregated into four area types, eight distance categories and six modes of travel. The framework is multidimensional, which allows for including detailed assumptions about passenger mobility trends in our future projections. Hence, in the final step, we develop future passenger mobility demand trajectories by tuning various dimensions of our framework (section 3.3.2). We discuss some of the important outcomes of the passenger mobility demand model in section 4.

The model is developed using open-source data and software (Python). The results and the code used in this version are archived on Zenodo (Gaur *et al* 2025).

3.3.1. Daily travel passenger demand model

We begin with the categorization of the population between urban and rural areas. Urban regions in India are further categorized into three groups based on their population size: large cities (>3 million residents), medium cities (between 1 and 3 million), and towns (< 1 million). Comparable classification systems, albeit with distinct population thresholds, are also applied to urban areas in other countries in the South Asian region (Bangladesh Bureau of Statistics 2011, United Nations 2011, GoI 2011a). The distribution of urban population within area types is outlined in the appendix B.

A daily travel passenger demand model is derived using data from the Indian Census 2011 (GoI 2011b). This data set includes information regarding commute travel distance ranges, share of each distance range (trip share), and the mode of travel across various regions, distinguishing between urban and rural areas within each district and city for commute purposes only. Based on the above population classification, we processed the census data to gather passenger transport characteristics for each area type. Trip rates are included for each area type from Singh *et al* (2008) and adjusted to reflect commute patterns. Commute-related journeys account for about 30% of total passenger trips (Shukla *et al* 2015). Due to a lack of comprehensive data for other types of daily passenger trips, it is assumed that comparable travel patterns are exhibited across other trip categories. We calibrate/validate the model by comparing annual PDT per capita for the base year (2011) with values found in literature, finding only marginal differences (Dhar and Shukla 2015). The detailed model is available in the appendix C.

The model has been adjusted for other countries to better reflect the rail travel. In Bangladesh, Pakistan, and Sri Lanka, rail usage is primarily for long-distance travel (greater than 30 km), with a limited share in large cities for short distances. Accordingly, their rail shares have been reduced, with the balance reallocated to 'bus'. Similarly, for countries like Afghanistan, Bhutan, Maldives, and Nepal, that do not have rail services, the shares have been reduced to zero and reassigned entirely to 'bus'.

3.3.2. Projecting mobility demand using dimensionality of model

As discussed previously, the passenger mobility demand model developed in this study is based on a multidimensional data set. This allows for the simultaneous adjustment of one or more dimensions, enabling the generation and visualization of detailed and diverse future mobility scenarios. In this section, we discuss the various dimensions of the model being tuned to develop future passenger mobility demand trajectories as summarized by figure 2.

The future pace of urbanization is directly derived from the SSP projections. However, determining the nature of urbanization is more complex. The distribution of urban population among large cities, cities, and towns is referred to as the nature or type of urbanization, and it plays an important role in shaping mobility patterns. The growth of population in either a city ora large city has profound implications, given the differences in settlement patterns and infrastructure provision. The trajectories considered in this study are described in section 3.1.1.

Trip rates in South Asia are significantly lower than those observed in developed countries (Ahern *et al* 2013). Hence, we hypothesize that increased affluence within a population positively correlates with higher trip frequency, along with increasing trip distances within each trip category. The future trajectories of trip rates are determined by changes in GDP per capita in each country. To project future trip rates, firstl,y we calculate the percentage change in GDP per capita for three time intervals: from 2011 to 2030, from 2030 to 2050, and from 2050 to 2100. Next, using equation (1) we determine the future trip rates in each time interval, where the *TR* represents the trip rate, *at* refers to area type and can take values from the set {large city, city, town and rural}, *s* denotes the SSP scenario (1–5), the notation y_i

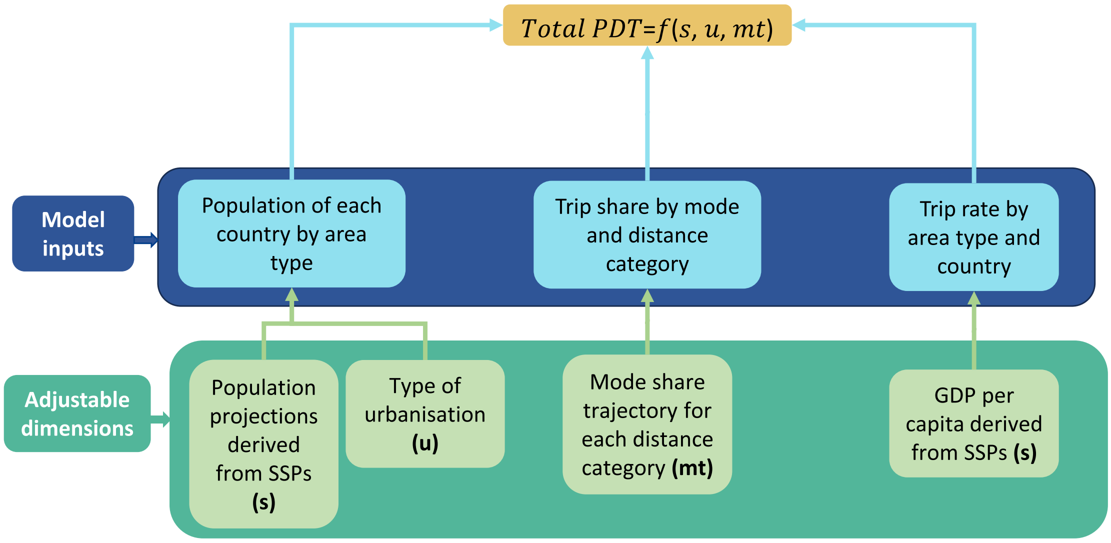


Figure 2. Passenger mobility demand model inputs and the adjustable dimensions.

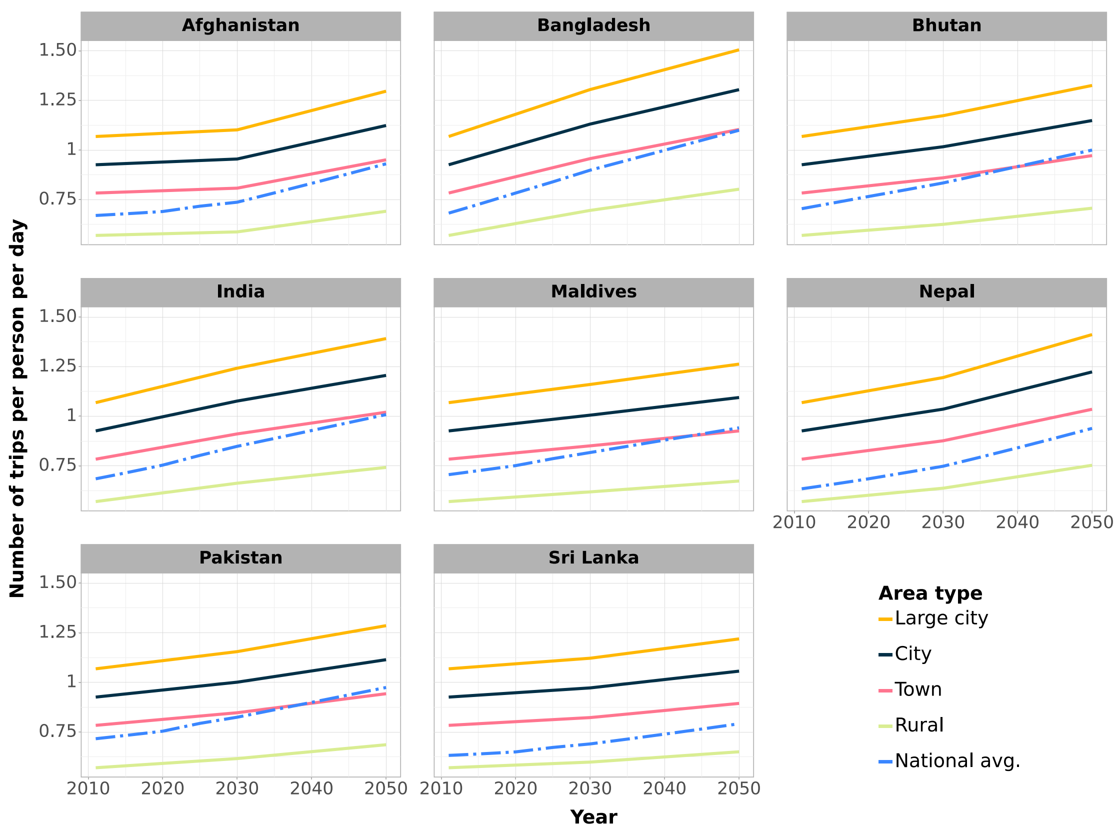


Figure 3. Trip rate trajectories in each country (calculated using GDP per capita values from SSP2 projections).

represents the year at the beginning of the interval, while y designates the year at the end of the interval, and GDP_cap is the GDP per capita for each country n in the South Asian region. The trip rates are then interpolated to obtain trajectories, as shown in figure 3, which is an example of trip rates in each country for SSP2.

$$TR_{at,n,y}(s) = TR_{at,y_i} \times f\left(\text{GDP\_cap}_{n,y}(s) - \text{GDP\_cap}_{n,y_i}(s)\right). \quad (1)$$

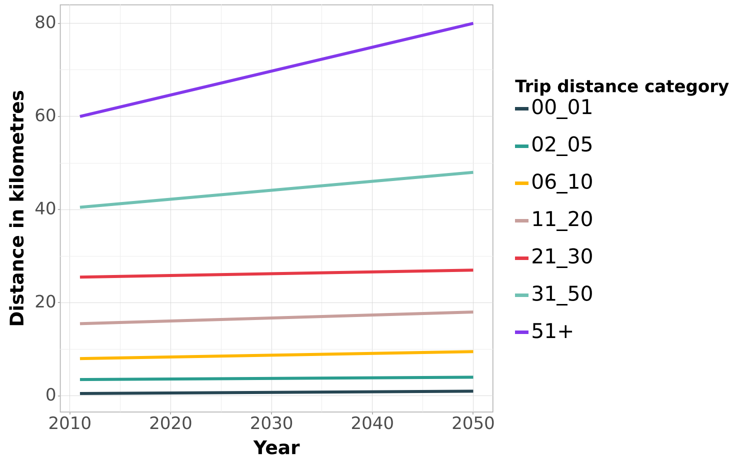
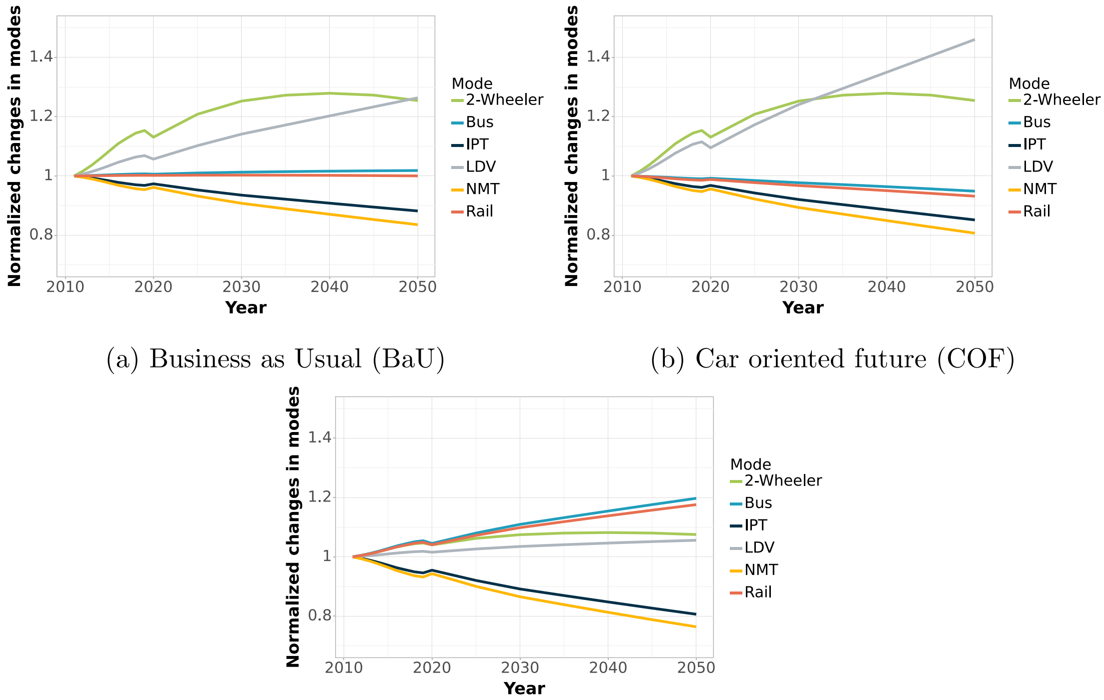


Figure 4. Trajectories of distance (in kilometers) in each trip distance category .

