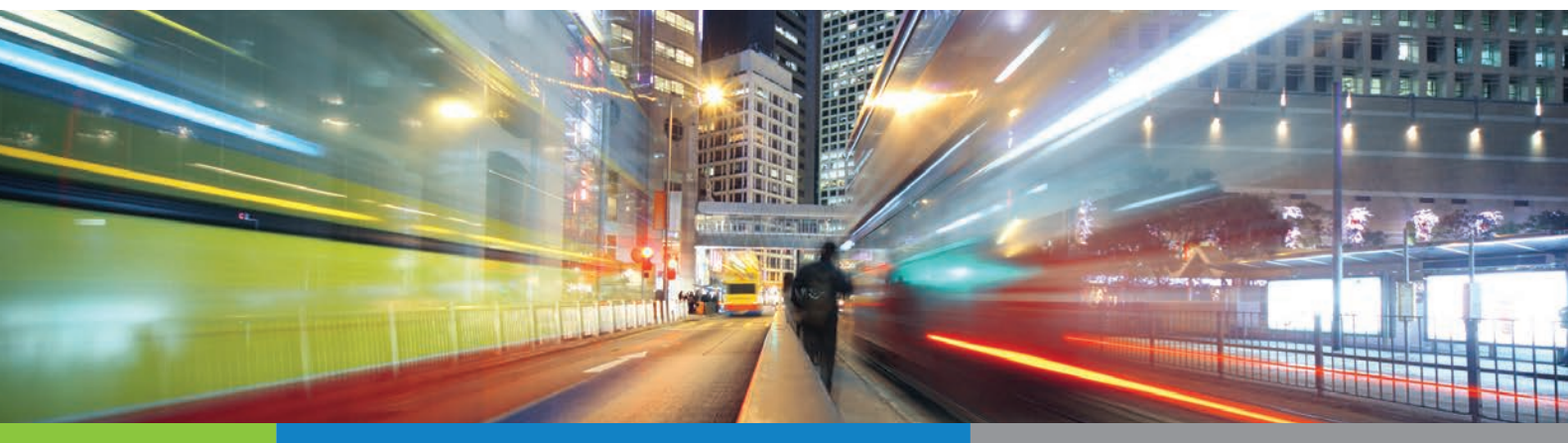




ITF Transport Outlook 2015



CHAPTER 4 PREVIEW: URBAN PASSENGER TRANSPORT SCENARIOS FOR LATIN AMERICA, CHINA AND INDIA

Chapter 4

Urban passenger transport scenarios for Latin America, China and India

This chapter presents long-run scenarios to 2050 for the development of urban passenger mobility and related emissions and health impacts in Latin American, Chinese and Indian cities, based on the ITF urban transport model, IEA's MoMo model and ICCT's health impacts methodology. The model projects levels of transport activity and modal shares under different urban policy scenarios. The chapter highlights the importance of urban agglomerations to economic development while also taking into account the challenges related to containing the negative externalities. The chapter discusses the importance of designing comprehensive urban policies in emerging economies on the basis of an empirical analysis using extensive data.

The growing population and economic concentration in urban areas call for particular attention to be paid to urban transport policies in emerging economies. By 2050, of the 2.7 billion additional urban dwellers, 94% will live in developing countries. Containing urban sprawl and expanding public transport could help slow growth in the number of vehicle-kilometres travelled by private vehicles without sacrificing the overall passenger mobility but reducing CO₂ emissions. Long-term urban transport planning and alignment of policies towards *private transport-oriented* or *public transport-oriented* urbanisation will translate into significant differences in modal composition of urban mobility in Latin America, China and India.

Urbanisation, economic growth and transport

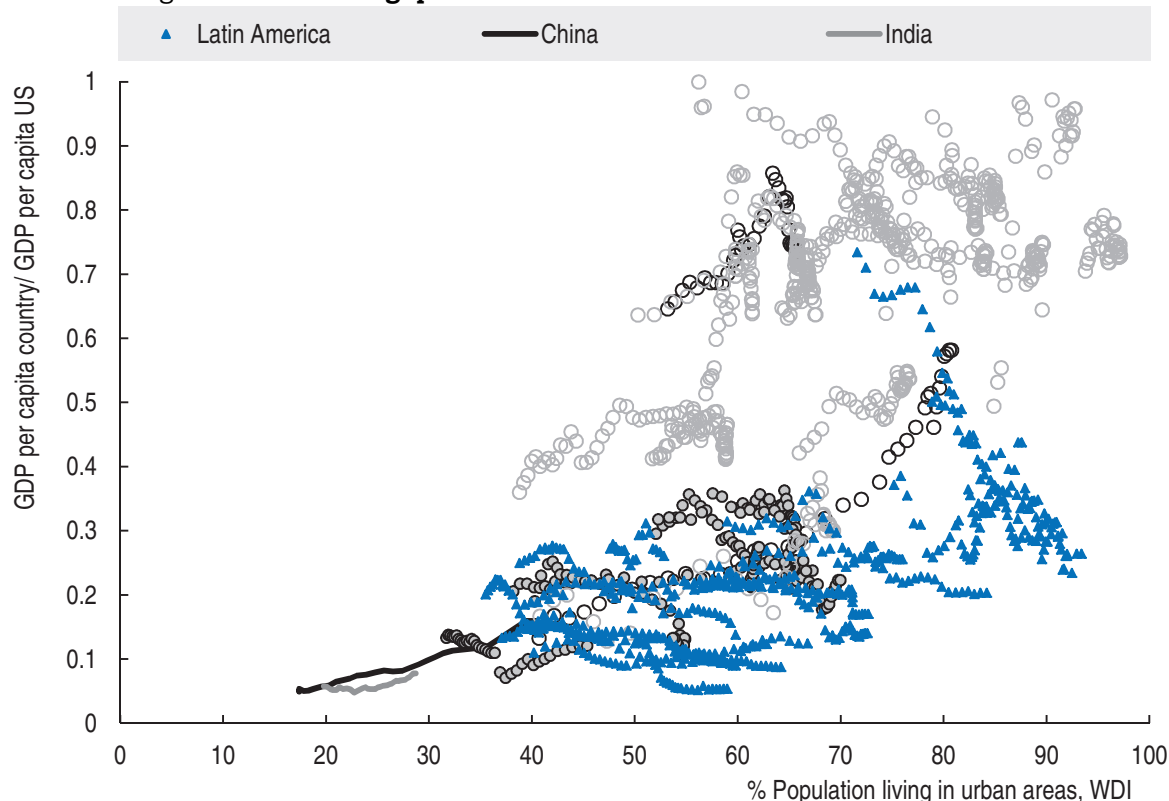
Urbanisation and economic growth

Urban agglomerations, and in particular large ones, tend to drive national economic development. Among the most important reasons for this are agglomeration economies: the effect by which “the concentration of firms and workers in space makes them more productive” (Combes, 2012). Agglomeration effects include localisation economies, which benefit particular industries through technological spillovers, opportunities to share intermediate inputs and access to a larger number and wider variety of skilled workers. Another set of effects are termed urbanisation economies. These provide benefits to the city as a whole and include the existence of larger markets, the availability of public goods that are only economically viable when provided on a large scale and the ease of inter-industry interactions (Graham, 2007).

