Four decarbonization pathways towards achieving a 1.5° degree scenario for land-transport in the four initial pilot countries Brazil, India, Kenya and Vietnam has been compiled. The decarbonisation pathways for the transport sector have been discussed with local and national authority counterparts at several occasions. Underlying assumptions have been verified and modelling has been adjusted accordingly.

The pathways are summarized in an academic paper .

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Transportation strategies for a 1.5 °C world: A comparison of four countries

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A R T I C L E I N F O

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A B S T R A C T

Decarbonizing transportation in emerging economies will be one of the key challenges in global climate change mitigation efforts. In this paper, pathways are developed towards achieving a 1.5° degree scenario for land-transport for four emerging economies (Brazil, India, Kenya and Vietnam). The aim is to highlight the key opportunities and challenges for low-carbon transport in countries with rapidly growing mobility demand. The main focus of this paper is to reconcile actual and required emission reduction targets and develop plausible pathways to achieve these targets. The paper also identifies potential strategies and measures for these countries to follow these pathways. The analysis considers the contributions of "avoid" (cutting travel growth), "shift" (to lower CO_2 modes) and "improve" (vehicle and fuel CO_2 characteristics) interventions to decarbonisation scenarios. These scenarios aim to inform renewed Nationally Determined Contributions and shed light on the feasibility of deep decarbonisation pathways that would be in line with the Paris Agreement. Results from this study show that achieving 1.5DS would require dramatic changes in travel patterns, technology and fuels, and major intensification of current policy approaches. Decarbonization solutions will need to include greater use and investment of efficient modes, major shifts toward near-zero carbon fuels such as clean electricity, systems integration, modal shift and urban planning solutions. Although the socio-economic situations and national transport systems differ between the selected countries, some fairly similar strategies appear likely to be core to the mitigation effort, such as rapid growth in light- and heavy-duty vehicle electrification and investments in public transit systems.

1. Introduction

The transport sector will have to play a key role in decarbonisation pathways that are in line with the very ambitous global climate change goals, outlined in the Paris Agreement. Current trajectories and the role of different interventions, in particular in emerging economies, provide important insights in this context. This paper assesses land-transport targets and scenarios for four selected emerging economies that have experienced rapid growth of transport related CO_2 emissions in recent years: Brazil, Kenya, India and Vietnam. Quantified transportation scenarios for each country to 2050 are developed in this paper, including specific CO_2 targets and the implications for each mode within each country. This forms the basis for potential strategies for achieving these targets, reflecting the level of ambition that will be needed. The countries selected for this paper are major emitters in the respective

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regions (Latin America, East Africa, South Asia and Southeast Asia) and represent different governance and socio-economics systems.[1] While learnings from this analysis will not be easiliy transferable to other countries, the systemic approach in different operating environments aims to provide useful insights on transport decarbonisation strategies more generally.

The analysis uses a simplified 'ASIF' (travel **Activity**, modal **Structure**, energy **Intensity,** and **Fuel** types and carbon intensity) model to create scenarios for each country and compare how these perform to a 'business as usual' (BAU) case for each, then consider the policy implications. As described in the methodology section below, a normative, backcasting approach was used in this analysis: the needed CO_2 targets in 2050 were considered and certain principles and judgement were followed to lay out ASIF pathways to achieve them. Policies to achieve these targets were also considered, using the related "ASI" (avoid/shift/improve) approach, for changing future travel patterns and transportation systems.

1.1. Contextual setting: transport decarbonisation in emerging economies as one of the keys to the Paris Agreement

At the 21st Conference of the Parties (COP21) of the United Nations Framework on Climate Change (UNFCCC), 195 nations adopted the Paris Agreement. The Agreement calls for stabilizing "the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels" (UNFCCC, 2015). The Paris Agreement target will require net-zero global Greenhouse Gas (GHG) emissions in the second half of this century (Allen et al., 2018; UNFCCC, 2015). Global assessments reveal that a "well below 2 degree" or 1.5 °C scenario would require nearly full economy-wide decarbonization by 2060 or sooner Rockström et al., 2017; Luderer et al., 2013; Rogelj et al., 2013). This will require transformative change in all sectors of the economy (Walsh et al., 2017). The current NDCs (Nationally Determined Contributions) for most countries do not align with such an ambitious long-term decarbonization scenario (Rogelj et al., 2016; Schleussner et al., 2016). In order to narrow the gap to 2 °C or even 1.5 °C ambitions, most countries will need to strengthen their mitigation efforts well before 2030 (Waisman et al., 2019; Pan et al., 2017).

Given the ambitious global targets, the transport sector has a major role to play, considering that transport is the second largest, but fastest growing energy end-use sector (Lee et al., 2017). The transport sector accounts with more than a quarter of overall energy, producing globally 22% energy end-use-related CO_2 (Sims et al., 2014). If current trends persist transport's share is likely to increase to 40% by 2030 and even 60% by 2050 (ITF, 2019). Considering the rapid growth of mobility demand and the surge in motorization in emerging economies, decarbonising the transport sector in these countries will be a particular challenge.

The evaluation of deep decarbonization scenarios in the transport sector demonstrates the importance for multiple approaches aiming to develop strong institutions, implement ambitious policies and leverage substantial investments to encourage the needed changes (Lah et al., 2019; IEA, 2017). This includes strong demand management actions and modal shift incentives (e.g. parking, road pricing, low emission zones, dedicated freight corridors, incentives for rail), adoption of clean and efficient vehicle technologies (incentives for electric vehicles, hydrogen vehicles, cycling) and the low carbon fuels/energy systems (renewable and low-carbon fuel standards) (Dhar et al., 2018).

In the following sections, an overview is provided on the transport sector and the specific commitments related to transport for the selected countries. Then, based on the analysis of current trajectories and a low carbon (1.5DS) pathway, scenarios for the transport at sector were developed for each country, including passenger and freight land travel. This outlines quantified changes related to different interventions. Finally, the interplay of strategies and measures is assessed, i.e. lowering overall travel growth, shifting travel to lower CO_2 modes, and improving modes to cut CO_2 via efficiency and technology/new fuels adoption strategies.

2. Climate change mitigation ambitions in selected emerging economies

This section provides an overview of the mitigation actions outlined in the Nationally Determined Contributions (NDCs) of the four selected countries and their goals, along with a brief discussion of policies and plans (as of December 2016) that could contribute to the achievement of their goals. The four countries have been selected as representatives of their regions to highlight the challenges of reconciling growing mobility demand and decarbonizing the transport sector.

2.1. Brazil

Brazil's NDC seeks for the decarbonization of the economy by the end of the century through a transition of the energy systems based on renewable sources. Brazil adopted an economy-wide and absolute mitigation target, and compared to its voluntary contributions action pre-2020, the current goal is more rigorous. The country committed to a reduction of 37% by 2025 and 43% by 2030, based on estimated emission levels of 2005 (Federative Republic of Brazil, 2015).

Transportation emissions will dominate in the near future in Brazil (Lèbre La Rovere et al., 2015). Although the current government has halted most climate policy action, Brazil's NDC states that the country aims to implement measures in the transport sector related to the promotion of efficiency measures, and improvement of the infrastructure for transport and public transportation in urbanized areas. Also, the share of sustainable biofuels in the Brazilian energy mix should increase from 8.5% to approximately 18% by 2030.

[1] This paper builds on the Urban Pathways (www.urban-pathways.org) and SOLUTIONSplus (http://www.solutionsplus.eu) projects, which support local and national authorities in Asia, Europe, Africa and Latin America on sustainable development implementation action.

2.2. India

India's NDCs proposes to work towards a low emission development, while meeting its developmental challenges. India aims to cut the GHG emissions intensity of its GDP by 33–35% by 2030 based on 2005 level (Government of India, 2015).