Figure 4 shows the assumed changes in the distance traveled in each distance category. In the base year (2011), we assume a mean value for distance in kilometers in each trip distance category. By 2050, we project a shift towards the upper boundary of the distance interval within each respective category.

The Indian Census data reports mode share for six modes of travel, each distance category, and area type. We constructed mode share trajectories for each mode as shown in figure 5. For countries that do not have rail, the trajectories are defined only for the other five modes. These trajectories depict changes in mode shares relative to the base year of 2011. Further, the mode shares have been adjusted to ensure that these changes do not disrupt the overall level of PDT, which is primarily influenced by trip rates and distances in each trip distance category. For the scope of this study, we have used the same mode share changes across all area types and distance categories. However, it is conceivable to define distinct cases for each distance category and area type to capture nuances in passenger mobility patterns. The study presents three distinct cases:

- Business as usual (BaU): In the BaU scenario, we anticipate a shift from NMT to motorized modes (2-wheelers and cars) with increasing GDP per capita. Specifically, the share of 2-wheelers follows an inverted U-curve, with 2-wheelers' growth peaking at a GDP per capita of about \$3000–\$4000, after which it declines (Law *et al* 2015). The growth of cars, on the other hand, follows a monotonically increasing curve with GDP per capita (Nishitateno and Burke 2014). While historical evidence suggests exponential growth in LDV ownership, the latest evidence for India suggests a linear increase (Mohan *et al* 2025).
  In our study, the BaU scenario assumes that the share of NMT decreases as GDP per capita rises, while the share of 2-wheelers increases until reaching \$3500 GDP per capita (a consistent value assumed for all countries). The share of cars also increases, albeit at a slower rate than 2-wheelers, and the share of PT sees a modest increase. Figure 5(a) outlines the normalized changes in modes in the BaU case.
- Car-oriented future (COF): In the COF scenario, we project an accelerated growth of cars compared to the BaU case. Initially, cars are expected to grow slower than 2-wheelers but will overtake the growth of 2-wheelers earlier than in the BaU scenario. The peak of 2-wheelers in this scenario is slightly lower than that considered in BaU. Additionally, PT is anticipated to experience a modest decrease, while NMT follows the pattern as in the BaU case. This scenario reflects a potential shift towards greater car usage in South Asian countries, highlighting the need for sustainable mobility strategies to mitigate the adverse effects on traffic congestion, air quality, and overall urban livability. Figure 5(b) outlines the normalized changes in modes in the COF case.
- Sustainable future (SF): In the SF scenario, we envision a shift towards sustainable modes of transportation, driven by greater investments in PT infrastructure. This scenario anticipates a significant increase in the share of PT, with buses and rail growing at a faster rate than in the BaU case. In contrast, the growth of cars and 2-wheelers is lower than in BaU, reflecting a conscious effort to prioritize sustainable modes of transport over private vehicles. Share of NMT goes down faster as compared to BaU and COF. This scenario underscores the importance of sustainable mobility strategies in South



(a) Business as Usual (BaU)

(b) Car oriented future (COF)

(c) Sustainable future (SF)

Figure 5. Changes in daily travel mode share trajectories for India (SSP2). (*IPT-intermediate public transport; LDV-Ligh duty vehicle; NMT-non-motorized transport*).

Asian countries, highlighting the potential benefits of reducing traffic congestion, improving air quality, and enhancing overall quality of life. Figure 5(c) outlines the normalized changes in modes in the SF case.

The future daily travel PDT is projected as in equation (2), where PDT is the product of trip rate (TR), derived from equation (1), share of trips (TS), which is a function of the mode share trajectory (mt), in each area type for each mode and distance category, an assumed value of typical distance (D) in kilometers for each distance category, as in figure 4 and the population (Pop), which is a function of the SSP scenario (s) and trajectory of the type of urbanization (u), in each area type and country. Index at refers to area type and can take values from the set {large city, city, town and rural}, m represents the mode of transport and there are six distinct modes in the model as follows: {car, bus, IPT, 2-wheelers, NMT and rail}, dc denotes trips categorized by distance and there are eight distance categories (in kilometers): {No travel, 0–1, 2–5, 6–10, 11–20, 21–30, 31–50, and 51+}, index n denotes the countries in South Asia and y denotes the year.

$$PDT_{at,dc,m,n,y}\left(s,u,mt\right) = Pop_{at,n,y}\left(s,u\right) * TS_{at,dc,m,y}\left(mt\right) * TR_{at,n,y}\left(s\right) * D_{dc} \quad (2)$$

3.4. Sustainable mobility and decarbonization scenarios

The phenomena discussed in section 3.1 in tandem with national policies in South Asian countries, form the basis for the development of four distinct scenario narratives. The narratives contain a rich description of each phenomenon, underpinned by substantial empirical evidence, primarily from South Asia and Global South. The central theme of each narrative is the imperative of ensuring sustainable development of passenger mobility in South Asia. The main focus lies in envisioning pathways that leapfrog traditional private car dependency while at the same time improving access to mobility for all segments of society. Each scenario is discussed below, and table 3 outlines the combination of phenomena considered in each scenario.

Further, the scenarios in table 3 are imposed over the mode share trajectories (figure 5), and their definition is independent of them. The multiple mode share trajectories were developed to showcase the flexibility and capabilities of our framework in accommodating multiple definitions, and they have no impact on PDT.

Table 3. Combination of phenomena considered in scenarios.

Category	Variable	Scenario			
		NP [1]	BP [2]	TOD [3]	TECH [4]
Growth	Urbanization	—	—	✓	—
Disruptive technology	Autonomous mobility	—	—	—	✓
	Ride hailing	—	—	—	✓
	Ride sharing	—	✓	—	✓
Infrastructure *	High speed rail	—	✓	—	—
	NMT related infrastructure	✓	✓	✓	—
	Public transport	✓	✓	✓	—
Behavior, Lifestyle & socio-cultural practices	Comfort, reliability, safety	✓	✓	✓	—
	Environmental awareness	✓	—	✓	—
	Higher standard of living	✓	✓	—	—
Complex	e-life	—	—	—	✓
	MaaS	—	—	—	✓
	Transit oriented development	—	—	✓	—

* Infrastructure upgrade over 'Base'. [1]NP- National Policies in South Asia. [2]BP- best mobility practices in Global South. [3]TOD- transit oriented development. [4]TECH- technology focus.

3.4.1. National Policies in South Asia (NP)

This scenario is founded on the set of phenomena that are named or implicated by the stated national goals, strategies, and/or policies of the countries within South Asia. In most cases, the phenomena are grounded in evidence, driven by dedicated outlines and plans for their implementation. This scenario reflects a case where policy implementation is aligned with targets and goals, resulting in sustainable progress within the passenger mobility sector. In general, the national policies across all countries in the South Asian region recognize the need for effective transport demand management to accommodate the mobility needs of a growing population and improve access to health, education, employment, etc, whilst ensuring the development in the sector is environmentally sustainable. The major passenger transport related policies in each country are listed in appendix D.

3.4.2. Best mobility practices in Global South (BP)

This scenario is a compilation of the best mobility practices observed in the Global South. These are successful implementations of innovative mobility solutions that have led to sustainable and equitable expansion of transportation systems in these regions. The main premise of this scenario is to apply observed phenomena from the broader Global South context to the specific context of South Asia. The similarity of socio-economic and demographic conditions in these regions renders the occurrence of such phenomena particularly more plausible than current transformations and/or policy trends taking place in Global North countries (which, again, dominate the literature). The phenomena considered are based on successful implementation elsewhere. Notably, the development of bus rapid transit systems in Latin American and Indian cities has proven to increase the share of PT in urban transport (Maluf 2014, C40 Cities 2016). Similarly, high speed rail (HSR) development in China has led to a significant modal shift from aviation to HSR for inter-city travel. Shared mobility is gaining increasing popularity in South Asia.

3.4.3. TOD

Amidst the expansion of urban centers in South Asia, both in population and area, this scenario is developed to understand the consequences of compact urban and transit oriented development on passenger mobility within these cities. Central to this scenario is the recognition that as cities are growing, the urban form they take will strongly shape passenger mobility in the coming decades. Embracing compact development could help steer cities away from private motorized transport towards more sustainable solutions. Combined with policy measures and infrastructure for PT and NMT, TOD can reduce travel distances and improve the quality of life within urban centers. For example, TOD in Beijing resulted in 30% of all trips by NMT (Zhang and Zhao 2017). This scenario also envisages a future where urban expansion is slower compared to current predictions and local economies are regenerated to prevent rural-to-urban migration.

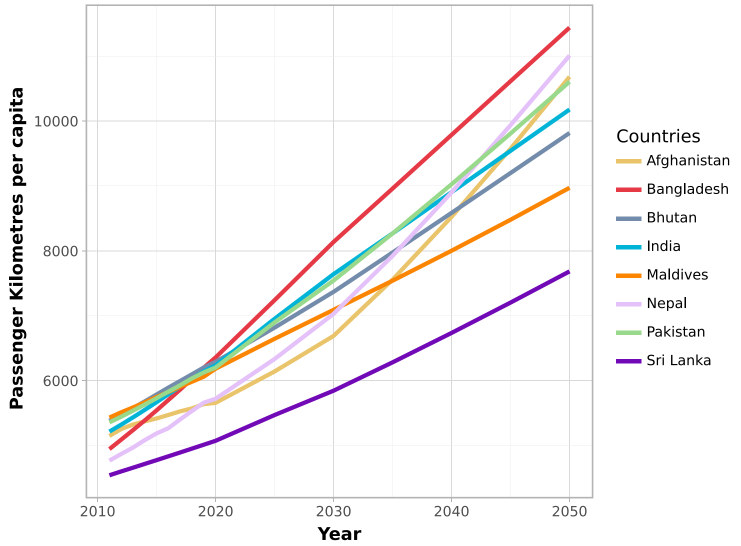


Figure 6. Total passenger kilometers per capita in all countries in South Asia for SSP2 (COVID-19 dip has not been captured).