But having a large concentration of population also brings important challenges that can undermine agglomeration advantages. Urban centres face strong pressures to maintain and expand infrastructure to ensure that access to opportunities for employment and services reach all parts of the population, and to contain negative externalities. Cities that do not manage to develop a “framework for urban life that can encourage the good interactions that density and connectivity allow whilst limiting the bad” (Romer, 2014) face diseconomies of scale very soon and turn into an obstacle to growth rather than an engine of economic development.

International experience shows divergent stories regarding how urbanisation has been translated into overall economic growth. Figure 4.1 shows the relation between urban population shares and the gap in per capita income of various countries relative to US per capita income. As it can be seen, Latin America and Eastern Europe (including Turkey in this data set) have not reached the income levels of Europe and Japan at similar levels of urbanisation. Korea has significantly closed the gap during the last decade. For China and India, which are still in early urbanisation stages, the future trend will depend on how well new and growing cities are able to remain competitive as they develop.

Even if the capacity of cities to maintain higher economic growth in the long-term varies, Gross Domestic Product (GDP) concentration in urban centers leads to urban

Figure 4.1. **Income gap with United States relative to urbanisation rate**

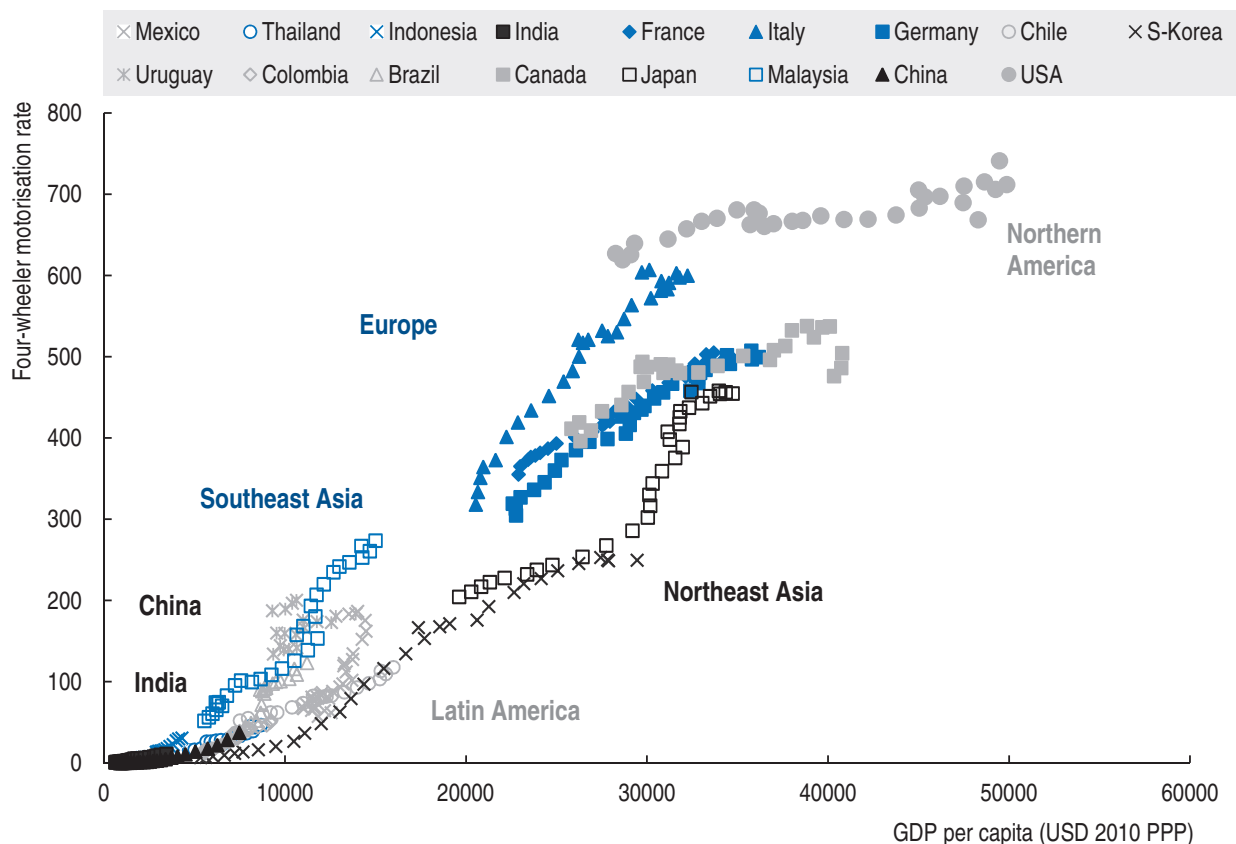
Source: Public Governance and Territorial Development Directorate (GOV) at OECD.

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populations arriving at higher income levels earlier than for a country as a whole. The relatively higher purchasing power causes private motorisation to start earlier in cities.

Nonetheless, due to higher density of demand, the scope for relying on public transport to meet mobility needs is broader in cities than elsewhere. Higher densities also make it more feasible for non-motorised transport modes to play a relevant role in urban mobility. Because road space is a resource that is particularly scarce in the urban context, and more so as motorisation grows, higher levels of congestion also tend to reduce earlier the benefits of using private transport in urban centers. Due to all of these reasons, the relation between economic growth and private motorisation would be expected to follow a less intensive pathway in cities. Urbanisation would therefore tend to decrease reliance in private modes in overall national mobility.

Looking at world historical car and two-wheeler motorisation relative to income growth, it is clear that the extent to which urbanisation has decreased the intensity of this relation has varied significantly between countries (Figure 4.2). The United States and Canada present higher car ownership rates than the selected Western European countries at similar personal income levels despite the fact that the United States and Canada have higher shares of urban population. Contrarily, in the case of Japan, very high urbanisation rates (97%) would seem to have decreased significantly intensity of car ownership relative to economic growth. South Korea also shows very low car motorisation when compared to that which Europe, the United States, and Canada had at comparable income levels (urbanisation rates of Korea are similar to those in the the United States and Canada).

Figure 4.2. **Four-wheeler motorisation relative to per capita income, selected countries**