Related to the transport sector, India's NDCs outlines plans to:

- Increase the rail mode share in total land transport from 36% to 45%
- Construct exclusive freight corridors: one from Mumbai to Delhi and another from Ludhiana to Dankuni
- Promote the expansion of coastal shipping and inland water transport
- Construct metro lines: over 550 km (around 236 km are currently in operation)
- Approve 39 projects for urban mobility
- Establish a Green Highways Policy
- Promote the adoption of hybrid and electric vehicles
- Set fuel-efficiency standards for passenger light-duty vehicles
- Establish a National Policy on biofuels.

2.3. Kenya

Kenya's NDC aims to address climate change in a holistic approach to also benefit the country to address other socio-economic challenges. The country established a reduction goal of 30% of GHG emissions by 2030 relative to "business-as-usual" scenario (Ministry of Environment and Natural Resources, 2015).

Currently, transport sector makes a small contribution to national energy consumption. However, this contribution has a potential to grow in the near future because of the increasing demand for passenger cars, trucks for freight activities and air travel (Dalla Longa and van der Zwaan, 2017). Kenya has committed to low carbon and efficient transportation systems in their NDC. Kenya's National Climate Change Action Plan 2013–2017 (NCCAP) suggests that GHG emissions in Kenya will increase until 2030 in all sectors, with transport emissions increasing by a factor of three. Transport-related actions in the NCCAP include infrastructure for mass transit system and for non-motorized modes. Additional to these measures, the Government also proposed measures to shift freight from road to rail, improve passenger and freight vehicle efficiency, and the adoption of bioethanol blending and biodiesel (Government of Kenya, 2012).

2.4. Vietnam

Vietnam's NDC is based on domestic resources and international support to address climate change. The country committed to reduce 8% of GHG emissions by 2030 compared to BAU projection with domestic resources. This contribution could be increased to 25% conditional on international support (Government of Viet Nam, 2015).

In recent decades, Vietnam has seen urban and economic growth along with the rates of motorization. This rapid growth is associated with a high rate of growth in transport demand, and is significantly impacting the energy resources for transportation (Nguyen et al., 2018). Vietnam's NDC commits to:

- Develop and improve the public transport system
- Reform freight transport: promote expansion of rail and inland waterways
- Encourage the adoption of compressed natural gas and liquefied petroleum gas
- Establish standards on fuel consumption
- Establish management program for fuel quality and vehicle maintenance

2.5. Overview of NDC commitments related to transport

In addition to the disaggregation of transport emissions into Activity, Structure, Intensity and Fuels (ASIF), which provides the basis for the modeling of this paper, the Avoid, Shift, Improve (ASI) approach is used to structure the strategies and policies for decarbonization. "Avoid" typically means avoiding travel, particularly energy intensive modes such as individual automobile or SUV trips. "Shift" typically means shifting travel to less energy intensive modes, such as to mass transit. "Improve" typically means improving vehicle fuel economy and reducing energy intensity, along with shifting to low carbon energy technologies like electric vehicles and lowering the carbon intensity of fuels and electricity. The paper retains the distinction in the following analysis, between energy intensity improvements (the "I" in ASIF) and fuel decarbonization ("F" in ASIF), despite their being combined into "I" in the ASI policy approach.

Table 1 provides an overview of all countries' commitments to transport in their NDCs, classified according to the ASI framework. Except for Kenya, which only considers 'Improve' components, the other countries consider all of the avoid/shift/improve aspects. Attempts were made to identify the level of commitment of these countries in three levels: low, medium and high quality of adoption of ASI measures. Low quality means little or no information on the ASI measures is provided, medium means disaggregated ASI measures, and high means deeply disaggregated ASI measures.

Brazil's and Kenya's commitment to transport is simple and it does not specify the measures; for this reason, the quality of the

Table 1
Countries' NDC transport interventions.

Country	Transport Related Emissions (%) (2014)	Interventions Proposed in Transport Sector	ASI measures	Level of detail
Brazil	16%	Transport interventions represent 3% of total content of NDC Promote efficiency measures; Improve the infrastructure for transport and public transportation; Increase the share of biofuels in the energy mix to approximately 18% by 2030;	ASI	Low
India	7%	Transport interventions represent 5% of total content of NDC Increase rail mode share in total land transport to 45%; Construct exclusive freight corridors Promote the expansion of coastal shipping and inland water transport; Construct metro lines; Approve 39 projects for urban mobility; Establish a Green Highways Policy; Promote the adoption of hybrid and electric vehicles; Set fuel-efficiency standards for passenger light-duty vehicle; Establish a National Policy on biofuels.	ASI	High
Kenya	22%	Transport interventions represent 0.4% of total content of NDC Low carbon and efficient transport systems.	SI	Low
Vietnam	13%	Transport interventions represent 4.3% of total content of NDC Develop and improve public transport system; Reform freight transport: promote expansion of rail and inland waterways; Encourage the adoption of compressed natural gas and liquefied petroleum gas; Establish standards on fuel consumption;	ASI	Medium

measures is classified as Low. Vietnam's NDC, when compared to Brazil's and Kenya's has specific measures, with some detailed information, and is thus classified as Medium. India's NDC is classified as high because it has clear and specific targets for almost all its ASI measures.

3. Methods

3.1. Modeling framework

The scenario investigation is carried out using a spreadsheet model developed by the authors, calibrated with historical (and especially our base year 2015) data from the International Energy Agency's Mobility Model (MoMo) (IEA, 2019) database for all the four countries, Brazil, India, Kenya and Vietnam. The estimation of energy consumption and CO_2 emissions is based on the ASIF method (Schipper et al., 2000). The original ASIF equation is shown in equation (1).

$$G = \sum_{modes} \sum_{fuels} A_{m,f} S_{m,f} I_{m,f} F_{m,f} \tag{1}$$

where

G = total emissions of CO_2 in the region,
A = *Activity:* passenger travel and freight transport in passenger-kilometers and tonne-kilometers, respectively,
S = *Structure*: share of travel for each mode
I = *Intensity*: modal energy intensity for each mode and fuel type,
F = *Fuel*: shares of vehicles and fuel used by fuel type, and carbon intensity (CO_2 per unit energy) for each fuel type in each mode.

For the scenario development a spreadsheet model is used, which projects these ASIF travel indicators, energy consumption, and CO_2 for the transportation system of each country. Fig. 1 details the ASIF framework, with the transport modes, vehicle technologies, fuels and other key variables considered in our model. All the projections were based on data available from MoMo[2] and augmented with data from the countries or inferred based on regional data. The BAU projections were calibrated to the MoMo 4 °C scenario (4DS). The low carbon scenarios were derived in this project and are described in detail below. This included adjusting vehicle stock, vehicle travel, share of vehicle technology, fuel efficiency. The projections do not include aviation or maritime activities.

The scenarios outlined in this paper can only be an illustration of potential developments. It is worth noting that there are a number of caveats and limitations. The model applied for this paper treats national travel in a simplified manner, using averages (or estimated averages) broken out by mode and taking into account differences in urban vs non-urban transportation. The model does

[2] Except for the projections related to country population growth rate that are from United Nations database (United Nations, 2019).