3.4.4. Technology focus (TECH)

This scenario encapsulates transformations in passenger mobility patterns driven by technological innovations and their widespread adoption. Disruptive technologies and the electrification of transport fleet are the main drivers of this scenario. The surge of digitalization and practices like work-from-home, online shopping (e-life) further fuel this evolution in passenger mobility. This scenario revolves around utilizing technology to leapfrog private vehicle dependency and usage.

4. Results

This section outlines the main results from our analysis. Section 4.1 presents the modeling outcomes of the passenger mobility demand model. It describes the outcome of the baseline of our study and is hereafter referred to as the 'Base' scenario, which is driven by population, GDP per capita, and urbanization for each South Asian country. Section 4.2 presents the outcomes in each mobility scenario discussed previously. It describes the interactions between various phenomena and other model parameters.

4.1. Outcomes of passenger mobility demand model

4.1.1. PDT

The total PDT in South Asia is projected to increase by 175%–184% between 2011 and 2050, with a compound annual growth rate of about 2.6%, for SSP2 and the two trajectories assumed for the type of urbanization (u). Figure 6 shows the total (daily travel and long distance) PDT per capita (in kilometers) for all countries. The passenger kilometers per capita is projected to increase by 130% in Bangladesh and Nepal, and 108% in Afghanistan between 2011 and 2050. The increase in PDT per capita is above 65% in all other countries in the same time period. The increase in total PDT and PDT per capita highlights the expected expansion of the transport system in South Asia, which will heavily determine the GHG emissions trajectory from this sector.

Figure E.1(in appendix E) shows the trends in GDP per capita and total PDT per capita in each country. The growth in mobility demand follows that of GDP, albeit at a lower rate. In Bangladesh and India, while economic growth is anticipated to be robust, growth in mobility demand is anticipated to be comparatively moderate. Conversely, Sri Lanka and Afghanistan anticipate an increase in GDP by a factor of 2.4 and 3, respectively, in 2050 relative to 2011. Despite the relatively lower GDP growth rates, the PDT doubles within the same time period. Hence, the ratio of PDT to GDP is 71% for Sri Lanka and 68% for Afghanistan, suggesting a strong correlation between economic growth and mobility demand. Bhutan, Maldives, Nepal, and Pakistan anticipate the ratio of PDT to GDP to be between 48%–63% in 2050. This indicates a moderate alignment between economic growth and mobility demand in these countries.

There is a steady increase in PDT across all countries and area types, as shown in figure 7. In all countries, except Sri Lanka and Nepal, most of the growth in PDT is observed in 'Large city' area type.

Figure 7. Total passenger kilometers disaggregated by area type for SSP2 .

Large cities have greater passenger mobility per person, and the population is assumed to grow in this area type in the future, resulting ina much rapid increase in PDT (See section 3.1.1 for the definition of type of urbanization). PDT in rural areas is mostly constant, except in Pakistan and Afghanistan.

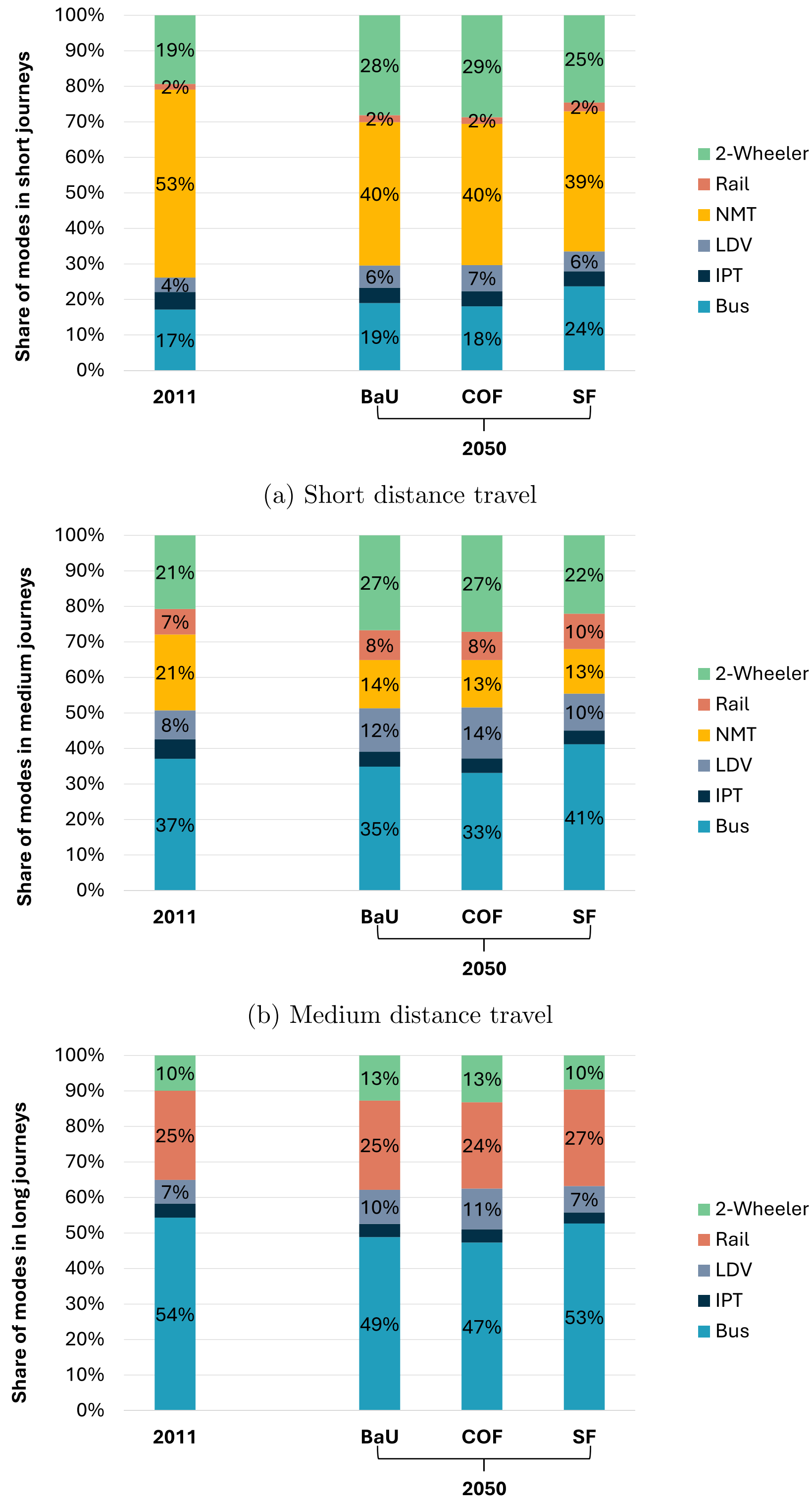
4.1.2. Share of modes in PDT

Figure 8(a) shows the resultant share of modes in short-distance (up to 10 km) PDT in the three distinct mode share trajectories (*mt*) in 2050. When compared to 2011, there is an increase in the share of private vehicles, LDVs, and 2-wheelers in all trajectories, with the lowest change in SF. The share of NMT declines significantly in all trajectories, by 13%–14% points, relative to 2011. The share of rail remains almost the same in all the trajectories. The share of bus changes modestly in BaU and COF, but is significantly higher in SF with 7% points.

The share of modes in medium-distance (between 11 km and 30 km) PDT is shown in figure 8(b). The share of 2-Wheelers increases in 2050 by 6% points in BaU and COF, while the change is only 1% point in SF, relative to 2011. Similarly, the share of rail is higher by 2%–3% points, and the share of LDVs is higher by 2%–6% points in the various trajectories. Relative to 2011, the share of NMT declines in all trajectories by 7%–8% points in 2050. The share of bus is higher in SF by 4% points and lower in BaU and COF by 2% and 4% points, respectively.

The mode shares in long-distance travel are shown in figure 8(c). In the BaU, share of LDVs increases by 3% points while that of bus and 2-Wheelers decreases by 5% and 3% points, respectively. The growth of share of LDVs is much higher in COF relative to other trajectories, while share of rail only increases in SF. Share of bus declines in all trajectories, but still remains the main mode in long distance passenger travel.

The impact of the type of urbanization in each country is shown in figure F.2, appendix F. In the concentrated growth trajectory, PDT in large cities is higher and lower in cities and towns relative to balanced growth, as expected from the definition of the two trajectories (and the higher amount of mobility in large cities). The overall PDT in the urban region of South Asia between 2011–2050 due to concentrated growth is approximately 2% higher than that in balanced growth.



(c) Long distance travel

Figure 8. Resultant mode shares in all mode share trajectories defined for both travel types (SSP2) (*IPT-intermediate public transport; LDV-ligh duty vehicle; NMT-non-motorized transport*).

In 2050, PDT in large cities is about 10% higher in the concentrated growth trajectory relative to balanced growth in all countries. These outcomes highlight the advantages of developing a high resolution modeling framework, adept at capturing diverse futures and modeling trends in certain contexts.

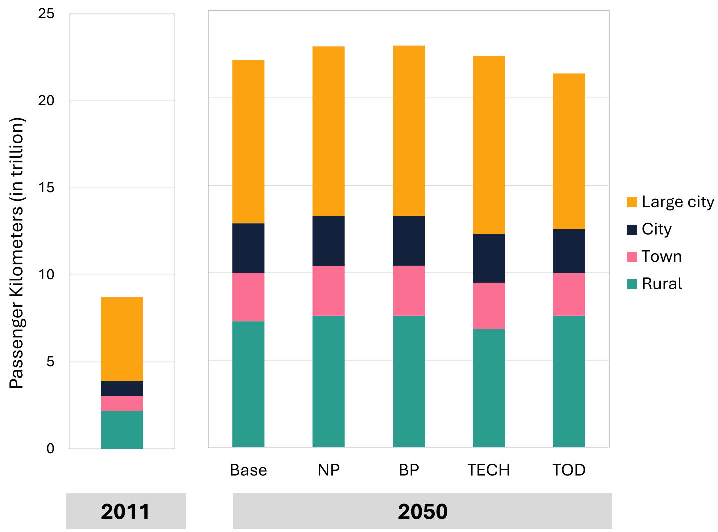


Figure 9. Daily travel passenger kilometers by area type at national level in all scenarios in 2011 and 2050 (*NP-National Policies; BP-best practices; TOD-transit oriented development; TECH-technology focus*).

4.2. Outcomes of phenomena interactions in scenarios

This section describes the results of the quantified effects of different phenomena outcomes passing through the passenger mobility demand model and how these interact with one another. The results are presented for the entire region in all the scenarios described above and the 'Base' scenario (without any phenomena) for SSP scenario 2 and type of urbanization trajectory 2 (balanced growth).

4.2.1. PDT

Figure 9 shows the total PDT (in kilometers) in all the scenarios by area type.