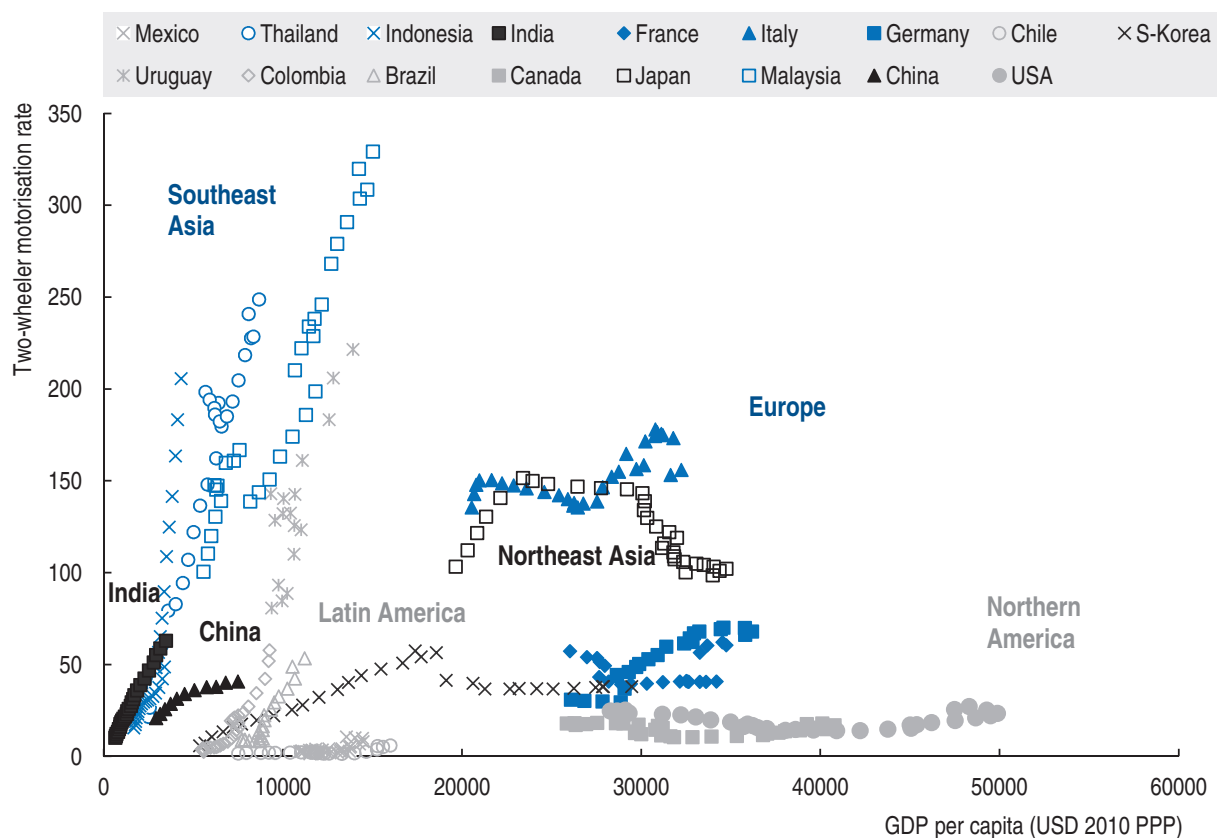
Source: IMF (2014); International Energy Agency. Momo ETP 2014 (2014); INEGI (2013); INE (2013); DANE (2013); data provided by Dr. Hua Zhang.

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In the case of two-wheeler ownership (Figure 4.3), the United States, Canada, and most selected Western European countries show very low levels at high income stages. Italy, Korea, and Japan show some acceleration toward middle-income levels but a reduction when reaching higher incomes.

Developing regions such as Latin America and Southeast Asia have shown relatively high intensity of private motorisation with respect to income. Latin America is a highly urbanised region but it is far from closing the income gap with developed countries with similar urbanisation rates. This explains why the region has a lower private car motorisation rate. However, Figure 4.2 shows that the intensity of car motorisation relative to income growth is very high in countries such as Uruguay, and Brazil. If continued into the future, the region would arrive at very high car ownership at the income levels that developed countries have now. Contrastingly, Chile's pathway shows itself to be more like the one presented by South-Korea. In the case of China and India, income levels are still low and car motorisation has just started to accelerate. Nonetheless, China already shows more intensive car motorisation than Korea, similar to Latin American trends at those income levels.

Regarding two-wheeler ownership, Southeast Asia has shown extraordinary levels compared to those shown by developed countries. Early introduction of two-wheelers into these markets was possible as many of these countries developed their own industries

Figure 4.3. **Two-wheeler motorisation relative to per capita income, selected countries**

Source: IMF (2014); International Energy Agency. Momo ETP 2014 (2014); INEGI (2013); INE (2013); DANE (2013); data provided by Dr. Hua Zhang.

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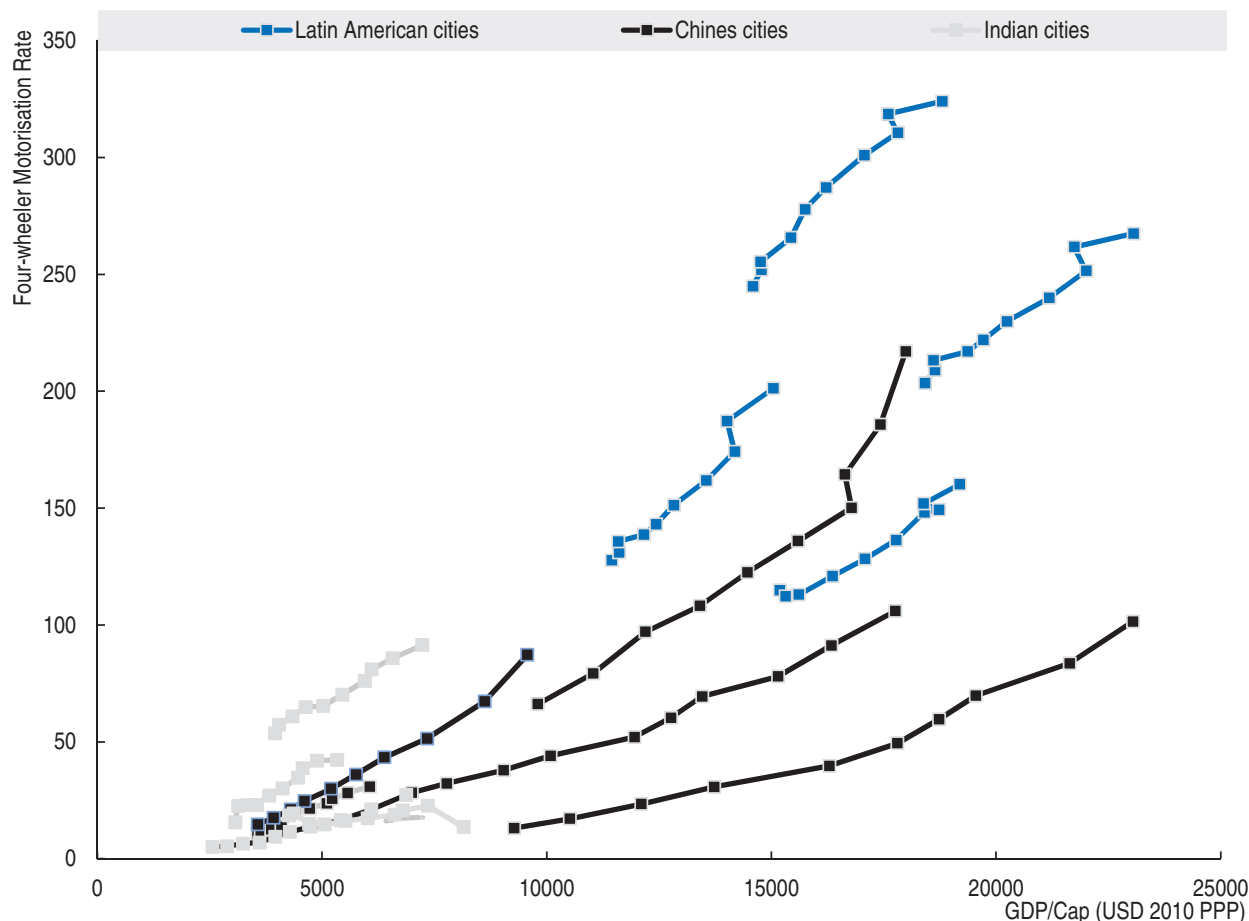
(e.g. Malaysia, Indonesia, Thailand). India and China (that also developed industries of their own) have shown pathways that are also very intensive. In the case of China, two-wheeler motorisation seems to have curbed before entering middle income levels. Data in the graph only refers to gasoline two-wheelers, which have been banned in many major cities. Electric two-wheeler ownership has recently grown very fast and is most likely offsetting this trend (see Box 4.4). In the case of Latin America, the first stage of motorisation was done only through car ownership. However, two-wheeler ownership has grown rapidly in some countries over the last decade (Figure 4.3).