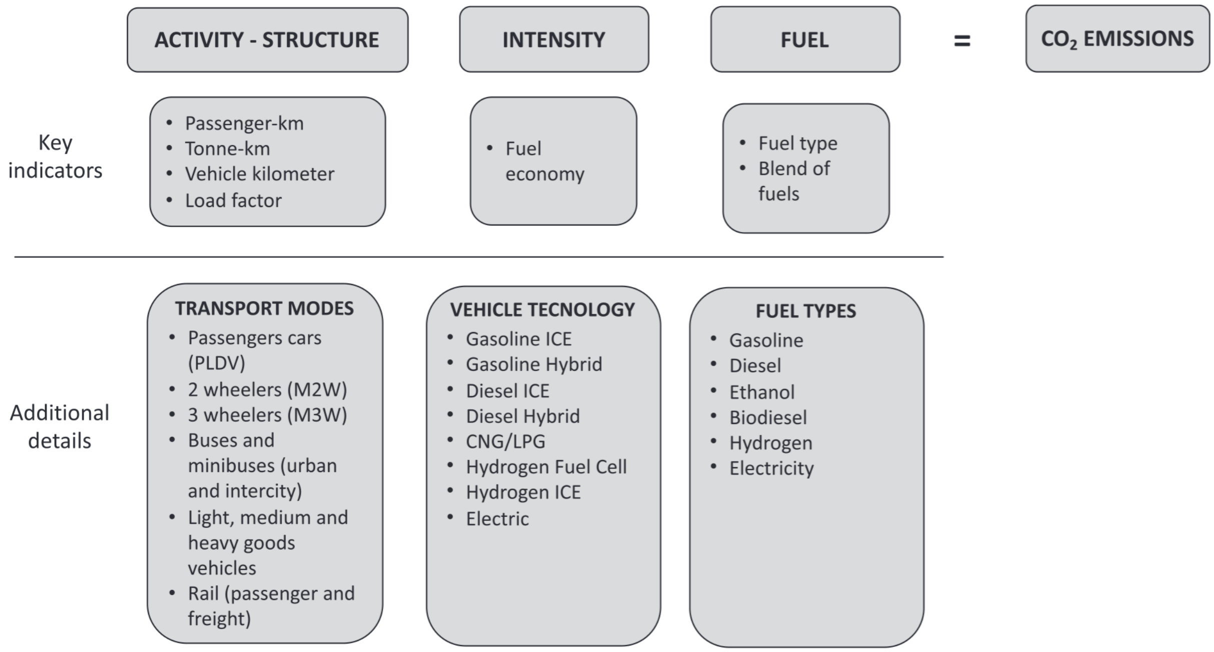

Fig. 1. Framework of key indicators and inputs detail according to ASIF model.

not, for example, directly consider land use and infrastructure factors explicitly. Demographics, behavioral aspects, political considerations socio-economic dynamics could not be properly be integrated into the modeling, although these factors heavily influence pathways. The approach is normative, considering a low carbon scenario that follows certain principles and demonstrates sector developments considering certain CO_2 targets. In addition, the CO_2 emissions reductions presented, while taking into account well-to-wheel factors (such as upstream emissions from biofuels production and electricity generation) do not explicitly allocate these across other sectors, such as industry.

4. Scenarios description and assumptions

The paper considers two scenarios spanning a time period from 2015 until 2050: a BAU scenario and 1.5 °C scenario (1.5DS). A 2 °C scenario (2DS) was also considered, but because of the uncertainty in separating a 2DS from a 1.5DS in terms of the preferred actions and measures, along with the simplicity of presenting just two scenarios, only one was completed. In the BAU scenario, future travel patterns and vehicle/fuel developments are according to MoMo assumptions and projections related to their 4 °C scenario (4DS). This tends toward a continuation of today's trends, most notably on-going increases in car and motorcycle ownership and use per capita, with little increase in the use of other modes such as public transport.

For transportation to play its part in achieving an overall 1.5DS, strong actions to shift away from the BAU are assumed to reach very low CO_2 levels by 2050. The exact targets have not been officially set and are not clear since required reductions will be affected by mitigation actions of sectors, such as electricity, industry and agriculture. A target for land transport of 0.2 tCO_2 per capita by 2050 (or about 2GT total across a 10 billion person world) seems a reasonable assumption (Gota et al., 2018). In this study this target is considered as an example to stress the deep CO_2 reductions countries would need to achieve. Other targets are possible; however, in a 1.5 °C scenario, the entire energy system will need to reach near-zero CO_2 levels not long after 2050, so much higher 2050 targets for transport do not seem very likely. It can be seen in Table 2 the CO_2 reduction challenge/effort that each country will need to commit to contribute to Paris Agreement target.

In the interest of meeting the 1.5DS target, the back-casting approach extrapolates back from this target CO_2 level in 2050 to current (2020) CO_2 emissions levels, and current travel patterns for passenger and freight activity. By identifying a transition

Table 2
CO_2 per capita levels in 2015 and projections to 2050 for the reference scenario (BAU) and the mitigation scenario (1.5DS).

	tCO_2 per capita			
Country	2015	2050 BAU	2050 Target 1.5DS	Reduction challenge
Brazil	1.32	1.25	0.20	1.05
India	0.23	0.90		0.70
Kenya	0.23	0.42		0.22
Vietnam	0.49	0.89		0.69

Table 3
Avoid/Shift/Improve measures for Passenger and Freight Transport included in the assumptions for the mitigation scenario (1.5DS).

	Passenger Transport	Freight Transport
AVOID-SHIFT	Reduced need for travel through urban planning (mixed use, compact urban design) Modal shares of NMT increase Improved occupancy Expansion and improvement of mass transit systems in cities Reducing the need for travel such as teleworking/teleconferencing, carpooling or local sourcing of goods	Measures to shift freight from roads to rail, coastal shipping and waterways Improved load factor
IMPROVE	Improve measures covering different powertrain technologies Decarbonization of gasoline/diesel, with consideration to various biofuel blends Fuel Economy Standards E-mobility, shares of electric vehicles/plug-ins	

pathway, this builds a foundation to then assess transport measures that will allow the achievement of the target. From an IEA-based business-as-usual scenario (a 4 °C scenario), a shift away from this as rapidly as feasible is required, taking into account the need for planning time and avoid extreme shifts over any particular 5 year period. Though once emissions are declining, they decline quite rapidly to reach the 2050 targets. This results in a peak CO_2 point, which varies by country depending on the starting CO_2 levels and their trajectory in the BAU. Brazil actually peaks before 2025, while India, Kenya and Vietnam peak by 2030.

There are in fact many different ways to get to a very low CO_2 future. This paper attempts to use a balanced approach of avoid/shift/improve measures, though the main pillar to reach the 1.5DS target is the component 'Improve', such as improved fuel economy, uptake of low (and eventually near-zero) carbon electricity and hydrogen, and blends of advanced biofuels (celulosic ethanol and biodiesel). This reflects the relatively strong emphasis of Improve measures in the countries' NDCs. Stronger contributions from urban planning and public transport interventions (avoid/shift) are certainly possible and even desirable from a wider urban development perspective.

The selected modeling structure is informed by a range of data and assumptions, along with our judgements about achievable and desirable changes into the future, that drive these scenarios and feed the ASIF formula, shown in equation (1), to determine the CO_2 reductions. These changes in future travel patterns, vehicle technologies, and fuels will need to be driven by policies and measures, which are classified here according to the related ASI framework as shown in Table 3. Our approach allows a clear linkage between key travel factors (ASIF) and CO_2 emissions, but does not link these quantitatively to the potential ASI measures. Thus, the paper provides the range of possible measures here without attempting to specifically indicate how each (or a set) of them could achieve the ASIF-based projections.

The basic ASIF assumptions and projections for the BAU and 1.5DS scenarios can be seen in detail in Appendix A. The following subsections present an overview of the assumptions categorized according to ASIF components.

4.1. Activity/Structure

The components 'Avoid' and 'Shift' play a major role for both passenger and freight transport, with assumptions of higher load factors and more travel by public transit modes as well as more walking and cycling. These shifts reduce private vehicle travel by up to 50% in 2050 in the 1.5DS compared to BAU scenario (though this varies considerably by country) and help achieve significant reductions in overall vehicle travel and energy use compared to the BAU.

Fig. 2 shows the share of passenger kilometers per capita by 2050 in BAU and the 1.5DS scenarios according to transport modes. By 2050 in 1.5DS in all countries, there is a shift in activity of PLDV and M2W modes to urban and inter-municipal buses and minibuses, with as much as a doubling of passenger-km per (PKM) per capita in public transit. However even in 1.5DS, private travel modes retain the majority role in Brazil, with 55% of the trips, and in India, with 40%. In Kenya and Vietnam, PKM for private transport (PLDV and M2W) represents one third of the trips. Also, in Kenya and Vietnam, overall travel actually is higher in the 1.5DS as bus travel growth is expanded faster than the reduction in private vehicle travel growth. The various shifts reflect the best estimates of the timing and extent to which public transit can be expanded and private vehicle travel reduced relative to the BAU, though other scenarios are certainly possible.