The largest increase in PDT is observed in 'large city' across all scenarios. This is attributed to an increase in population combined with higher mobility (PDT per capita) in large cities as compared to other area types. Rural areas foresee the lowest increase, mainly due to lower mobility in this region and decreasing population. The NP and BP scenarios have the highest increase in PDT in all area types relative to Base. Despite penetration of MaaS (modeled as a combination of ride hailing and ride sharing services), which leads to a rapid increase in LDV associated PDT from 2030 onward in the TECH scenario, the overall increase in daily travel PDT between 2011–2050 is about 1% lower than in Base. The TOD scenario foresees the lowest growth in daily travel PDT due to shorter travel distances, underscoring the influence of transit oriented development in urban areas. Due to the mixed evidence on the impact of e-life on PDT, appendix H.2 shows the difference in PDT (% change) in the TECH scenario with and without e-life in each mode.

The increase in PDT since 2011 exhibits notable variations across different urban typologies in each country, as shown in figure 10. Across all countries except Sri Lanka and Nepal, large cities witness the most substantial growth in PDT, while in the Maldives, the growth in cities and towns is comparable to that in large cities. Afghanistan observes the highest PDT increase across all urban area types and scenarios. Conversely, Bhutan and Sri Lanka anticipate the lowest increase in PDT relative to 2011. Large cities in these countries foresee a growth of about 300%, cities and towns anticipate a growth of about 180%, and rural areas expect a modest increase of around 35%. In Bangladesh, India, Maldives, and Pakistan, PDT is projected to increase by about 200%–300% in large cities and by around 400% in cities. Nepal anticipates even higher growth rates, with a projected increase of about 500% in large cities and 300% in cities. Additionally, PDT in towns across these countries is expected to increase by 200%–300%, while rural areas foresee a more modest increase ranging from 50% to 100%.

There are variations in PDT in 2050 between the scenarios as well. Both Afghanistan and Nepal anticipate a lower PDT in all scenarios relative to Base, specifically in large cities and cities. In contrast, across all other countries, the NP, BP, and TECH scenarios anticipate higher PDT than Base in large cities. Similarly, this trend is observed in cities and towns within the NP and BP scenarios. However, in the TECH scenario, PDT levels are projected to be lower in cities and towns compared to the Base scenario. In all the countries, rural areas anticipate a higher PDT in all scenarios, except TECH, relative to Base.

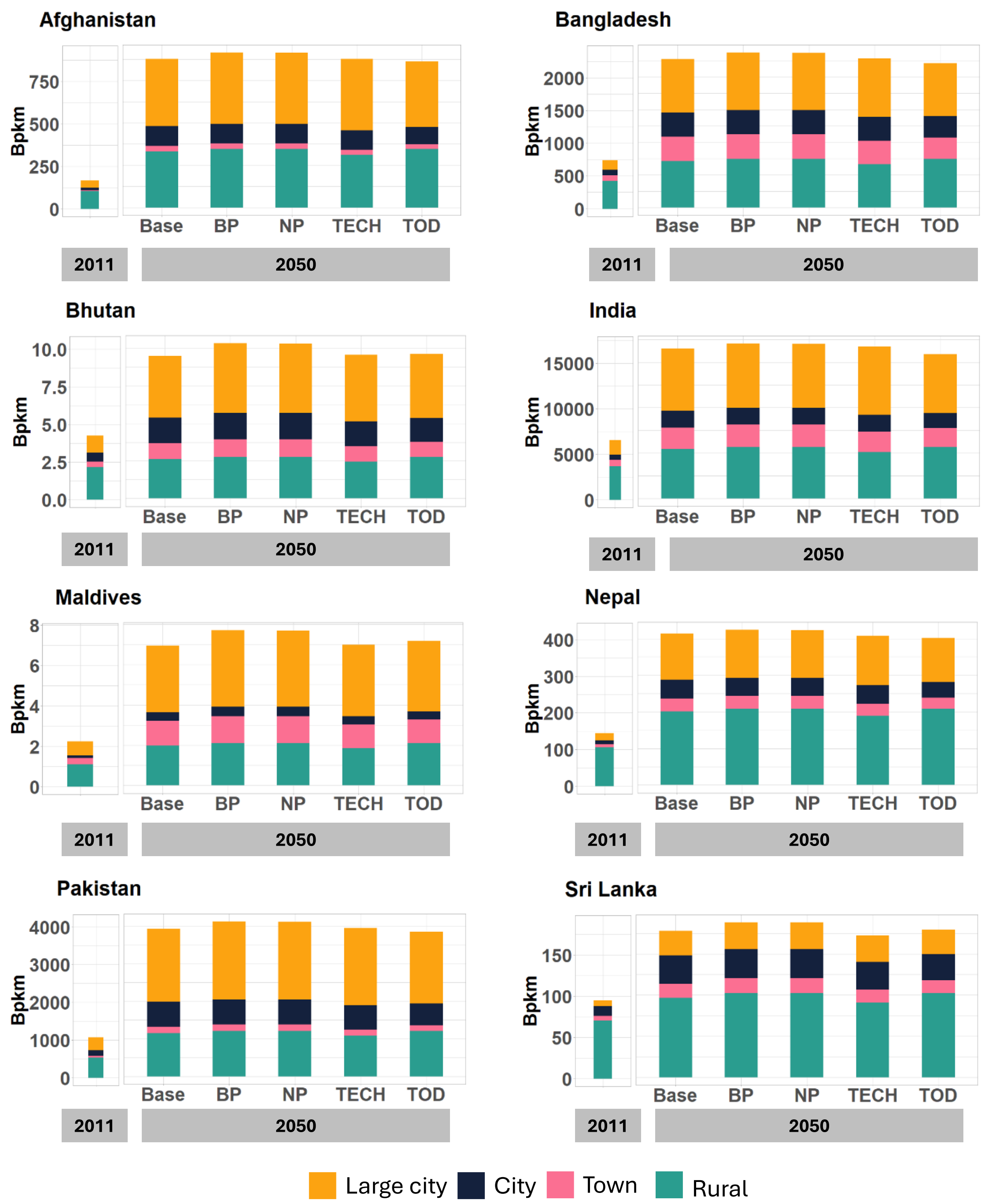


Figure 10. Passenger distance traveled in billion passenger kilometers (Bpkm) in every country and scenario (*NP-National Policies; BP-best practices; TOD-transit oriented development; TECH-technology focus*).

In the NP scenario, the most significant increase in PDT relative to Base is observed in Bhutan and the Maldives, across all area types. Respectively, large cities anticipate a 12% and 14% higher PDT, cities and rural areas 6% and 7%, and towns anticipate a 7% and 9% higher PDT. In Sri Lanka, large cities and cities under the NP scenario are expected to have a PDT 8% higher compared to the Base scenario, while towns and rural areas anticipate increases of 6%. For Afghanistan, Bangladesh, India, and Pakistan, the NP scenario suggests PDT increases of about 5%–6% in large cities, negligible in cities, 3%–4% in towns, and 4%–5% in rural areas compared to the Base scenario. Similarly, PDT in large cities and rural areas is anticipated to be higher by 3%. However, PDT in cities is anticipated to be lower by 4%. The BP scenario anticipates comparable trends in PDT to those observed in the NP scenario, with differences of 1%–2%.

In the TOD scenario, the most notable reduction in PDT relative to Base is observed in Nepal. In Nepal, large cities are expected to have a lower PDT by 5%, while cities and towns anticipate reductions of 14%–16%. Similarly, in Afghanistan, PDT is anticipated to decrease by 3% in large cities and 12%–13% in cities and towns. For Bangladesh, India, and Pakistan, PDT reductions relative to the Base scenario are expected to be significant, with decreases of 2%–6% in large cities, 11%–12% in cities, and in towns. Finally, Bhutan, Maldives, and Sri Lanka also anticipate reductions in PDT in the TOD scenario. Large cities expect reductions of 1%, while cities and towns anticipate decreases of 4%–8%.

The TECH scenario foresees some changes in PDT relative to Base. PDT is anticipated to increase by 6%–10% in large cities, while there it is anticipated to decrease by 1%–2% in cities, by 4%–5% in towns, and by 6% rural areas.

4.2.2. Share of modes in PDT

Figure 11 outlines the mode shares in all the scenarios, considering different mode share trajectories.

For short-distance travel (figure 11(a)), compared to the Base scenario, NP, BP, and TOD foresee a higher share of bus and NMT while TECH foresees a reduction. NP, BP, and TOD, all consider PT infrastructure development, which leads to an increase in the share of bus. The share of LDVs and 2-wheelers is lower in NP, B,P and TOD scenarios relative to Base. The decrease in the share of private vehicles in the NP and BP scenarios (despite the presence of ride-sharing) can be attributed to the development of PT and NMT infrastructure, which increases the share of PT and NMT (for trips <5 km only) modes while encouraging a long-term shift away from private vehicles. The reduction in TOD is notably greater due to the interaction of transit oriented development and PT and NMT infrastructure development. Transit oriented development brings about a reduction in total PDT, while PT and NMT infrastructure development further reducesthe share of private vehicles. The TECH scenario anticipates a greater share of LDVs (about 11% points) relative to Base, while the share of 2-wheelers is almost the same as in Base.

In the Base scenario, the share of bus in short distance PDT is 1% points lower in COF and 5% points greater in SF compared to BaU trajectory, while the share of LDVs is 1% points higher in COF and 0.6% lower in SF. Share of 2-wheelers is about the same in BaU and COF, while it is 3.5% points lower in SF relative to BaU. The share of rail is about the same in COF and 0.5% points higher in SF, relative to BaU. In the NP and BP scenario, the relative differences in mode shares echo those observed in the Base scenario for buses and LDVs. However, there are deviations in SF, where the share of 2-wheelers decreases by 2.2% points, and the NMT share decreases by 2.4% points compared to BaU. In the TOD scenario, the relative differences in bus and LDV shares follow similar trajectories as observed in the Base scenario. Notably, the 2-wheeler share decreases by 2% points in SF compared to BaU, while the bus share drops by 1% point in COF and increases by 5% points in SF relative to BaU. In the TECH scenario, the bus share decreases by 1% point in COF and increases by 3.9% points in SF relative to BaU. LDVs see a 2.6% point increase in COF and a 1.5% point decrease in SF. The 2-wheeler share only experiences a notable change in SF, decreasing by 2.8% points relative to BaU. Additionally, the rail share remains the same in COF and rises by 0.5% points in SF compared to BaU.

For medium-distance travel (figure 11(b)), compared to the Base scenario, the share of bus is higher by 14%–16.5% points in NP, BP, and TOD, while it is 11% points lower in TECH. On the other hand, the share of LDVs is lower by 1.5% points in NP, BP, and TOD, while it is about 20% points higher in TECH. The share of 2-Wheelers is significantly lower in NP, BP, and TOD by about 10% points and 6.2% points higher in TECH. Changes in rail and NMT are in the order of 1%–2% points. In the Base scenario, the share of bus is 1.8% points lower in COF and 6.3% points higher in SF, compared to BaU. Contrastingly, the share of LDVs is higher by 2% points in COF and 1.8% lower in SF. The share of 2-Wheelers is significantly lower in SF by 4.6% points, while the share of rail is 1.5% points higher in SF, relative to BaU. In the NP, BP, and TOD scenarios, the relative differences between BaU, COF, and SF are similar to those observed in the Base. In the TECH scenario, the share of LDVs is 4% points higher in COF and 3.7% points lower in SF, relative to BaU.