In addition to differences between countries and regions, it is also interesting to note that the relation between economic growth and private motorisation shows differences even within countries and regions. Figures 4.4 and 4.5 show the relation between per capita income and car and two-wheeler motorisation in selected cities of Latin America, China and India. The different trends in intensity and income threshold at which motorisation has accelerated could lead the region and countries into different motorisation futures if all cities were to follow.

Overall, policies implemented at the urban level can play a crucial role in the extent to which urbanisation can translate into mobility that is less dependent in private modes while meeting growing mobility demand. This can significantly reduce negative externalities such as congestion, pollution and CO₂ emissions.

Figure 4.4. **Four-wheeler motorisation relative to GDP per capita**

Cities in Latin America, China and India



Source: Urban Mobility Observatory (CAF) (2007); TERI (2014); McKinsey Global Institute, Cityscope 2.0 database (2010); data provided by Dr. Hua Zhang.

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Urban transport policy scenarios for Latin America, China, and India

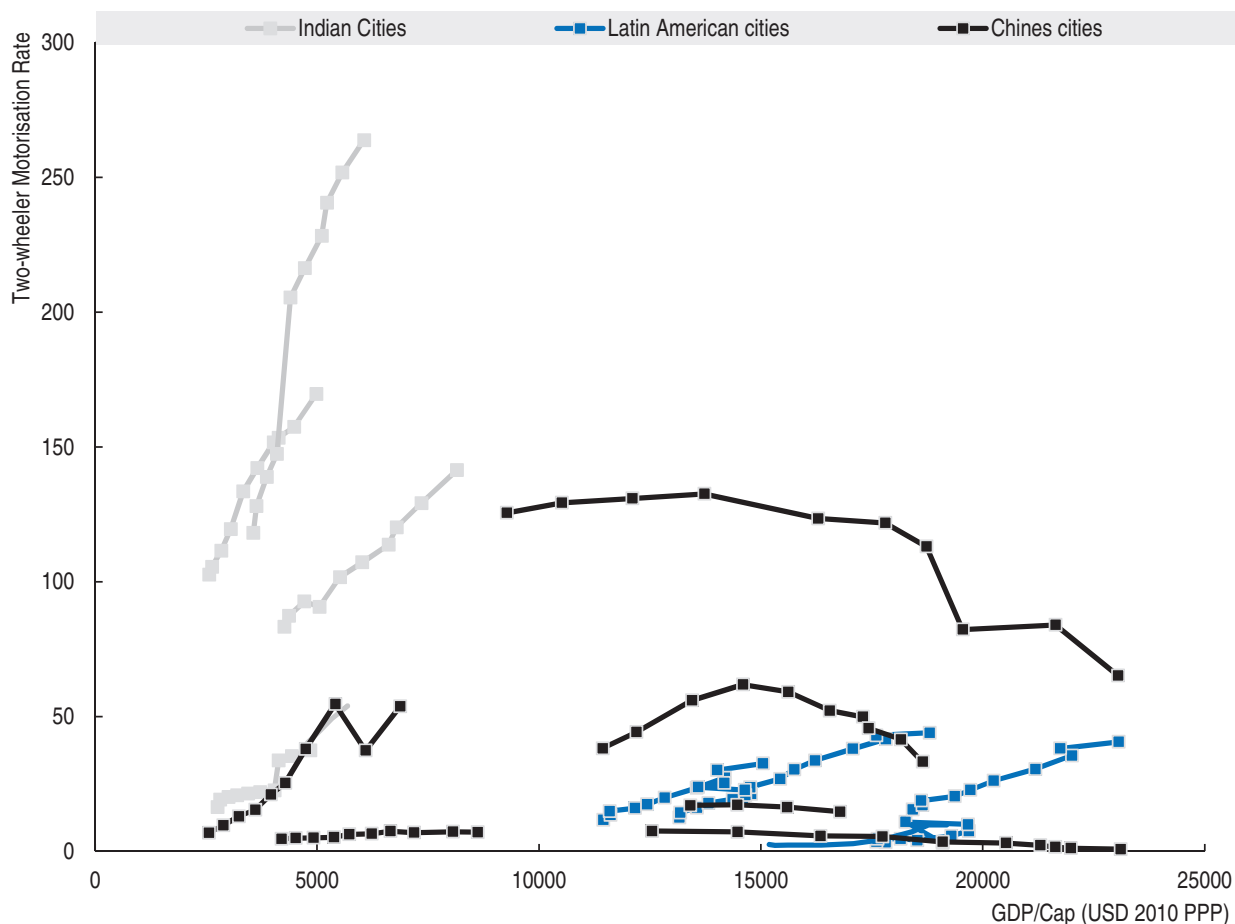
Urban transport case studies for Latin America, China and India were developed using the ITF urban transport model (Box 4.1). All scenarios are modelled under the same assumptions for urban population and economic growth. The model simulates transport volumes and modal shares for the 2010-50 period for all urban agglomerations above 500 000 population under different policy scenarios. We calculate CO₂ emissions that would result from the transport activity levels using the Mobility Model (MoMo) of the International Energy Agency (IEA). All scenarios are modelled under the *New Policy Scenario* developed by the IEA. Emissions of local air pollutants and health impacts related to urban transport activity in each scenario are calculated by the International Council for Clean Transportation (ICCT).

General modelling framework

Vehicle ownership for cars and two-wheel vehicles is modelled using an S-shaped relation between economic growth and private motorisation. Variables of the urban context, such as quantity and quality of public transport, fuel prices and road intensity are

Figure 4.5. **Two-wheeler motorisation relative to GDP per capita**

Cities in Latin America, China and India



Source: Urban Mobility Observatory (CAF) (2007); TERI (2014); McKinsey Global Institute, Cityscope 2.0 database (2010); data provided by Dr. Hua Zhang.

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Box 4.1. ITF urban transport model for Latin America, China and India

The ITF urban transport model simulates the evolution of variables of the urban context that are relevant to transport demand in urban agglomerations under different policy scenarios (land-use, public transport, road infrastructure and fuel prices). The model derives levels of transport activity and modal shares that would result from each scenario. Agglomerations included are those that have 50 000 population or above. The model adopts assumptions on load factors, fuel economy and CO₂ emission factors from the MoMo mobility model of the *International Energy Agency*. Emissions of local air pollutants and health impacts that would result from each scenario are calculated by the *International Council for Clean Transportation* (ICCT).