Fig. 3 shows urban travel per capita by major mode in 2015 and projected to 2050 for the BAU and 1.5DS. In 1.5DS, urban travel in all four countries converges toward the range of 3–4 thousand PKM per year or around 8–10 km per person per day. This is to some degree a result of pushing mode shares in a similar direction in each country but also a natural result of cutting private vehicle travel and ensuring adequate levels of public transit and in each country. Essentially, the modal structure and travel per person by mode converge in this sustainable scenario.

Fig. 4 shows freight activity in 2050 in BAU and the 1.5DS. In all 4 countries, there is a shift to rail due to significant rail expansion. However, rail starts with such a low share of freight movement that even a doubling or tripling of rail freight service does not alter the modal structure dramatically, except in Kenya where trucking levels are comparatively low. This type of shift would require major investment in rail systems, the cost and feasibility of which have not been considered here. The relatively low percentage of truck haulage shifted to rail in these scenarios could focus on the most important goods to shift, such as long-haul/heavy products. There is also a slight reduction in overall freight tonne-km in the 1.5DS, assuming some improvements in supply chain and

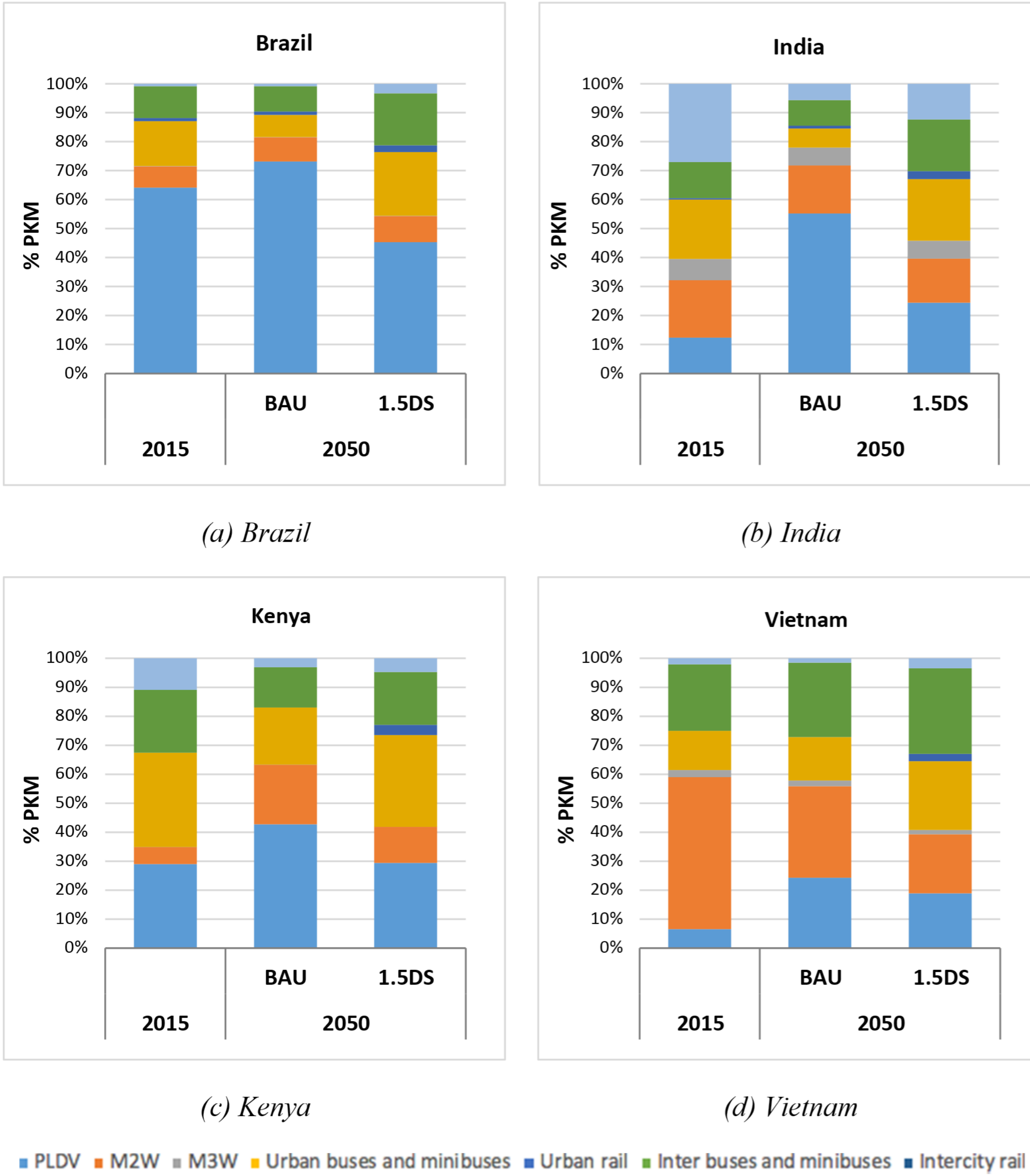

Fig. 2. Share of PKM per capita by mode in BAU and in 1.5DS by 2050 in (a) Brazil, (b) India, (c) Kenya and (d) Vietnam.

logistic efficiencies, except for Kenya with very low levels projected per capita even for the BAU.

4.2. Intensity/Fuel

Both vehicle energy intensity and fuel carbon intensity are strongly reduced by electric vehicles (EV), as long as electric systems are decarbonized as EV stocks grow; this is a basic foundation of any global low-carbon scenario, such as the IEA 1.5DS (IEA, 2017). Electric vehicles can already be cost effective if a focus on lightweight, resource efficient vehicles and system integration is considered (UEMI, 2017). Electric vehicles are likely to become more cost-effective over time as battery costs decline, i.e. a cost of ownership well below that of internal combustion engine vehicles (Wappelhorst et al. 2018), and thus it is assumed in this paper that electric vehicles will play a very important role in decarbonizing light modes, which not just includes cars but where also 2- and 3-wheelers

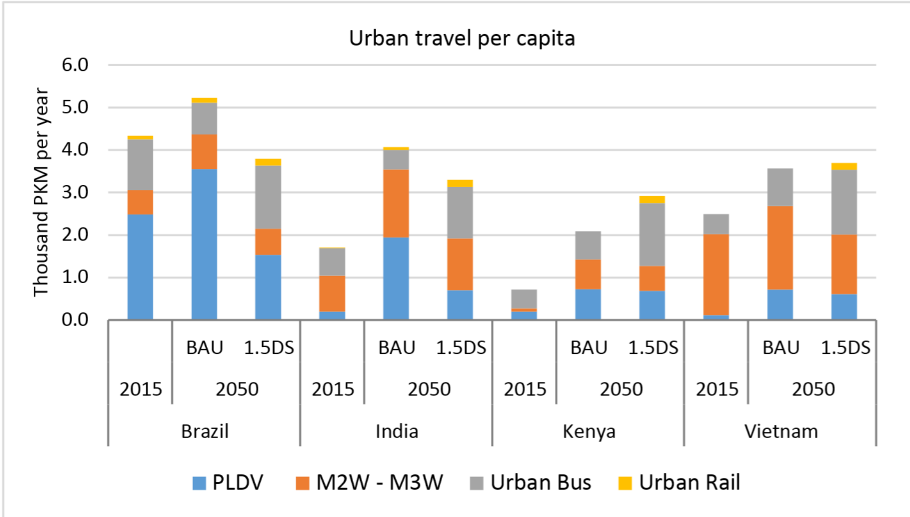

Fig. 3. Urban travel per capita in thousand PKM per year by modes in 2015, BAU 2050 and 1.5DS 2050 in Brazil, India, Kenya and Vietnam.