The variation in mode shares in long distance travel (figure 11(c)) across scenarios is determined by the development of high speed rail. Since high speed rail development is only considered in the BP scenario, the share of rail almost doubles relative to the Base scenario, whereas in NP, TOD, and TECH scenarios, the share of rail remains the same as in the Base scenario. The share of bus and LDVs is about 15% lower in the BP scenario, relative to Base. Between mode share trajectories, in the Base, NP, TOD, and TECH scenarios, share of LDVs is 1.8% points higher in COF relative to BaU and 2.2% points lower in SF. On the other hand, share of rail is lower by 1% in COF and higher by 2% points in SF relative to BaU. The share of bus is 1.6% points lower in COP and 3.9% points higher in SP, relative to BaU. In BP scenari,o these variations are quite small (in the range of −1.5% to 1.5%).

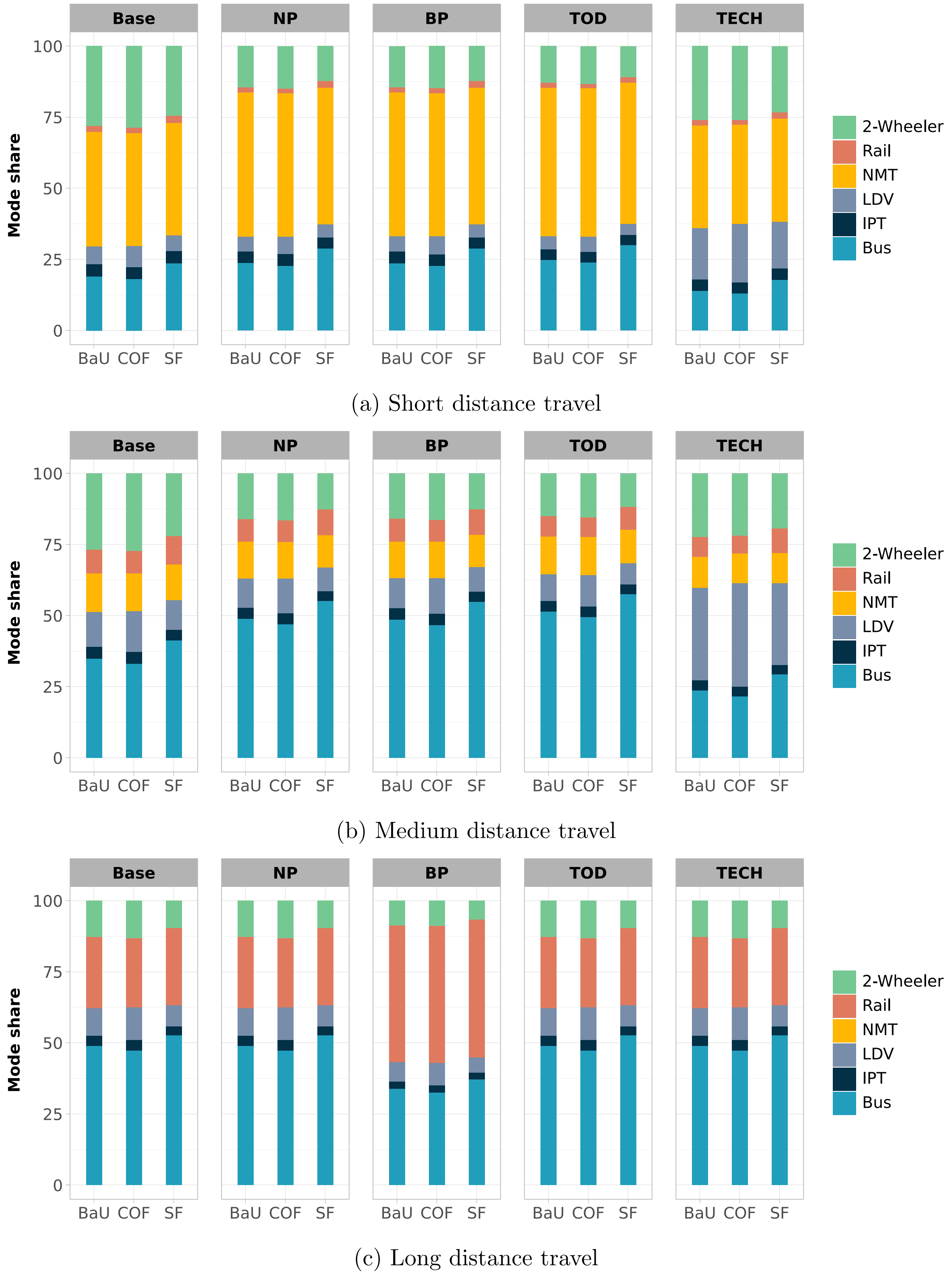


Figure 11. Resultant mode shares in all scenarios and mode share trajectories in 2050 and SSP2 (*NP-national policies, BP-best practices, TOD-transit oriented development, TECH-technology focus; BaU-business as usual, COF-car oriented future, SF-sustainable future; IPT-intermediate public transport, LDV-light duty vehicle, NMT-non-motorized transport*).

Figure 12 shows the comparison of mode shares for daily travel in all countries and across all scenarios. Comparison of mode share trajectories (BaU, COf, and SF) is shown in appendix G.

The scenario outcomes highlight the complex interaction between various factors, including policy interventions, infrastructure development, and technological advancements, which collectively shape the future of mobility. By understanding the nuances captured by this modeling framework, policymakers can make informed decisions to create more sustainable and accessible passenger transport systems for the future.

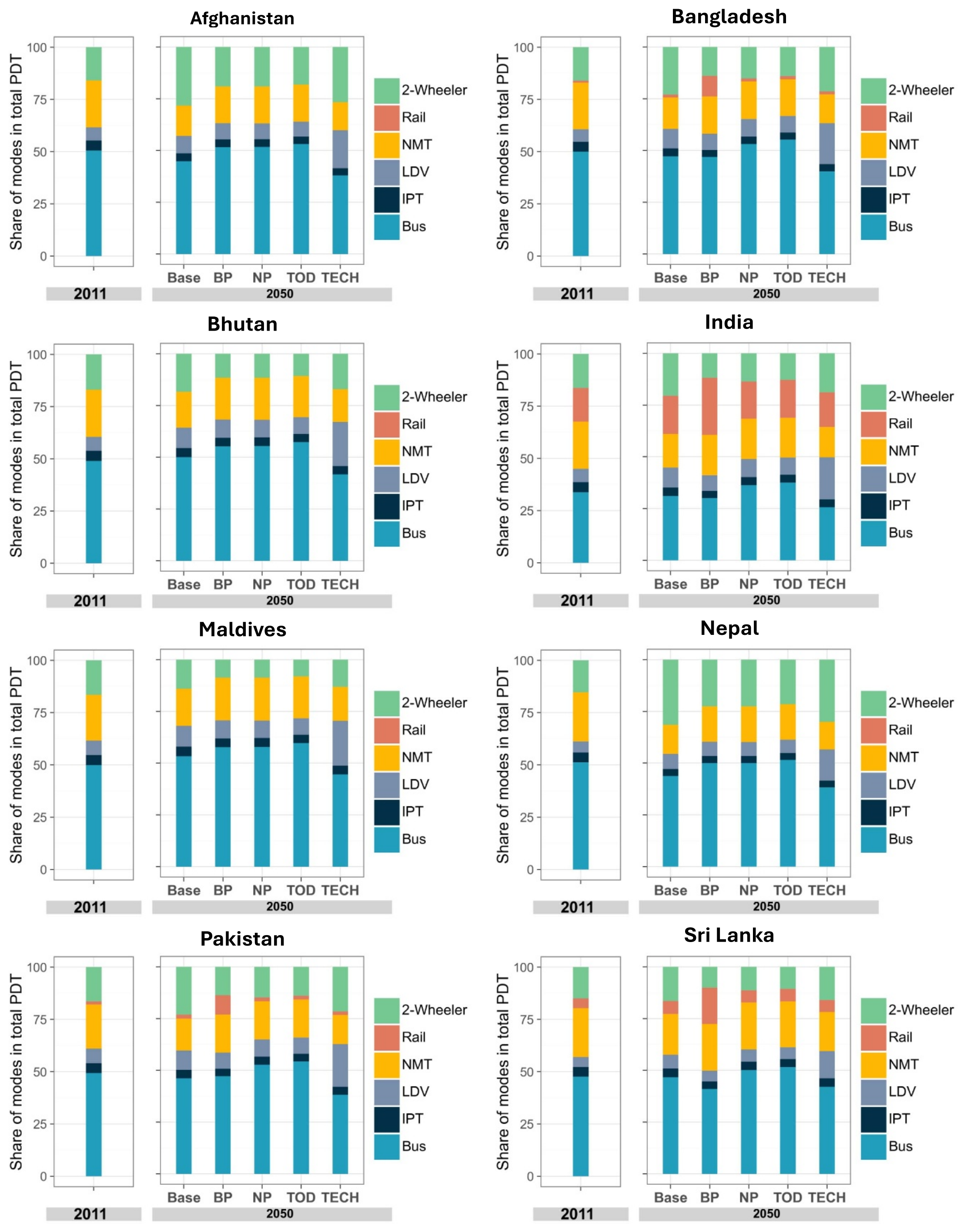


Figure 12. Share of modes in total PDT (*NP-National Policies, BP-best practices, TOD-transit oriented development, TECH-technology focus; IPT-intermediate public transport, LDV-light duty vehicle, NMT-non-motorized transport*).

5. Discussion and conclusion

5.1. Contributions to IAM/ESOM methods

The methodological approach adopted in this study is a step towards converting measured data and literature-based evidence into useful IAM inputs. We review existing literature that explores causal relationships between passenger mobility and various phenomena. These relationships are then mapped to exogenous IAM parameters such that the impacts of each phenomenon on transport activity can be effectively represented. The approach also allows including direct measures of 'less quantifiable' phenomena like socio-cultural practices, behaviors, and lifestyles, that significantly affect passenger mobility patterns, in a large-scale global IAM.

A detailed region-specific passenger transport data set is linked to a global IAM in this study. Thereby, the scenarios developed align with actual mitigation potential in this region. Further, the proposed scenarios are grounded in evidence from the specific region under consideration, South Asia in this case, and other Global South countries. The shared socio-cultural and demographic characteristics in these regions facilitate reasonable extrapolation of the occurrence and impacts of phenomena across them. Since the literature and data collected prioritize evidence from the Global South, the methodology adopted can be applied to other Global South regions. This approach helps overcome biases arising from modeling methods and calibrations grounded in evidence from the Global North, often encountered in global scenarios.

The high resolution of this framework allows modeling trends within distinct contexts and capturing distributional effects. For example, transit oriented development reduces PDT but this impact can vary between area types, large cities versus towns. Further, the mode shift due to TOD is not uniform across distance categories (0–1 km versus 11–20 km). Similarly,an increase in ride hailing services will lead to greater PDT and share of *t*axis, with a simultaneous decrease in PT use. The relative richness of the data set allows including such differential impacts of various phenomena and replacing the typical top–down calculations encountered in IAM scenarios, such as in Grubler *et al* (2018), Kuhnhenn *et al* (2020).