The ITF urban transport model framework is built on the projections of urban agglomeration of the UN Urbanization Prospects, 2014 Revision. We extend their projections from 2035 up to 2050 using the United Nations methodology described in United Nations (2011), comparing the results to existing literature where possible.

Urban GDP per capita scenarios are calculated from national GDP projections provided by the ENV-Growth model of the OECD Environmental Directorate, using the estimated relation between the concentration of population and the concentration of GDP shown by urban agglomerations in each country.

Box 4.1. ITF urban transport model for Latin America, China and India (cont.)

Data for this analysis is taken from the MGI cityscope, provided by the McKinsey Global Institute. This database contains 2010 population and GDP observations for 51 agglomerations in the Latin American region, 203 for China and 234 for India. The database then provides a 2025 forecast for these same cities. Using these data for projections up to 2050 implies the assumption that countries maintain the same relation between population and GDP concentration for the 2025 -50 period as between 2010 and 2025. The relation between urban concentration of population and GDP is modelled with an S-shaped curve. This reflects that when urban agglomerations are relatively small the elasticity between wealth and population concentration is lower, then rises as agglomerations grow, and when agglomerations get very big the marginal benefit of increasing the concentration of population begins to decrease.

The model is composed of individual regional modules. This allows flexibility to use the available urban transport data of each region and set relations between variables according to the specific trends found in each of them. Three modules have been constructed to date: Latin America, China, and India.

For Latin America, relations between urban variables and transport activity were estimated using data from the Urban Mobility Observatory created by the Development Bank for Latin America-CAF. This database contains information for fifteen Latin American cities for 2007: Buenos Aires, Bogotá, Caracas, Mexico City, Guadalajara, León, Lima, Sao Paulo, Rio de Janeiro, Curitiba, Porto Alegre, Belo Horizonte, Montevideo, Santiago, San José. Data from this source was complemented with time series on private motorisation available from Government sources.

In the case of China, province level car motorisation and GDP per capita time series were collected from the China Statistical Yearbook (see general modelling framework for details on methodology to use province level calibrated model for urban projections). Two-wheeler motorisation, urban buses and urban road area time series were taken from a database provided by Dr. Hua Zhang, from the Maglev Transportation Engineering R&D Center at the Tongji University. This database contains data for Beijing, Shanghai, Tianjin, Guangzhou, Shenzhen, Nanjing, Suzhou, Wuxi, Wuhan, Hangzhou, X'ian, Ha'er'bin and Chongqing for the last 15-20 years.

These data was complemented with urban buses and road area for the years 2003, 2007, and 2011, for 173 cities of above 500 000 population. This last database was provided by Dr. Hao Han from the Tsinghua University. Data on urban buses, road provision, and income per capita was also complemented for the year 2010 by databases provided by Dr. Cherry and Dr. Ziwen Ling from the University of Tennessee-Knoxville, and Dr. Jeiping Li from the Boston Region Metropolitan Planning Organisation. Mass transit data was taken from the China Statistical Yearbook and the ITDP mass transit database.

As for India, data on 35 major cities on private cars, two-wheelers, three-wheelers and public transport fleets were provided by the Energy and Resources Institute (TERI) for the years 2001 and 2011. Data for vehicle ownerships at state level were retrieved from Indiatat. The ITDP metro database was used for mass transit systems (metro and BRT). Complementary data was provided by Dr Geetam Tiwary from the Indian Institute of Technology, New Delhi.

also introduced as explanatory variables. This implies that economic growth is an important driver of private motorisation, but that the evolution of the urban context has an impact on how intensive the relation between income and private motorisation is.

In the case of Latin America, S-curves for both cars and two-wheelers are modelled based on the econometric analysis of data from the Urban Mobility Observatory and car and two-wheelers time series available from local and national Government sources. We control for differences found in cities regarding the effect of public transport on vehicle ownership by calculating three different coefficients (cities above 10 million population, cities from 5-10 million population, and cities below 5 million population).

In the case of China, we found limited data for constructing time series for private-ownership that could give us a representative sample of cities of different sizes and various regions. For this reason, in the case of car-ownership we constructed province level income-car motorisation curves. In the case of the urban context variables we used bus and road information obtained for individual cities (see data description in Box 4.1). In the case of mass transit we used data available in the ITDP mass transit database.

Total urban variables (public transport and road area) for cities above 500 000 population in each province were divided by the total urban population in these cities. In this way, we constructed urban variables for the average agglomeration of 500 000 population and above for each province. We weighted this indicator by the percentage population in urban agglomerations relative to total population in the province. This allowed us to come up with coefficients that reflect how available public transport and road infrastructure service in cities impact the province level intensity of car ownership relative income. We account for both the effect of average public transport and road provision in urban centers and the weight of urban access due to urban population shares in the province. The specification can then be used at the urban level with urban context variables being simply multiplied by 1 (since all population is urban).

In the case of two-wheeler ownership, province level data series were not available. Therefore we worked with a set of thirteen cities for which this information is available. The model is calibrated using data from before cities introduced a restriction on two-wheelers (whether on ownership or use). Data used corresponds only to gasoline two-wheelers but since data corresponds to a period when most two-wheelers were gasoline based we assumed that the trend calculates two-wheeler levels regardless of the penetration of electric two-wheelers (see Box 4.2). We assume the two-wheeler technology shares depicted in the International Energy Agency (IEA) MoMo New Policy Scenario.

In the case of India, we encountered similar data constraints as with China to arrive at a reasonable sample with detailed time series ownership information for diverse size cities and for different regions. For this reason, we constructed state level income-motorisation curves and applied a methodology with the same logics as for China's province level car ownership curves (see above). Because we did not count detailed bus and urban road infrastructure by city (as in China) we used state level data of state carriages as a proxy for total urban buses. Urban road infrastructure was extracted from cities in each state from open data sources. Mass transit network length was taken from the ITDP mass transit database.

Since in the case of India state level motorisation time series are available for both car and two-wheeler motorisation, we used the same methodology for both. In the case of India, three-wheelers are included in the model. The number of three-wheelers is also computed using an S-shape curve; it then serves as an input for the model concerning two-wheelers.

Implications of results for mobility

The results of our modelling exercise suggest that in the case of Latin American cities fuel prices will have an effect on the income threshold at which vehicle ownership starts to accelerate: higher fuel prices will result in ownership accelerating only at higher levels of income. This applies to both cars and two-wheelers. In the case of public transport service, higher levels and better quality (higher % of mass transit service) tend to slow-

Box 4.2. The development of two-wheelers in China

Electric two-wheelers (E-2Ws) emerged at the end of the 1990's in China. The expansion of the fleet rocketed in only a few years, from 40 000 to 10 million units produced per year between 1999 and 2005 (Jamerson and Benjamin, 2005). The denomination "E-2Ws" includes both E-bikes and E-scooters, subcategories for which reliable data is not available to the best of our knowledge. Current E-2Ws ownership is estimated to be one for every ten people (Fu, 2013).