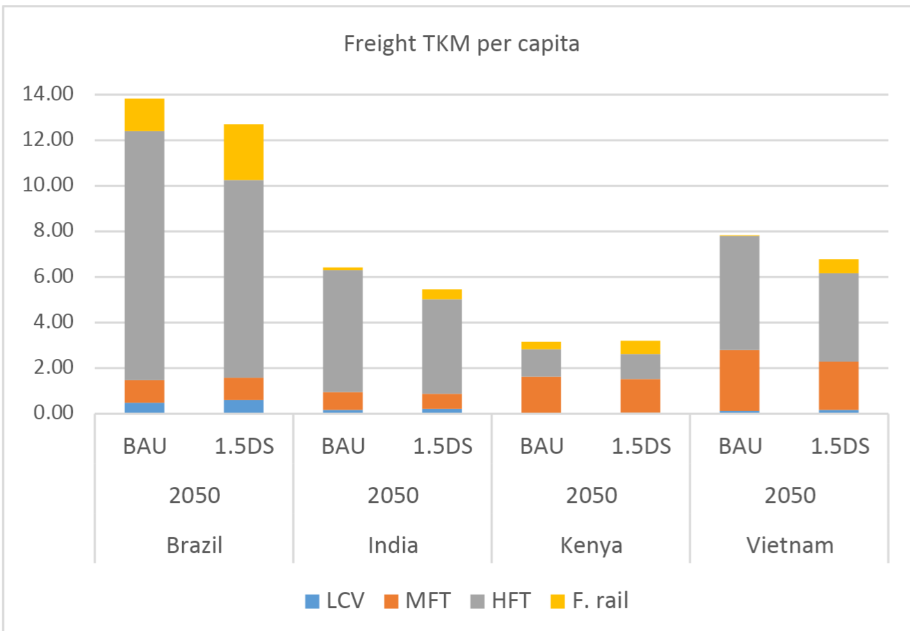

Fig. 4. Freight TKM per capita by freight modes by 2050 in BAU and 1.5DS in Brazil, India, Kenya and Vietnam (notes. LCV = light commercial vehicle; MFT = medium freight truck; HFT = heavy freight truck; F. rail = freight rail).

play an important role. A rapid transition of these vehicle types toward electrification in all four countries is included, though the rates vary somewhat, as can be seen in Fig. 5.

On the road freight transport side (Fig. 6), energy and fuel technologies are also expected to play a key role, given limits on the modal shift of goods. Some shifts from truck to rail are assumed, but most reductions are achieved via a combination of strong ICE truck efficiency enhancements and the uptake of electricity, hydrogen and biofuels. Urban logistics trucks (mainly medium duty) are assumed to be electrified, as this would be in line with current urban logistics trends. Long-distance trucking is mostly shifted to hydrogen in each country, while it is important in each of the selected countries shares vary and are relatively small during the projected period.

Fig. 5 and Fig. 6 show the technology stock in 2015 for both light-duty and heavy-duty vehicles in Brazil, India, Kenya and Vietnam (and world-wide), dominated by conventional internal combustion engines with gasoline and diesel fuel. The stocks of different types of vehicles in the BAU scenarios follow the IEA projections, while those in the 1.5DS reflect the range of avoid/shift measures described. Thus, the stocks in 2050 for different vehicle types are radically changed in the 1.5DS. One of the most important changes is a dramatic uptake in electric vehicles for cars (Fig. 5), but it also includes strong hybridization of ICEs and an increase in

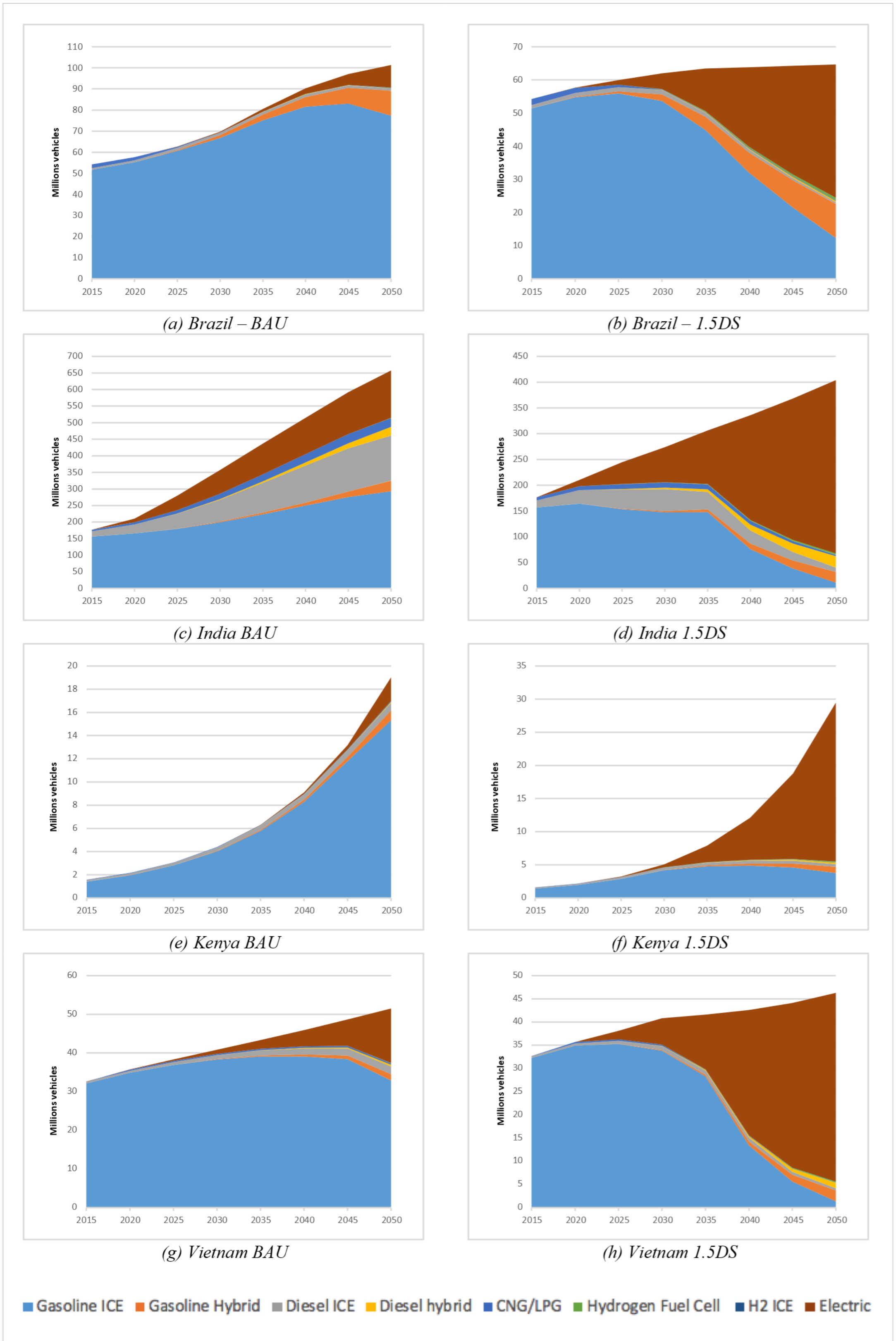

Fig. 5. Total passenger vehicle stock by technology from 2015 to 2050 in BAU and in 1.5DS in Brazil, India, Kenya and Vietnam.