5.2. Key insights from model projections

The demand model outcomes emphasize the anticipated expansion of the passenger mobility system in South Asian countries. It is estimated that the total PDT will more than double in 2050 relative to 2011. Since investment in infrastructure has long-term lock-in effects, choices made in the near term will determine mobility demand and, therefore, climate mitigation options and GHG emissions trajectory in the coming century.

5.2.1. TECH and TOD as AVOID (demand management) strategies

TECH scenario projectsthe lowest PDT relative to others; however, it has the highest share of LDVs, indicating the prevalence of less sustainable development if LDV electrification does not keep pace with PDT growth. Conversely, NP and BP foresee greater increases in PDT compared to the Base scenario. Nonetheless, these scenarios exhibit higher proportions of sustainable modes such as buses and rail.

The 'The World in 2050' study highlights the complex relationship between digitalization of daily life and climate change mitigation (Nakicenovic *et al* 2019). The penetration of digital technologies and practices can facilitate the smart management and monitoring of energy demand and efficient resource use, thereby reducing emissions. However, it can also exacerbate existing inequalities and lead to an increase in emissions through a rapid rise in consumerism. The TECH scenario highlights this aspect of digitalization-while in the short term practices such as ride sharing and e-life can reduce passenger mobility demand, in the long run, adoption of digital services such as ride hailing and MaaS can lead to rapid LDV associated travel and a reduction in PT use.

The scenario results also indicate that TOD will emerge as a pivotal strategy for mitigating and managing transport energy service demand in South Asian countries. Compact development will also enhance the feasibility of networked public infrastructure. However, it is essential to approach these initiatives with caution to avoid exacerbating existing urban challenges, such as overcrowding and the proliferation of informal settlements. Moreover, transport decarbonization cannot be achieved by designing transport policies in silos but requires holistic and coherent interaction with other sectors, such as land-use and urban planning (Danielis *et al* 2022, Creutzig *et al* 2024).

The results also highlight the regional (country level) differences captured by the modeling framework. As shown by the results discussed in section 4, patterns of economic growth, urbanization rates, and the type of urbanization impact the projections of demand for mobility in South Asian countries. These discrepancies underscore the complexity of mitigating emissions within different scenarios and regional contexts and offer valuable guidance for policymakers and stakeholders in formulating effective mitigation strategies tailored to the specific dynamics of each scenario and region.

5.2.2. Importance of PT

Our findings indicate that PT options, especially buses, are likely to be the key modes of transport (both for daily as well as long distance travel) in South Asia-across all scenarios and growth trajectories. This observation was similarly noted by Dixon *et al* (2024) in their analysis of another emerging economy, Kenya. Despite growing motor vehicle ownership and a relatively low number of buses per 1000 person (UITP India 2022), this mode of transport remains the key for meeting mobility demands in South Asia. In part, this is due to a hybrid formal and informal system where public buses co-exist with informal IPT forms of bus systems that can provide services at very low prices and offer enough flexibility (& accessibility) for users. In most of our projections, rail based transportation sees a limited increase, with the exception of BP, where rail sees major investments and thereby becomes the dominant mode, especially for long-distance travel. In many ways, while rail offers the possibility of scale and speed to attract users away from car travel, buses offer the advantages of granular modular technology that has lower investment needs and relatively rapid deployment rates (Wilson *et al* 2020).

However, while the attributes (this informal system) are key for the predominance of bus use, there is evidence that users are not very satisfied with the status quo and treat bus travel as an inferior good (i.e. the usage decreases as the income/spending power increases) (Das and Pandit 2013). This has led to a significant shift away from bus usage to 2-wheelers, especially for daily travel. This trend is concerning as our projections indicate that under car-oriented development scenarios, 2-wheelers and cars are bound to take away a significant share of daily travel demand from bus mode. This is likely to be the case under BaU & TECH focused scenarios, where investments in public transit are not prioritized. Overall, the share of private vehicles is above 25% for daily travel even in the most optimistic scenario for sustainable mode share (SF). The increase in private vehicles will further exacerbate passenger mobility associated externalities such as congestion and air pollution. Hence, improving PT services, their safety, and reliability can increase access to mobility for all and help curb forced vehicle ownership, particularly for low income households. This development will also help manage growing mobility demand, especially in urban areas. From our findings, it is clear that the road to sustainable mobility transition in South Asia goes through bus-based transportation. The investments in development (provision as well as management & operation) of a bus-based transport system that provides low-cost, safe, reliable, and flexible mobility options, while complemented by rail-based long-distance mobility, is a key marker of sustainable transportation in South Asia.

5.3. Impact of Global South-specific assumptions

Making quantitative claims about Global South-specific assumptions is challenging, given that this is the first time such an approach is being undertaken in the context of IAMs. However, we discuss some qualitative insights into how such assumptions have influenced the results.

First, the urbanization rates are much lower in South Asian countries, in comparison to the Global North. Further, the cities and towns are expected to play a large role in urban growth, given the increasing pressure on resources and services in large cities, especially in India. Second, the impact of phenomena like ride hailing/sharing and MaaS differs between the Global North and Global South. Ride hailing/sharing is well-established in the Global North, whereas these are still emerging in the Global South. Implementation of MaaS in the Global South would require integration of informal modes as well. Third, private car ownership is high in the Global North, while 2-wheelers continue to dominate the market in South Asia. Finally, the Global South presents unique opportunities for sustainable mobility development, given that a large part of the infrastructure is yet to be developed.

In general, modeling practices have overlooked evidence from the Global South, which creates an incomplete picture of the mobility transition needed in these regions.

5.4. Limitations

In this study, the national population has been categorized primarily according to area type, namely, large city, city, town, and rural areas. We assume that the effects of observed phenomena have a uniform influence across the population group. However, it is important to acknowledge the limitations in our approach, as various socioeconomic factors such as income and family size play an important role in shaping individual and community responses to the phenomena considered herein. Furthermore, as the outcomes from the passenger mobility demand model are aggregated, the total PDT loses its various dimensions, and the meaningful differences between scenarios start to disappear. This, coupled with the limited resolution of MESSAGEix-Transport, restricts the representation of specific policy measures.

The reliance on an old dataset from 2011 means that the current socio-economic and demographic contexts, which heavily impact transportation patterns, have not been accurately captured. As a result, our findings may not reflect actual changes in vehicle ownership, travel patterns, infrastructure development, or policy initiatives. Furthermore, the impact of rapid urbanization over the past decade, which has exacerbated infrastructure limitations and access to mobility, along with the introduction of ride-hailing apps that have changed the mobility landscape in cities, has also not been accurately captured. However, reliance on walking/cycling, PT, and IPT has likely remained the same, especially for low-income households (Haldar and Mistri 2025).

Due to a lack of data, we have assumed comparable travel patterns across all trip categories. However, the purpose of the trip determines distance and mode of travel and is impacted by socioeconomic factors and spatial distribution. This assumption oversimplifies some of the complexities of passenger mobility in these regions, potentially making policies less effective. Also, certain causal relationships, such as an increase in distance traveled with a switch to faster modes, have not been accurately captured. Further, as the primary data set used to calibrate the daily travel demand model is from India, the regional heterogeneity between countries in travel patterns has not been adequately considered. However, since India is the largest country (in terms of population and economy), the impact of not accounting for these details on the overall demand for mobility within South Asia is expected to be relatively minimal.

Our analysis lacks a consideration of domestic aviation, whose demand is increasing strongly in South Asian countries. Domestic aviation will play an important role in shaping intercity mobility patterns in these countries. Future work could expand the scenario narratives to include the dynamics of domestic aviation. Similarly, micro-mobility, such as e-bikes and scooter,s is gaining momentum in several countries, and this phenomenon could potentially be important in South Asia in the future. However, since micro-mobility is generally used for first and last mile connections, their share in total PDT under the current status of deployment is negligible and is hence not considered in this study.

The literature review and data gathering processes have highlighted the existing data gaps in South Asia and the Global South at large. We also observed considerable variability in the projections of future passenger kilometers for India, ranging from 10–32 trillion for road based travel in 2050, estimated by several other modeling groups (Paladugula *et al* 2018, Gupta and Garg 2020), and the projection in this study is about 21 trillion in the 'Base' scenario. This uncertainty in projections underscores the urgent need for measured data to refine the empirical work, ensuring that scenarios and other modeling efforts align with actual regional empiricism.

Another limitation of this current research is that we explore only one outcome for each phenomenon. As mentioned previously, each phenomenon can have multiple outcomes depending on interaction with policy development and other factors. Future work should focus on alternate futures for each phenomenon, as these can significantly impact the results of the scenarios considered. While this study makes a significant contribution to the passenger transport system discussion in the South Asian context, results must be viewed with caution, considering the potential variability in phenomenon outcomes.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://zenodo.org/records/10303828.

Acknowledgments

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Appendix A. Detailed description of definition of each phenomenon

Table A.1. Modeling approach for each phenomenon in the framework.

Phenomenon	Parameter	Description	
		Short-run	Long-run
Urbanization	PDT	% growth between 2011 and 2030	% growth between 2030 and 2050
Autonomous vehicle	LDV based PDT	% growth between 2011 and 2050	
	PT share	% reduction in bus-based between 2011 and 2050	
Ride hailing	VDT	% growth in taxi-based VDT between 2011 and 2050	
	NMT share	% in NMT-based PDT reduction between 2011 and 2030	% reduction between 2030 and 2050
	PT share	% reduction in bus-based PDT between 2011 and 2030	% reduction between 2030 and 2050
	Vehicle ownership	% reduction between 2011 and 2050	
Ride sharing	VDT	% reduction in taxi-based PDT between 2011 and 2030	% growth in taxi-based PDT between 2011 and 2030 (rebound effect)
High speed rail infrastructure	Share in long distance travel	% growth of rail-based PDT between 2011 and 2050; equivalent reduction in share of road-based travel	
NMT infrastructure	NMT share	% shift in PDT from 2-wheelers and LDVS to NMT between 2011–2050 for trips <5 km	
PT infrastructure	PT share	% growth in bus-based PDT between 2011–2030	% growth in bus-based PDT between 2030–2050 due to shift from 2-wheelers and LDVs
Environmental awareness	EV sale share	% growth between 2011–2030	% growth between 2030–2050
Higher standard of living	LDV ownership	% growth between 2011 and 2050	
e-life	Trip rate	% reduction between 2011 and 2030	% reduction between 2030 and 2050
MaaS	—	Combination of ride hailing and ride sharing	
Transit oriented development	PDT	% reduction between 2011 and 2030	% reduction between 2030 and 2050
	NMT share	% growth in NMT-based PDT between 2011 and 2030	% growth in NMT-based PDT between 2030 and 2050
	PT share	% growth in bus-based PDT between 2011 and 2030	% growth in bus-based PDT between 2030 and 2050
	Vehicle ownership	% reduction between 2030 and 2050	

Appendix B. Share of urban population in each area type for each country in 2011

Table B.2. Distribution of population between urban area types in 2011.

Country	Large city	City	Town
Afghanistan	57%	31%	12%
Bangladesh	34%	30%	36%
Bhutan	41%	33%	26%
India	43%	23%	34%
Maldives	47%	14%	39%
Nepal	42%	31%	27%
Pakistan	54%	33%	13%
Sri Lanka	20%	50%	30%

Appendix C. Daily travel model estimated using Indian Census 2011

Table C.3. Daily travel demand model.