The rise of E-2Ws results inform the convergence of several factors: the steady increase in GDP per capita, the massive urbanisation process coupled to a large urban sprawl and the lack of public transport provision, which dramatically increased the number of conventionally fuelled cars and motorcycles on Chinese roads. This generated massive congestions and air pollution in urban areas. To counter these disastrous effects, numerous cities restricted registration of conventionally fuelled cars and motorcycles, registrations even banning them in some city centres. This context, coupled to technological break thru in the electric battery industry, led to the extremely fast emergence of E-2Ws as a private mobility alternative.

Several factors are restraining a further expansion of E-2Ws, however: heterogeneous quality of the products and reckless driving that has resulted to in numerous road accidents; congestion caused by the slower speed of E-2Ws compared to cars; lack of charging facilities; improvement in the provision of mass transit systems; negative environmental impacts (lead pollution) due to from worn-out batteries. To offset the negative externalities of E-2Ws, several Chinese cities included them in the ban of conventional gasoline two-wheelers. Indeed, as of 2007, at least 8 large cities were already in such the process of banning or partially restricting E2Ws (Weinert and al. 2008), and it seems that this trend is on-going.

The issue balance of pros and cons of E-2Ws is not clear cut yet. Since E-2Ws are an alternative to cars (Chinadialogue 2013), they provide a way to limit car motorisation and consequently traffic congestion and air pollution. Restricting E-2Ws might then be counterproductive, at least in the short to medium term: although China is investing in improving mass transit systems in its cities, effects will not be immediate and if the ban on E-2Ws is largely extended widely, it could lead to an even larger increase in the number of cars on Chinese roads.

Although the phenomenon of the development of the E-2W fleet is important to the evolution of mobility and emissions, it was not possible to take it into account in the scenarios. Indeed, the denomination "E-2Ws" includes both E-bikes and E-scooters, subcategories for which reliable data is not available to the best of our knowledge.

For further reading, see Weinert et al. (2008), Jamerson and Benjamin (2004), Fu (2013), Chinadialogue (2013).

down motorisation growth (the relevant coefficient is that affecting approach to saturation). Higher road intensity has the effect of increasing car saturation levels but decreasing saturation level for two-wheeler vehicles.

As China is only at the beginning of the S-curve for car ownership and therefore not close to the saturation level, the road variable gives more consistent results when introduced in the approach to saturation rather than the saturation level itself. Public transport provision is also introduced in the approach to saturation (just as in the case of Latin America). The results of our modelling exercise suggest that in the case of Chinese cities, higher levels of public transport service tend to slow down the car motorisation growth rate, while higher road intensity significantly increases it. The public transport indicator is here defined as mass transit length of network per capita since buses are not found to have a significant impact on car ownership. Cities in provinces that are in the Northwest and Southwest regions showed to have higher intensity between income and car ownership *per se*. We control for this effect by allowing a different coefficient for income, depending on the geographical location of the city.

Regarding two-wheeler ownership road infrastructure did show a direct impact on the saturation level for these vehicles. As in the case of Latin America, higher road intensity decreases saturation level for two-wheeler vehicles. In the case of public transport provision, both buses and mass transit per capita slow-down the speed at which the saturation level is approached.

The underlying analysis for our model suggests that public transport quality and quantity modify ownership levels for all types of vehicles in Indian cities. High bus and mass transit provision slow down the growth of cars, motorcycles and three-wheelers per capita, but the effect of mass transit is preponderant in the case of cars: buses do not appear to act as an effective replacement of cars.

Our model also confirms that three-wheelers may serve as a replacement for more official forms of public transport. The level of public transport provision has a negative impact on three-wheeler motorisation. In turn, high three-wheeler penetration rates are associated with lower two-wheeler ownership levels but do not affect four wheelers.

A main difference with the models described for Latin America and China lies in the role played by road provision. Higher road provision accelerates the growth of ownership; this effect is most preponderant for cars than for two and three-wheelers but, contrary to Latin America and China, road provision also accelerates growth of motorcycle ownership. A possible explanation is that due to the lower incomes relative to those in Latin America and China two-wheelers are overall a cheap alternative and much less of a replacement for cars in congested environments in India. Road provision is generally much lower in India than in China or Latin America. This may explain why any improvement in roads is beneficial for two-wheelers as well as four-wheelers.

Urban population and economic growth 2010-50

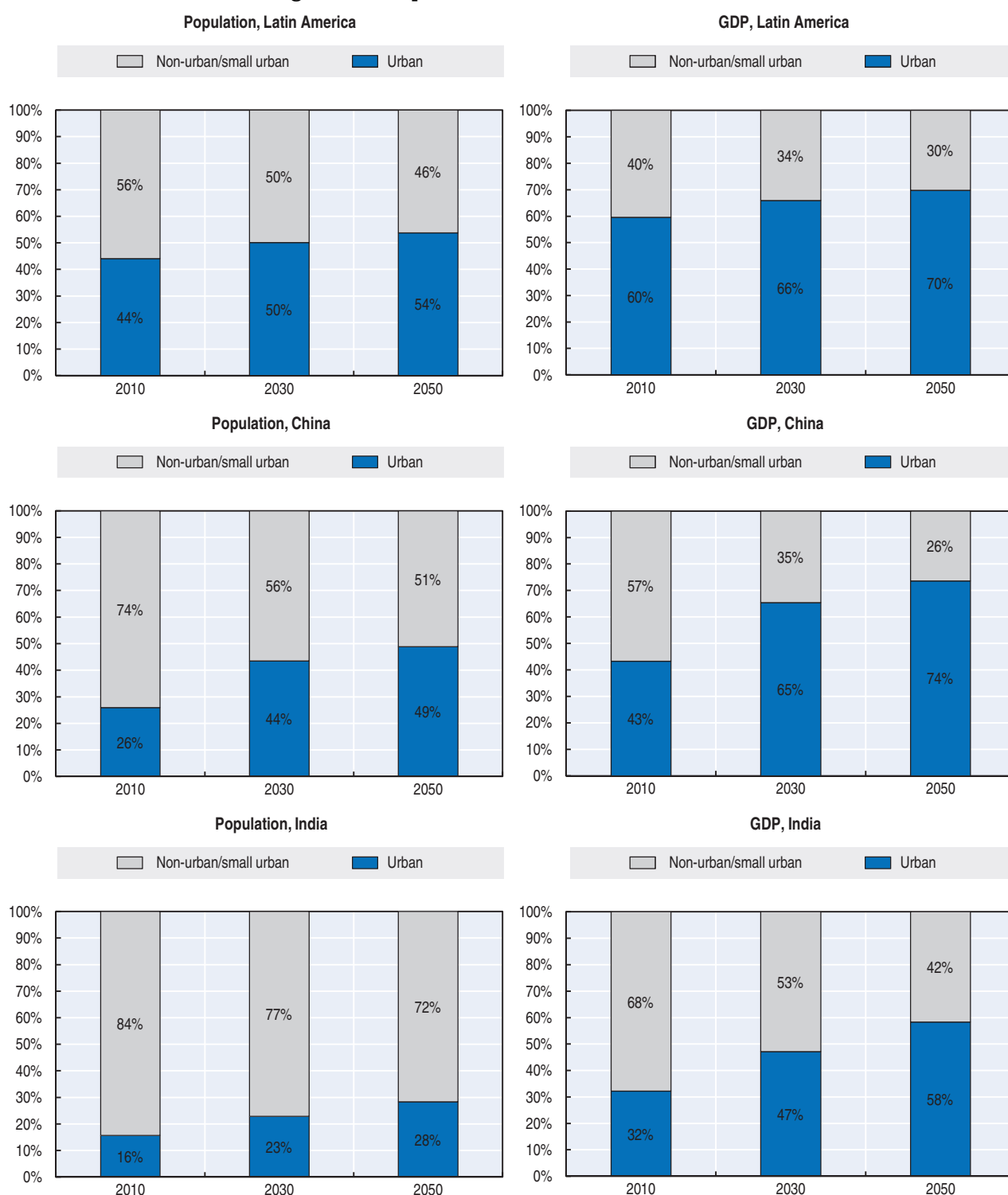
Between 2010 and 2050, the urban population in agglomerations with 500 000 population or more is expected to grow at an average yearly rate of 1.15% in Latin America, 1.64% in China and 2.41% in India. Latin America is already a highly urbanised region with around 45% of its population living today in agglomerations of more than 500 000 population. Contrastingly, China and India had in 2010 only 26% and 16% of their respective population living in such agglomerations. By 2050, urban population in centers of above 500 000 inhabitants will account for 54% of the total population in Latin America. In China and India, the proportion will remain lower than in Latin America. Nonetheless, the proportion will have doubled for both these countries, reaching 49% in China and 28% in India.