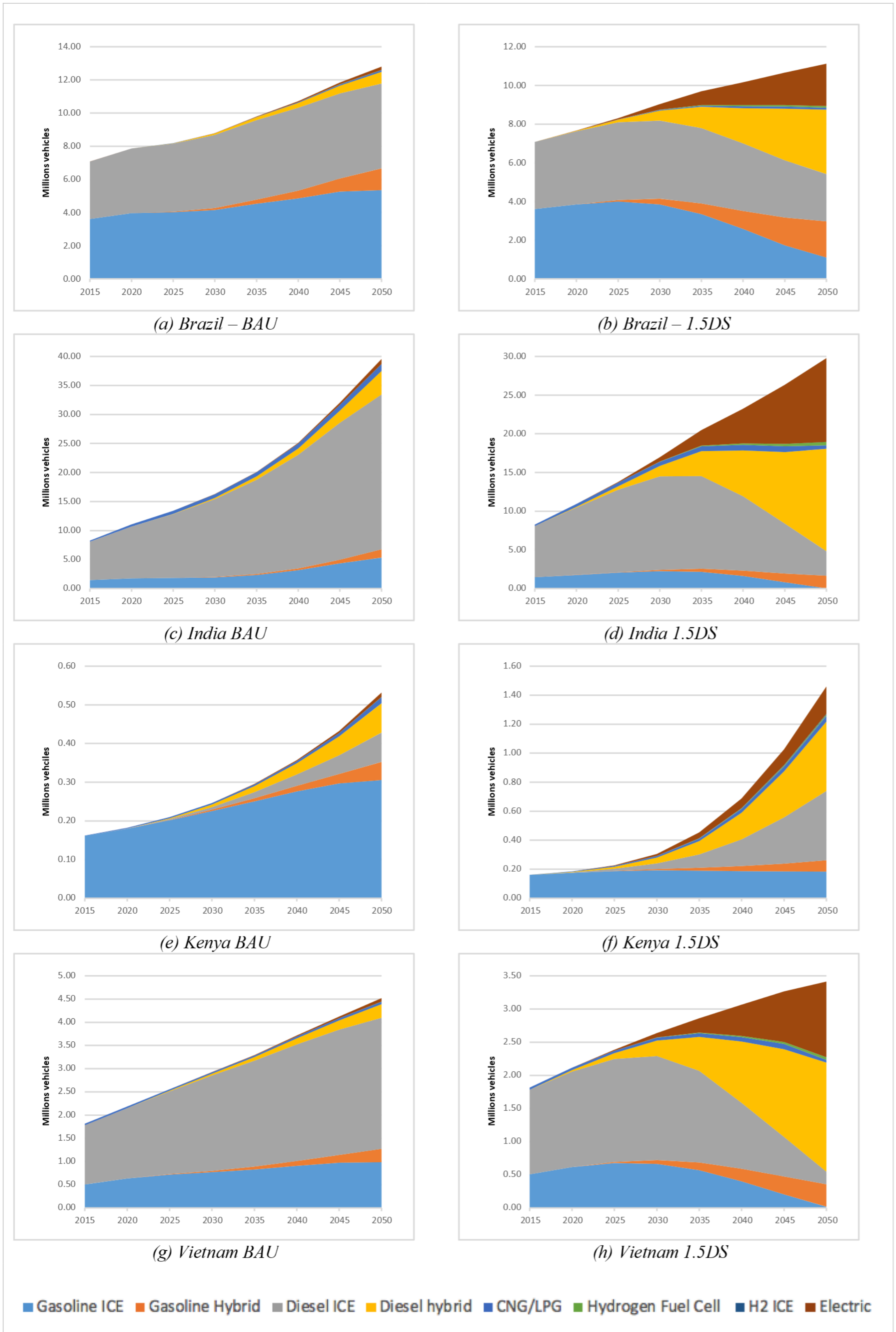

Fig. 6. Freight vehicles stock by technology from 2015 to 2050 in BAU and in 1.5DS in Brazil, India, Kenya and Vietnam.

Table 4
Share of biofuels of total transportation fuel use.

Country	Ethanol (%)			Biodiesel (%)		
	2015	2050 BAU	2050 1.5DS	2015	2050 BAU	2050 1.5DS
Brazil	27%	50%	85%	6%	20%	84%
India	1%	7%	28%	1%	8%	17%
Kenya	1%	6%	27%	1%	6%	16%
Vietnam	1%	7%	30%	2%	8%	25%

H_2 vehicles and biofuels (Fig. 6).

The role of hydrogen vehicles reflects the fact that while electric vehicles appear likely to offer among the lowest cost CO_2 reductions, hydrogen vehicles also may play an important role for larger vehicles that require longer range capabilities and shorter refueling times. H_2 can also be produced with very low CO_2 emissions, when produced via electrolysis from renewable electricity sources. Biofuels can also play an important role when produced from low life-cycle CO_2 feedstocks and systems, and are used extensively in the remaining ICE vehicles in the scenario after 2030 (except in Brazil where they play an important role throughout the 2020–2050 time frame).

Given recent trends and their geographic locations in Asia, a hub for electric vehicle production and adoption, India and Vietnam are assumed to undertake a much more aggressive adoption of EVs over the next 10 years when compared to Brazil and Kenya, though by 2050 all four countries have high EV sales shares. However, in all cases, this seems only realistic of electric 2- and 3-wheelers which play an important role in the overall take-up of electric vehicles.

If Brazil would aim to achieve more CO_2 reductions from ICE vehicles by increasing the use of biofuels; this would require less penetration of EVs to hit a particular CO_2 target. This, however, would come with the caveat of indirect emissions through land-use changes from increase biofuel production. In Kenya, the need for high penetration rates of low-carbon vehicle technologies depends on the growth in travel demand overall and in motorized travel in particular. During the assessed period travel demand in Kenya is considerably lower than in the other countries but increasing rapidly.

The uptake of low carbon biofuels by type, country and scenario is shown in Table 4. While all 4 countries increase their use in 2050 by a factor of 2–4 compared to BAU, Brazil achieves much higher percentage levels given its strong starting position and infrastructure. There are also concerns about the availability of low-carbon biofuels around the world, and thus this strategy is used in a limited way in this study. Also note that the production of electricity and hydrogen would be mostly from very low carbon renewable sources by 2050, not reflected in this figure. More detail information can be seen in Appendix A.

5. Modeling results and discussion

5.1. CO_2 emissions

As described, modeling the 1.5DS scenario is a backcasting exercise from the CO_2 emissions per capita target established as 0.2 tonnes of CO_2 per capita in 2050 (Gota et al. 2018). The development of our scenario was designed to reach the 0.2 t CO_2 per capita

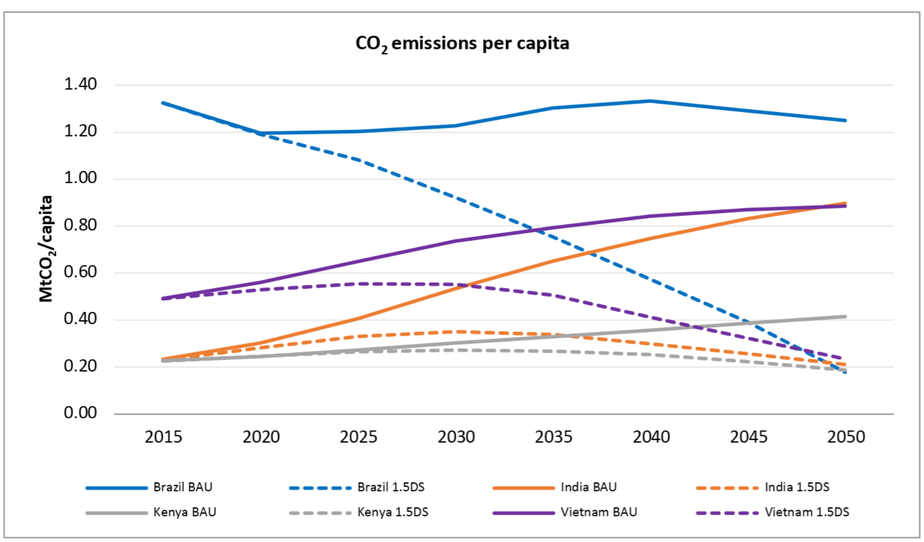

Fig. 7. CO_2 emissions per capita from 2015 to 2050 in BAU and in 1.5DS in Brazil, India, Kenya and Vietnam (note. emissions are for land transport CO2 only, as is true throughout the paper).