Area type	Trip distance category	Typical distance in km	Trip share	LDV	Bus	NMT	2-Wheeler	Rail	IPT	Not stated
Large city	No travel	0	19%	—	—	—	—	—	—	—
	00_01	0.5	16%	3%	4%	80%	9%	1%	2%	1%
	02_05	3.5	25%	6%	18%	44%	22%	3%	6%	1%
	06_10	8	19%	9%	28%	29%	23%	7%	5%	1%
	11_20	15.5	12%	15%	33%	5%	25%	17%	4%	1%
	21_30	25.5	5%	16%	26%	13%	15%	25%	4%	1%
	31_50	40.5	3%	15%	22%	0%	12%	43%	6%	1%
	51+	60	1%	10%	19%	0%	8%	53%	7%	3%
City	No travel	0	25%	—	—	—	—	—	—	—
	00_01	0.5	15%	2%	2%	78%	14%	1%	2%	1%
	02_05	3.5	29%	4%	11%	51%	29%	1%	5%	1%
	06_10	8	18%	5%	19%	39%	30%	1%	6%	1%
	11_20	15.5	7%	8%	31%	15%	35%	2%	7%	1%
	21_30	25.5	3%	7%	25%	43%	16%	4%	4%	1%
	31_50	40.5	2%	13%	42%	0%	24%	13%	7%	2%
	51+	60	2%	8%	36%	0%	10%	38%	4%	3%
Town	No travel	0	27%	—	—	—	—	—	—	—
	00_01	0.5	20%	1%	2%	81%	14%	1%	1%	1%
	02_05	3.5	28%	3%	7%	58%	26%	1%	5%	1%
	06_10	8	13%	4%	17%	47%	23%	2%	6%	1%
	11_20	15.5	5%	8%	37%	11%	29%	8%	6%	2%
	21_30	25.5	3%	5%	30%	36%	14%	11%	3%	1%
	31_50	40.5	2%	8%	45%	0%	18%	22%	5%	2%
	51+	60	2%	7%	44%	0%	8%	35%	3%	4%
Rural	No travel	0	39%	—	—	—	—	—	—	—
	00_01	0.5	14%	1%	2%	90%	5%	1%	1%	1%
	02_05	3.5	18%	2%	8%	72%	12%	1%	4%	1%
	06_10	8	13%	2%	18%	56%	15%	1%	6%	2%
	11_20	15.5	7%	4%	37%	23%	23%	3%	8%	2%
	21_30	25.5	4%	4%	38%	32%	15%	5%	5%	2%
	31_50	40.5	3%	5%	57%	0%	15%	15%	5%	3%
	51+	60	3%	4%	50%	0%	5%	34%	2%	5%

Appendix D. Description of National Policies

(i) Afghanistan—invest in road network and PT to improve accessibility (Baligh 2017).

(ii) Bangladesh—The National Integrated Multimodal Transport Policy (NIMTP) emphasizes the need to reduce travel demand through better land management, develop an integrated transport network, and ensure pedestrian safety. The target in the Revised Strategic Transport Master Plan for Dhaka is to ensure 60% of share of total urban passenger transport demand is met by PT by 2030 (DTCA 2015).

(iii) Bhutan—National Transport Policy 2017 recommends integrated land-use and transport planning, greater use of PT, higher road safety for urban transport, and greater inter-city connectivity to improve access (KPMG 2017).

(iv) India—The main sustainable transport development related policies are summarised in NMT infrastructure, deployment of electric buses, and banning vehicles in urban centers. The Green Urban Transport Scheme aims to reduce pollution by PT in cities (electrification of buses). The National Policy on Transit-Oriented Development aims to increase modal share of PT and NMT through mixed land-use development. The National E-Mobility Programme has set an ambitious target of 6-7 million electric vehicle (EV) and hybrid vehicle sales annually from 2020 onward (incentives for buyers).

(v) Maldives—In-Depth Technology Needs Assessment on Transport Sector 2007 outlines the need for public and integrated transport systems, a shift towards EVs and low emissions vehicles, and promoting public awareness and digitalization of services (Abdulla 2007).

(vi) Nepal—Key strategic issues to be addressed outlined in the National Environmentally Sustainable Transport Strategy for Nepal are: develop an integrated transport system, improve NMT infrastructure, and reduce travel demand (Government of Nepal 2018).

(vii) Pakistan—The objectives of the National Transport Policy are: integrated transport development, transit oriented development of urban areas, improving PT system and NMT infrastructure (Planning Commission 2018).

(viii) Sri Lanka—The objectives of this Draft National Policy on Transport In Sri Lanka 2009 are to develop PT system, manage vehicle fleet, promote NMT modes, increase rail passengers, and ensure minimum level of mobility for rural and estate areas (Ministry of Transport 2009).

Appendix E. Economic and passenger mobility growth trends

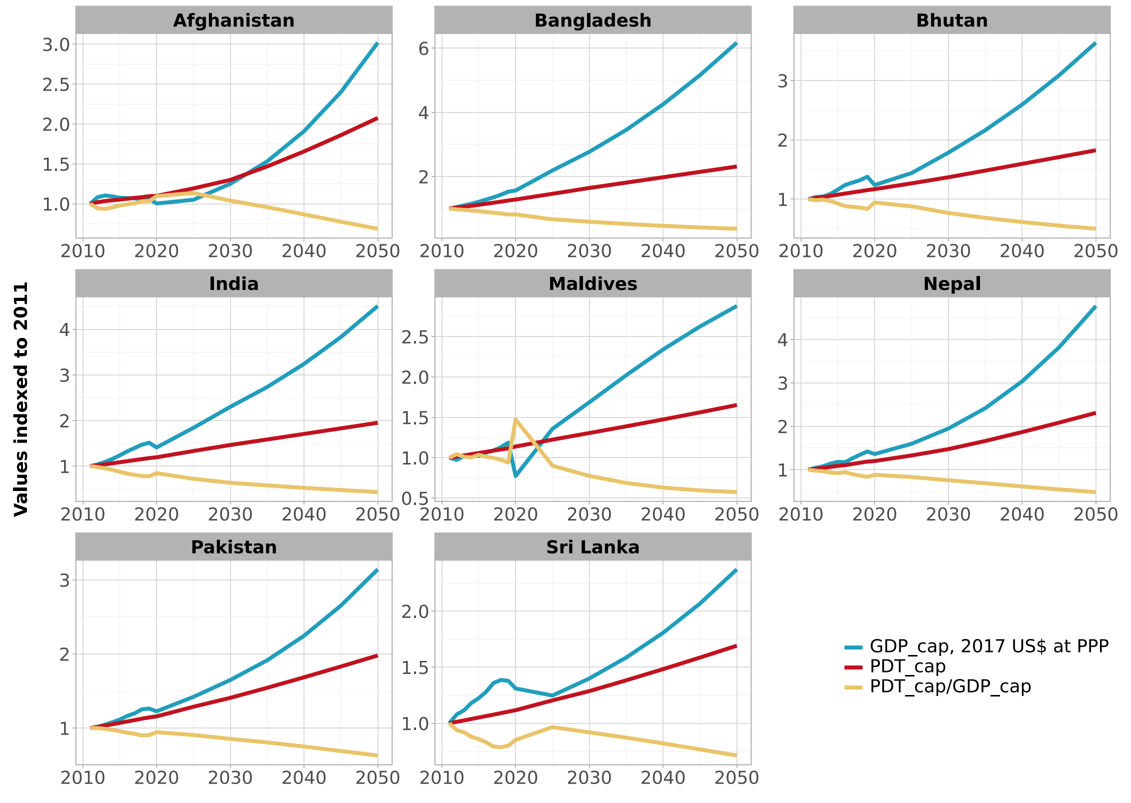

Figure E.1. Trends in GDP per capita and PDT per capita (values indexed to 2011).

Appendix F. Impact of type of urbanization

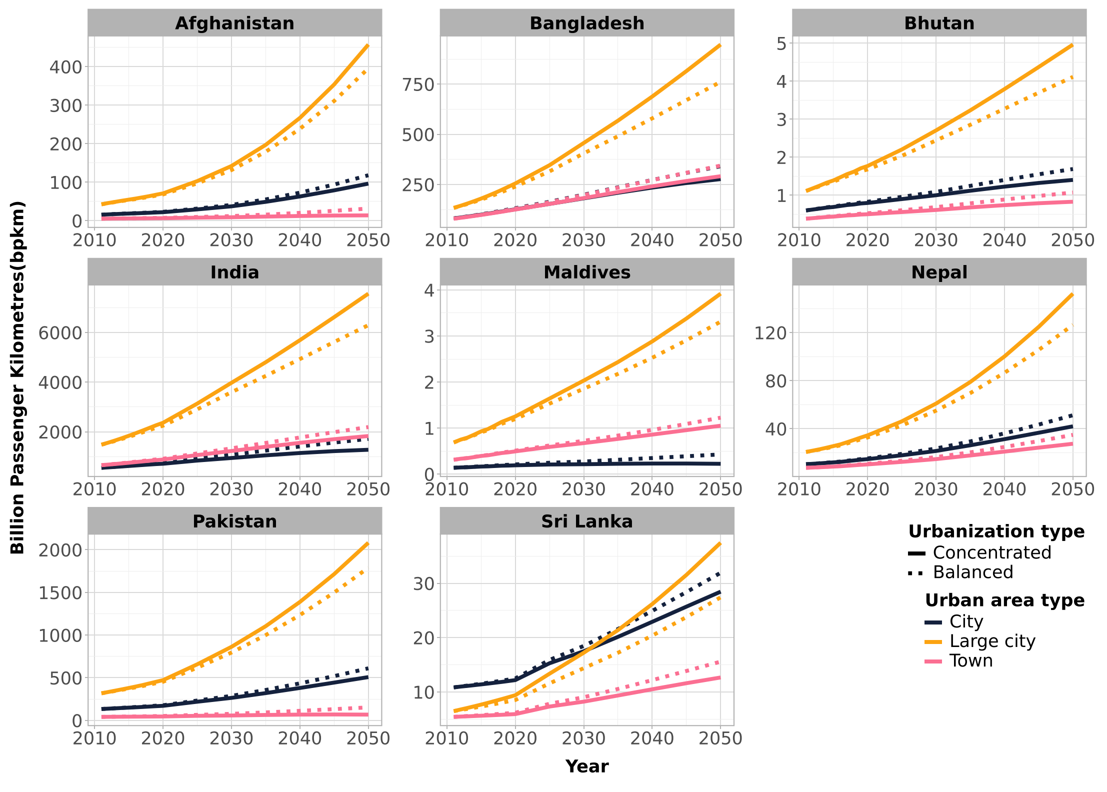

Figure F.2. Urban PDT in each country for balanced and concentrated types of urbanization.

Appendix G. Trends in mode composition of growth in total travel

Figure G.3 outlines the share of modes in daily travel in each country for every mode share trajectory and scenario in 2050 and compares with country level mode share in 2011.