Among the three, India will be the most dynamic in terms of total output growth. Per capita average growth rates will be very similar for China and India and significantly lower for the Latin American region. Table 4.1 shows average annual growth rates for GDP, GDP per capita and total population for the 2010-50 period.

Table 4.1. Annual national average growth rate of GDP and GDP per capita (real USD PPP) for Latin America, China and India

	Latin America (%)	China (%)	India (%)
GDP	3.25	4.68	5.54
GDP per capita	2.61	4.53	4.73
Total Population	0.62	0.05	0.74

Source: ITF calculations based on ENV-Growth GDP projections and UN World Population Prospects (2014 Revision).

Figure 4.6. **Population and GDP concentrations**

Source: ITF calculations based on UN World Population Prospects (2014) and the Cityscope database from the McKinsey Global Institute

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The increasing shares of urban population will also be reflected in important increases in the concentration of economic wealth in urban areas above a population of 500 000. In Latin America these cities accounted already for 60% of the region's GDP in 2010. By 2050 they will represent more than 70% of total output. In the case of China, urban agglomerations over 500 000 inhabitants will make up more than 50% of GDP in the short-run (2015) and 74% by 2050. In India, the 50% threshold for GDP concentration in this size urban agglomeration will take a longer time to be reached: in 2040 urban areas will generate 51% of GDP.

Urban policy scenarios

Scenarios for Latin America, China and India were constructed with the aim of testing the long-run impact that diverse urban transport policy packages could have if adopted as a general strategy for the region. We identify four types of variables of the urban context that are relevant to transport demand: land use, public transport, road infrastructure, and fuel prices.

Baseline scenarios for all variables are built by assuming that what we identified as business as usual trends in each of the contexts will continue into the future. Two divergent policy pathways were modelled:

1) A *private transport-oriented* urbanisation scenario is constructed by applying policy trends that intensify the shift to private mode use. These are *high sprawl*, *low expansion of public transport*, and *low fuel prices*. This scenario was combined with a scenario of rapid expansion of road infrastructure (*high roads*).

2) A *public transport-oriented* urbanisation scenario was built by assuming alignment of policy trends that increase the role of public transport in urban mobility. This scenario is the combination of *low sprawl*, *high public transport expansion*, and *high fuel prices*. This policy pathway is modelled with a scenario where urban road infrastructure lags behind urban population growth (*low roads*).

The difference in the evolution of each variable between the different scenarios is limited to stay within the bounds of what has been identified as high and low bound in each region. Summary tables with the growth of each variable in each scenario are provided below for each region. In the case of China, assumptions about the future of car ownership restrictions were also incorporated into the baseline and the two alternative scenarios.

Besides the two main diverging policy pathways described, additional scenarios for each region were also constructed to analyse particular aspects of urban transport evolution in each of the contexts: the recent growth in use of two-wheeler vehicles in Latin America, the possible ban of auto-rickshaws in India, and the impact of private-oriented or public transport-oriented urbanisation under the same assumption for future car ownership restrictions in urban China.

Latin American cities

Urban policy scenarios for the Latin American region presented in this section were modelled for the first time for the *ITF Transport Outlook 2013*. Inputs for GDP and urban population have been updated for this publication with the latest ENV-model economic projections of the OECD Environmental Directorate and the 2014 revision of the *Urbanization Prospects of the United Nations*. Differences between the evolution of

variables described in Table 4.2 and those presented in the *ITF Transport Outlook 2013* are explained by changes in urban population and distribution of population among different size cities.

Land-use scenarios. Land-use scenarios adopt alternative paths for the evolution of urban density. Pathways describing the relation between urban population growth and urban surface expansion were constructed by country. Argentine urban agglomerations were found to have on average the greatest surface expansion relative to population growth. Contrastingly, Colombian cities were found to have patterns with the least sprawl.

In the *Baseline* scenario all urban agglomerations in the region expand in urban surface area, relative to population growth, following their own pathway. The average density of all urban agglomerations is maintained at values similar to 2010 through 2050.

In the *High sprawl* scenario urban agglomerations in the region expand in surface area following the Argentine trend. By 2050 the cities have on average a density that is 30% lower than in 2010.

In the *Low sprawl* scenario urban agglomerations in the region expand in surface area following the Colombian trend. By 2050 the cities have on average a density that is 20% higher than in 2010.

Data analysis for Latin America shows evidence that urban density is positively related to public transport service per capita and negatively related to road infrastructure provision per capita. For this reason, public transport and road infrastructure scenarios are influenced by sprawl scenarios. Urban density is also assumed to be positively related to ridership of public transport. The elasticity used is derived from the Singapore Land Transport Authority (LTA) Academy. This work finds a positive elasticity that increases as density rises.

Public transport scenarios. Public transport variables used in the Latin American module are total vehicle-kilometres per capita of public transport service and the share of public transport service provided by mass transit modes. In mass transit modes we include urban rail (heavy, light and underground) and BRT in confined lane segments.

In the *Baseline* scenario expansion of public transport service per capita corresponds to the baseline urban density evolution. From 2010 to 2050 total vehicle kilometres of public transport service grow 1.7 times. This results in a per capita service that is only slightly above 2010 levels. Under this scenario, public transport services offered through mass transit modes increase from 4.2% in 2010 to 10% in 2050. Overall capacity of public transport (seat kilometres per capita) double by 2050.

In the *High public transport* scenario cities follow the *Low sprawl* scenario but also intensify policies of urban transport service expansion. Total vehicle-kilometres of public transport service increase 2.5 times, while per capita service grows 55%. Mass transit participation also grows more rapidly and accounts for 15% of total public transport service. Capacity of public transport service per capita is three times the 2010 levels.