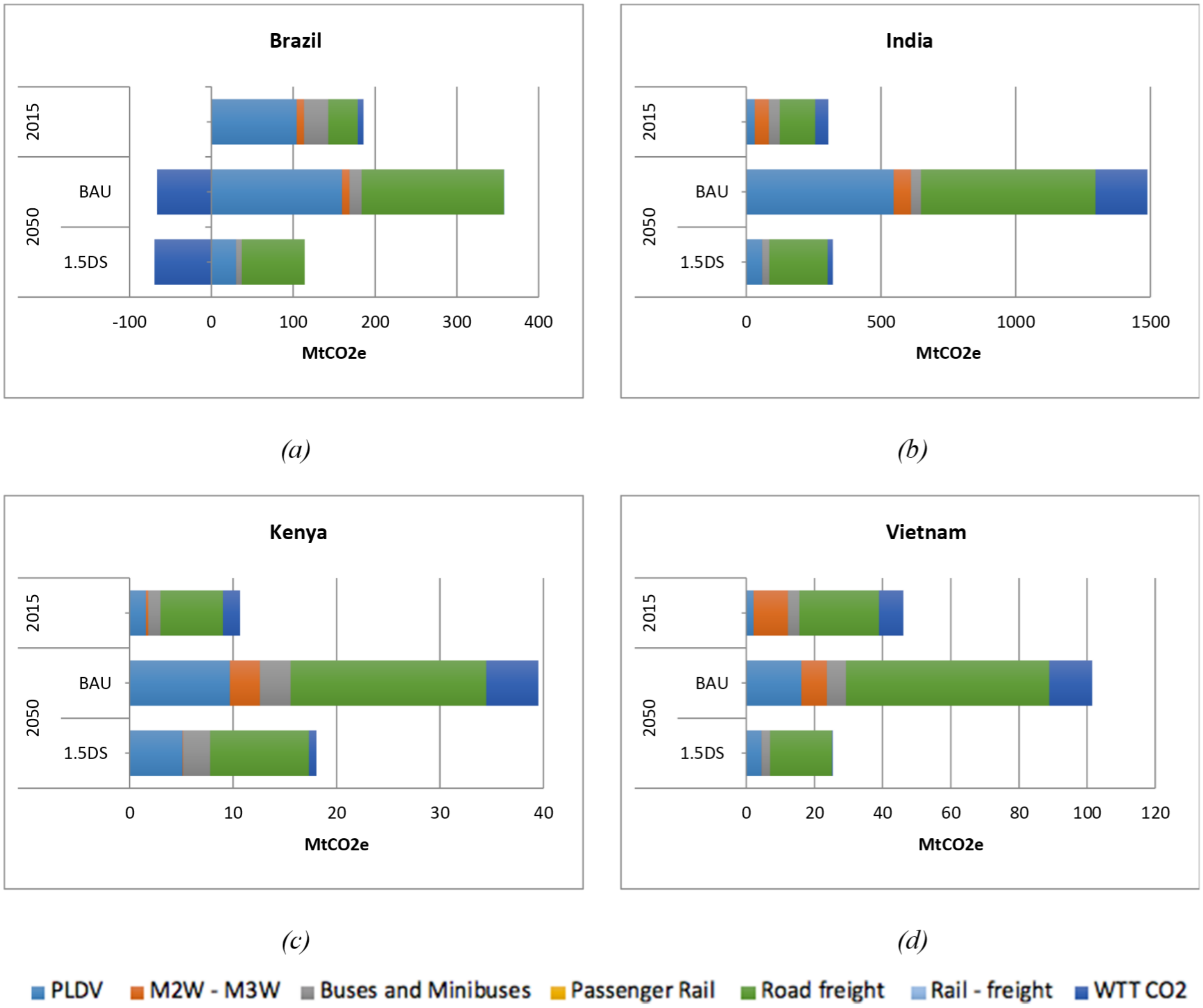

Fig. 8. Total CO_2 emissions by mode in *(a)* Brazil, *(b)* India, *(c)* Kenya and *(d)* Vietnam in 2015 and 2050 (BAU and 1.5DS).

target, and does so. Fig. 7 shows CO_2 emissions per capita in the BAU and 1.5DS for the period of 2015–2050 for the four countries. In the BAU, the countries have quite varied trajectories, and only Kenya remains anywhere near the target of 0.2 t CO_2 per capita. This reflects on-going low income and low travel levels per capita in that country. India and Vietnam show rapid increases toward 1 t CO_2 per capita, reflecting rapid income growth and motorization. Brazil's CO_2 does not increase per capita but remains around today's level of 1.2 t CO_2 per capita, given already moderate levels of motorization and offsetting trends between travel growth and improved efficiency in their BAU.

Fig. 7 also shows CO_2 emissions per capita in the 1.5DS. In order to provide an illustrative and equal pathway towards 1.5 °C by 2050, all countries' emissions reduce to the same CO_2 emissions per capita, 0.2. The peaking of CO_2 emissions per capita has already occurred in Brazil and continues heading downward after 2020. In India, Kenya and Vietnam, the peak occurs around 2030, provides time for a range of policies to take effect before steep reductions begin occurring. Steady declines in CO_2 per capita in these three countries occur from 2030 to 2050.

The results of total CO_2 emissions for land transport broken down by mode in 2015 and in 2050, for both the BAU and 1.5DS, are shown for each country in Fig. 8. BAU shows strong increases in road freight CO_2, from dramatic increases in heavy-duty vehicle travel. In all cases, in the 1.5DS there is a strong reduction across modes by 2050 relative to the BAU, and typically lower than or similar to 2015.

It should also be noted that the dark blue stack in all graphs shows well-to-tank (WTT) CO_2 emissions, while the other stacks show tank-to-wheel (TTW) CO_2 emissions according to the transport mode. Thus Brazil, with the negative well-to-tank emissions, has overall net emissions that are lower than they appear.

It can be seen that CO_2 emissions reductions are greatly reduced in the 1.5DS compared to BAU for all countries. In Brazil and India, the predominant emissions are from PLDV (private light duty vehicles) and trucks in the BAU; these are also the modes with the greatest reductions (though they remain the largest) in 2050. In Kenya, trucks stand out as major emitters, followed by PLDV. In Vietnam, major emitters are the same as in Kenya, however emissions from M2W (motorized two-wheelers) are also high.

The reduction of CO_2 emissions for PLDV and M2W is achieved via a combination of factors: reduction of PKM (passenger km)