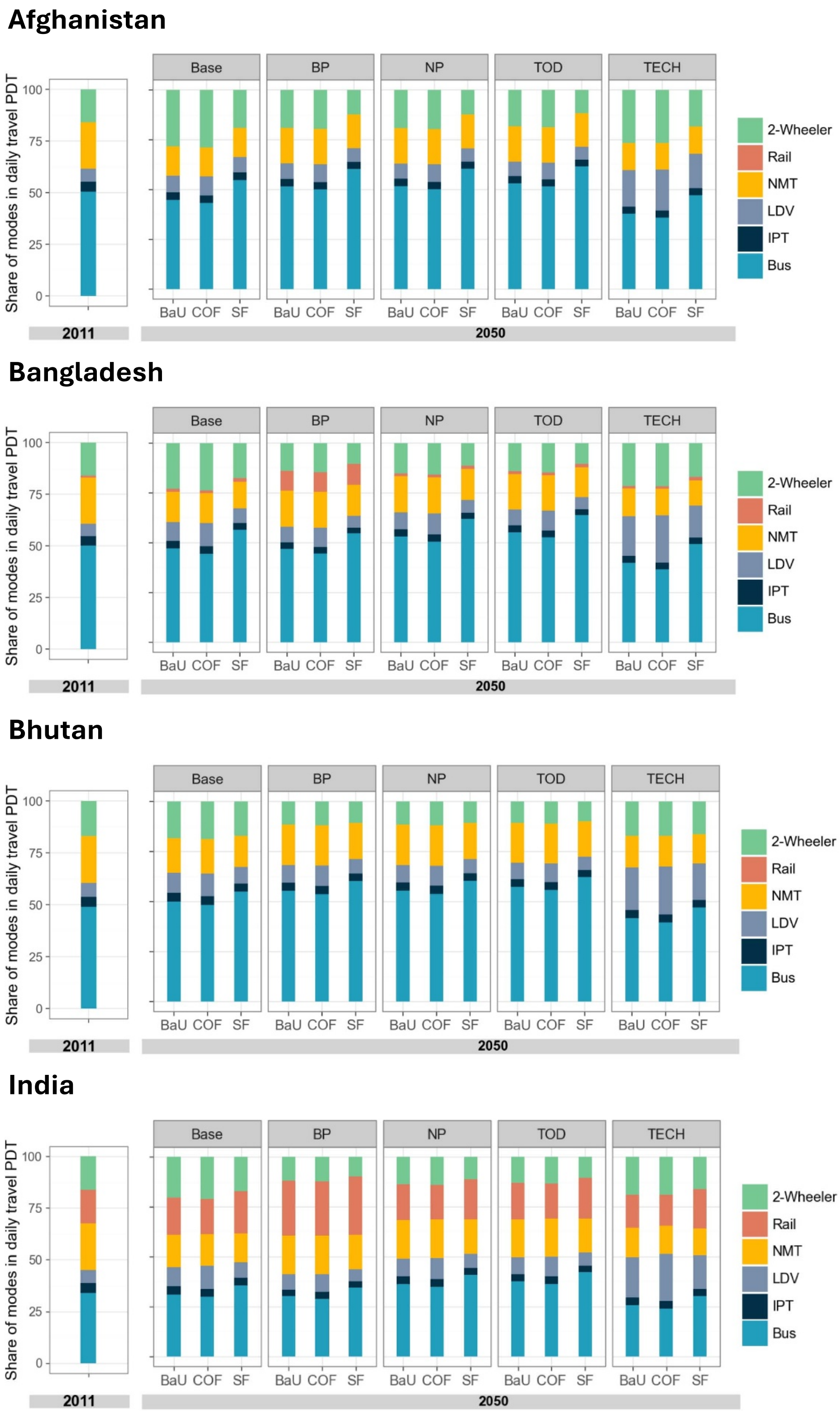

Figure G.3. Share of modes in total PDT (*NP-National Policies, BP-best practices, TOD-transit oriented development, TECH-technology focus; BaU-business as usual, COF-car oriented future, SF-sustainable future; IPT-intermediate public transport, LDV-light duty vehicle, NMT-non-motorized transport*).

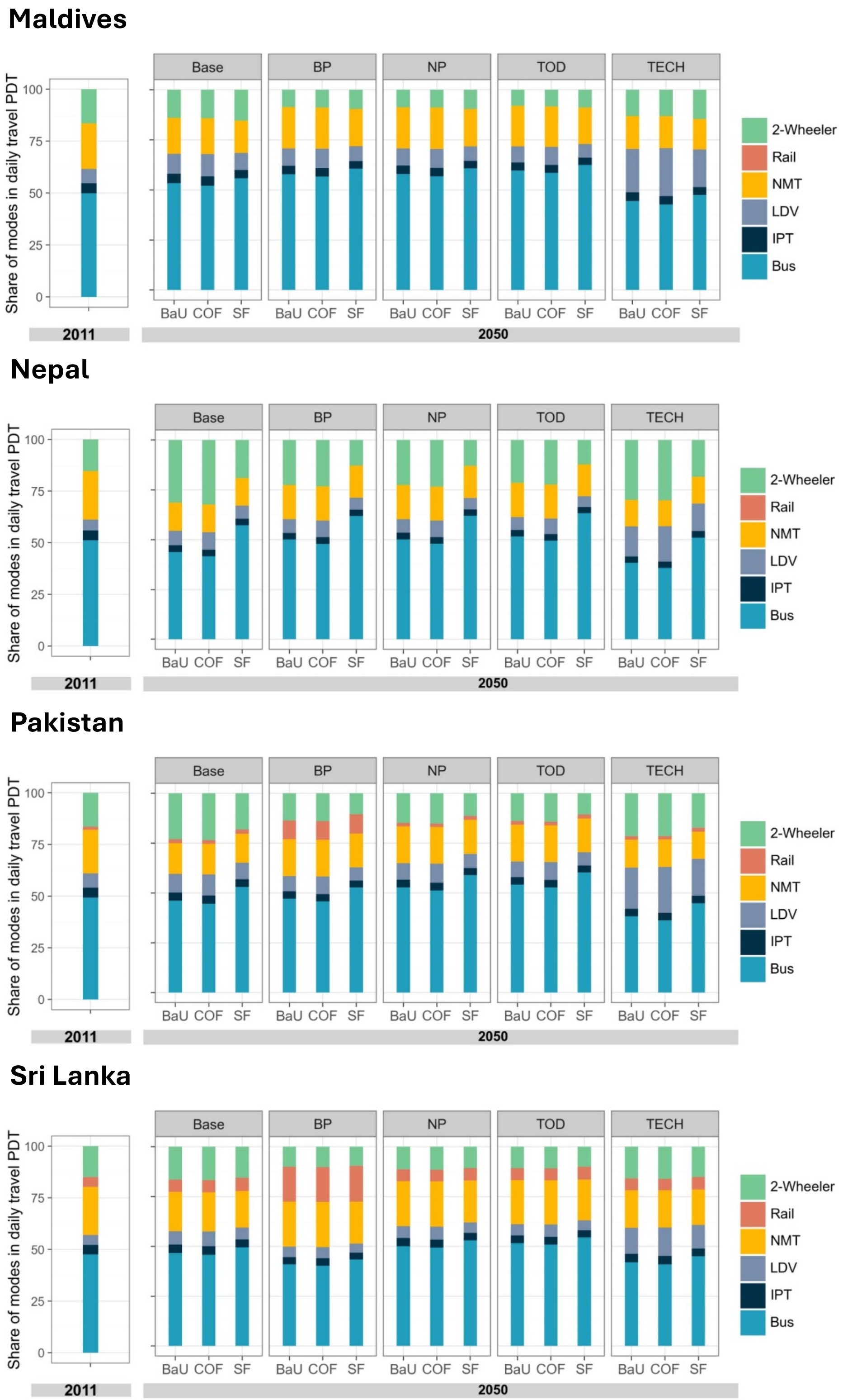

Figure G.3. (Continued.)

Appendix H. Alternate model settings

H.1. Commute vs non-commute trip rates–This section shows the resultant PDT per capita when the share of commute in total travel is changed from 28.74% to 32%.

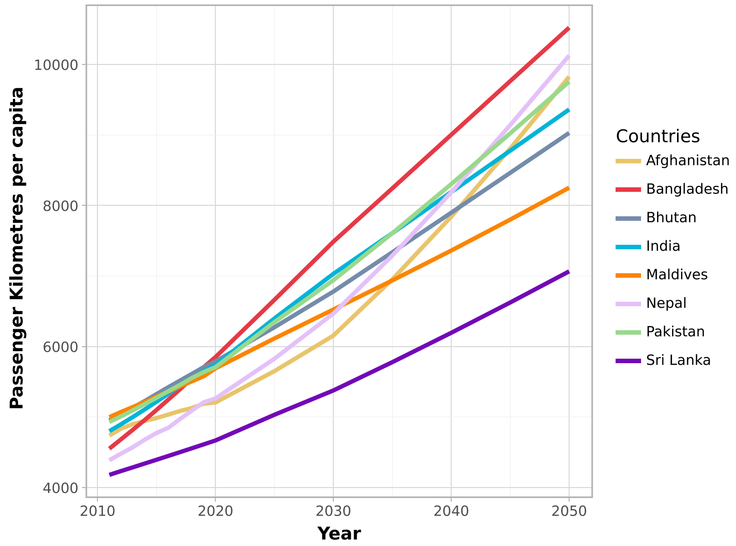

Figure H.4. Passenger kilometers per capita for an alternate setting.

H.2. No e-life in TECH–This section shows the impact of removing e-life from TECH. The percentage difference in total passenger kilometers for each mode between 2011 and 2050 is calculated relative to the case with e-life.

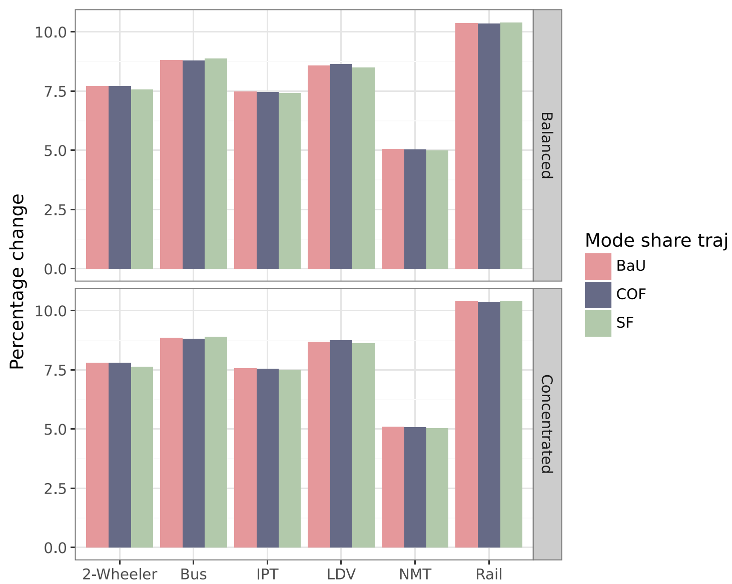

Figure H.5. Percentage change in total passenger kilometers by each mode in the TECH scenario with and without e-life (*BaU-business as usual, COF-car oriented future, SF-sustainable future; IPT-intermediate public transport, LDV-Ligh duty vehicle, NMT-Non-motorized transport*).

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