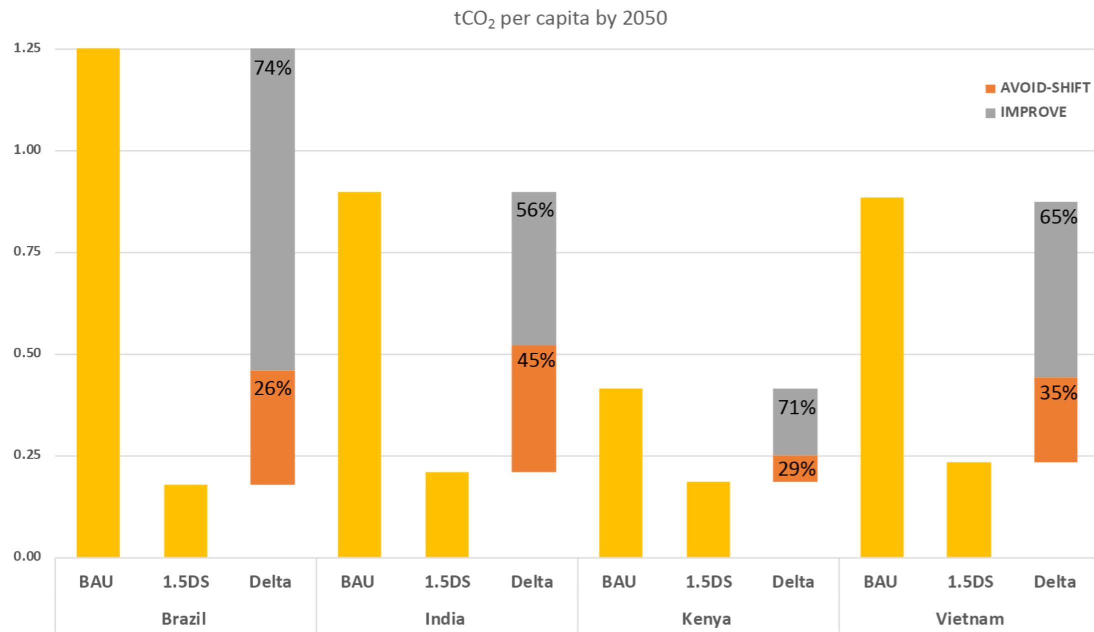

Fig. 9. CO_2 emissions per capita reduction by 2050 in 1.5DS compared to BAU according to Avoid-Shift-Improve measures adopted in Brazil, India, Kenya and Vietnam.

(see Figs. 2 and 3), adoption of gasoline hybrid electric and fully electric vehicles (see Fig. 5) and also a higher blend of low-carbon biofuels. The reduction of CO_2 from heavy trucks in India and Vietnam also results from the adoption of hybrid and electric technologies, improvement of fuel economy and adoption of biofuels. These will require strong investment for freight vehicle technologies and refueling infrastructure, along with investments in rail for the modal shift that would reduce truck travel annually.

It can also be seen that Brazil is the only country that presents negative WTT CO_2 emissions in both scenarios (dark blue negative bars), due to the extensive use of sugarcane ethanol and a clean electricity grid compared to the other countries in this analysis. Despite the other countries' not having negative WTT CO_2 emissions, a reduction can be observed in 1.5DS compared to BAU, reflecting cleaner electricity and some adoption of biofuels in those countries, as detailed in Table 4.

5.2. Major strategies for 1.5DS

The scenarios developed for this paper represent an illustration of a possible way to accomplish the CO_2 target for transportation in each country; there are variety of options how this could be achieved. The main point is to show that reaching 1.5DS is possible but would need a major shift from the current set of policies, well beyond what is pledged in current NDCs.

In terms of the types of strategies implied by the scenarios presented in this paper, Fig. 9 shows the breakdown of mitigation strategies aggregated into 'Avoid-shift' measures, illustrated in orange stacked bar, and 'Improve' measures, gray stacked bar. Avoid and shift measures are combined as it is difficult to separate these in many cases – basically, travel by private LDV drops and travel by other modes increase, with a mixed avoid/shift effect on CO_2. The energy intensity reductions and reduced fuel carbon intensity are attributed to 'Improve'. The balance of ASI measures considered to achieve the target of 1.5DS scenario clearly demonstrates the efforts that each country analyzed in this study should be committed to. More detail of the ASI balance can be seen in Appendix A.

In general, the countries have a similar amount of 'Improve' but somewhat varying 'Avoid-shift' components in the CO_2 reduction. In part, this relates to the initial and 2050 BAU level of CO_2 emissions that must be reduced, and how much reduction is thus required to get to 0.2 tonnes of CO_2 emissions per capita. Kenya is a particular case in this regard, starting with very low per capita CO_2 and travel levels. Each country is considered below.

Brazil has the advantage, as previously mentioned, of the favorable context on the adoption of biofuels (with uncertainties around the land-use change implications) and a relatively high share of renewables in the electricity grid, in this case 'Improve' measures represent 74% of total emissions reduction by 2050. This is roughly aligned with Brazil's NDC, that commits to promote efficiency measures and the adoption of biofuels, as shown in Table 1. The NDC was classified at low detail level, for this reason, even though the interventions proposed are aligned with 1.5DS it will require a much more detailed approach to support the development and implementation of such policies, in addition to strong policies related to electric mobility.

In India the reduction effort to achieve the target is more balanced between 'Avoid-shift' and 'Improve' measures compared to the other 3 countries. This results from a combination of strong policies to reduce, substitute or avoid passenger transport activity, allied to improve measures in freight transport activity. In general, these balance of ASI measures is already reflected in India's NDC, that presents a high detail level of the interventions proposed for transport sector, and shows the country is in the path of a 1.5DS.

As noted above, Kenya starts with, and even in 2050 BAU retains, very low travel levels per capita, particularly urban public transit levels. Here, these levels were raised to be somewhat similar to those of the other countries by 2050 in the 1.5DS, to reflect a well-functioning urban travel system. This means many more buses and rail transit systems, and more CO_2 from these systems along with the higher travel levels. Thus, for Kenya, the 'Avoid-shift' component of CO_2 reduction is small. Adoption of electric vehicles provides most of the CO_2 reductions. The path for 1.5DS in Kenya would require moderate policies to shift transport activity to public transport modes associated to strong adoption of electric vehicles for passenger and freight modes. This could represent a more specific plan under Kenya's existing NDC commitment to 'low carbon and efficient transport systems'

Vietnam would also need to adopt strong 'Improve' policies to keep the path aligned to 1.5DS combined with moderate 'Avoid-shift' measures, especially to reduce or substitute freight transport. According to Table 1, Vietnam's NDC was classified as medium and covers all ASI measures. In order to enhance the NDC, in addition to current policies, the country should consider stronger policies related to electrification of the fleet.

6. Conclusion

In this paper, pathways towards a 1.5 °C scenario (1.5DS) for land-transport in four countries (Brazil, India, Kenya and Vietnam) are presented to highlight some of the key challenges of decarbonizing transport in emerging economies. The simplified 'ASIF' model is adopted to provide BAU and 1.5DS scenarios for each country and evaluate how these scenarios differ between them and then consider the policy implications. The main focus is evaluating and presenting the types of changes in travel activity, transport modes and vehicle technologies that would be needed in each country to meet a deep reduction target for transportation CO_2 emissions. The analysis shows that current policies are insufficient to meet mobility demand and CO_2 emission reductions. Stronger measures are needed that consider all relevant aspects of the Avoid-Shift-Improve framework and increased ambition is required.

Meeting such targets, as part of broader strategies to reach 1.5 °C is certainly possible, but it will require implementation and delivery of very strong strategies to manage passenger and freight travel demand and foster efficient modes (Avoid/Shift), only then the shift to low-carbon powertrains and fuels is conceivable (Improve). This should be reflected in strengthened pledges and much clearer setting of targets and strategies in transportation for updated NDCs, initially with a 2030 focus but followed by commitments to deep mitigation in the 2030–2050 time frame. For this, an overreliance on vehicle technologies would be counterproductive. While the CO_2 emission reduction potential might suggest a focus on Improve measures, 'Avoid' and 'Shift' measures are vital to manage the overall efficiency of the mobility system and are also major contributors to other objectives, in particular urban accessibility. Such an encompassing approach requires a joint effort between national, regional and local authorities on the development of policy measures that will enable the investments and implementation of measures that lie in the jurisdiction of different levels of government.

Although the transport systems differ between Brazil, India, Kenya and Vietnam, and the countries are at distinct level of development, they can benefit similarly from an integrated approach including all relevant interventions, although perhaps at different levels of adoption by 2030 and 2050 according to each country's level of motorization and background situation, such as the capability of the electricity grid to deliver low-carbon electricity. The feasibility and inherent costs of the electrification of the vehicle fleet critically depends on the ability of countries to manage overall travel demand and provide modal choices.

CRediT authorship contribution statement

Magdala Arioli: Conceptualization, Methodology, Writing - review & editing. **Lew Fulton:** Methodology, Formal analysis. **Oliver Lah:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

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