In the *Low public transport* scenario expansion of public transport, service per capita reflects the *High sprawl* trend assumed. Total vehicle kilometres of service only grow 9% between 2010 and 2050. As a consequence, public transport service per capita decreases by 30%. The growth in the share of mass transit service is maintained similar to the baseline scenario (10% by 2050). Total public transport capacity per capita grows by only 43% by 2050.

Road infrastructure scenarios. The variable used for road infrastructure for this module is length of urban road kilometres per capita.

In the *Baseline* scenario per capita roads grow according to the *Baseline* land use scenario. The result is an expansion of total kilometres of 55%. In per capita terms, road provision is maintained similar to 2010 levels.

In the *High road* scenario cities follow the *High sprawl* scenario which increases expansion of road infrastructure. Cities also intensify their policy towards urban road expansion. Total urban roads in the region expand 2.4 times relative to 2010. Per capita road length grows 50%.

In the *Low road* scenario expansion of roads per capita responds to the *Low sprawl* trend assumed. Total urban road length increases only 36%, making roads per capita decrease by 16%.

Table 4.2. **Latin American urban context under different scenarios**

			2010	2030	2050
Population			100	134	164
GDP			100	203	361
GDP/Capita			100	169	278
Land use	Urban Density of Average urban agglomeration	Baseline	100	102	103
		High sprawl	100	79	72
		Low sprawl	100	114	120
Public transport service	Total vkms of public transport	Baseline	100	141	168
		High public transport	100	158	251
		Low public transport	100	100	109
	Per capita vkms of public transport	Baseline	100	103	104
		High public transport	100	114	155
		Low public transport	100	73	68
	Share of rapid vkms (quality)	Baseline	4.2%	4.9%	10.0%
		High quality expansion	4.2%	6.2%	15.0%
	Public transport capacity seat.km/capita	Baseline	100	142	205
High public transport		100	168	331	
Low public transport		100	106	143	
Road infrastructure	Total kms of road	Baseline	100	134	155
		High roads	100	153	235
		Low roads	100	122	136
	Per capita kms of road	Baseline	100	98	96
		High roads	100	110	146
		Low roads	100	89	84
Oil prices	Baseline	100	150	160	
	High oil prices	100	253	264	
	Low oil prices	100	65	64	

Chinese cities

In the case of Latin America we construct our scenarios based on divergent trends found in the different countries. Since China is such a large country, we conduct the same type of exercise accounting for geographical trends found within the country. We divide China into seven regions: Center, East, North, Northeast, Northwest, South and Southwest (Table 4.3 shows provinces included in each region).

Table 4.3. **Provinces included in each region for Chinese model**

Region	Province
Center	Henan, Hubei, Hunan
East	Shanghai, Fujian, Jiangsu, Jiangxi, Shandong, Zhejiang, Anhui
North	Beijing, Hebei, Inner Mongolia, Shanxi, Tianjin
Northeast	Heilongjiang, Jilin, Liaoning
Northwest	Gansu, Ningxia, Qinghai, Shaanxi, Xinjiang
South	Guangdong, Guangxi, Hainan
Southwest	Chongqing, Guizhou, Sichuan, Yunnan

Note: Only provinces with agglomerations above 500 000 population are included.

Land-use scenarios. Just as in the case of Latin America, land-use scenarios refer to different evolution of urban density. In the case of China, pathways describing the relation between urban population growth and urban surface expansion were constructed by region of the country. Urban agglomerations in the Northeast region were found to have on average the most intensive surface expansion relative to population growth. Cities in the Northwest region were found to have the less intensive pathway.

In the *Baseline scenario* all urban agglomerations in China expand in urban surface, relative to population growth, following the average pathway of the region that they belong to. By 2050 the average density of all urban agglomerations is 10% higher than in 2010.

In the *High sprawl scenario* urban agglomerations expand in surface following the Northeastern trend. By the end of the 40 year period cities have on average a density that is similar to the 2010 level.

In the *Low sprawl scenario* Chinese cities expand in surface following the Northwestern trend. By 2050 the cities have on average a density that is 20% higher than in 2010.

In contrast to the case of the Latin American region, we did not find evidence of a significant relation between density and public transport or road provision in the Chinese context. For this reason, in the case of China land-use scenarios have no influence on public transport or road infrastructure scenarios.

Density however has the same positive effect on ridership of public transport as in the Latin American module.

Public transport scenarios. Public transport variables in the Chinese module are buses and network length of mass transit per 1000 population (urban rail and bus-rapid transit). Increase in buses per capita is modelled based on the calculation of average growth rate of total buses relative to population growth in the different regions. A significant difference in the relation between bus and population growth was found where cities have population of less than 5 million, and where they pass such thresholds. Therefore for every region, two different coefficients are calculated, depending on the size of cities. In the case of cities below 5 million inhabitants those in the Eastern region were found to have the highest average growth in buses relative to population growth, while cities in the Southern region show the lowest. In the case of cities above 5 million inhabitants those in the Central region were found to have the most intensive growth in buses relative to population and cities in the Northeast the lowest.

Mass transit network length also grows relative to population growth. Coefficients are not region specific because no significant differences could be found in the available

Chinese data. Three coefficients were computed to reflect *Baseline*, *High* and *Low* expansion of the mass transit network. In the *Baseline* scenario, the average growth of mass transit length relative to population was used. In the *High Public Transport Scenario*, the growth of mass transit relative to population was computed using only the 25% of cities with the highest per capita levels of mass transit. In the *Low Public Transport* scenario, only the 25% of cities with the lowest per capita levels are used. Finally, in all scenarios, we only assumed that there is mass transit when the predicted length is at least 15 kilometres. The figures were then benchmarked against mass transit planned openings by 2025 (reported in the ITDP mass transit database), which constitute a reference value for mass transit length in the *High Public Transport* scenario for this horizon.

The length of the mass transit network is divided between BRT and urban rail based on the positive correlations found between the proportion of urban rail in mass transit and GDP per capita, population density, and urban area size: large, rich and dense cities are more likely to develop an urban rail network than small, low-income and sparsely populated urban areas. These last favour BRTs when they build a mass transit network. Finally, the data for Chinese cities also shows that the number of buses per 1 000 inhabitants decreases with the length of the mass transit network in a city. Buses per capita figures are corrected in each scenario to account for this effect, thereby producing public transport provision measures that reflect the quality, as well as the quantity, of public transport provision.

In the *Baseline* scenario, buses in cities grow relative to population following the average growth rate found for the region they belong to. After converting buses into bus kilometres travelled the *Baseline* scenario is one where total bus-kilometres grow 56% from 2010-50. In per capita terms, bus kilometre expansion lags behind population growth and is 5% lower than in 2010. At the same time, total mass transit length increases by 120%, while in per capita terms the increase is much less pronounced (+40%). Overall per capita capacity of public transport (seat-kilometres per capita) is 5% above 2010 levels.

In the *High public transport* scenario, urban buses in Chinese cities grow relative to population following the trend found for the Eastern region, if they are below 5 million population, and the trend found for cities in the Center when they reach 5 million inhabitants. Total vehicle-kilometres of bus service increases by 29%, while per capita service decreases by 20%. However, mass transit participation grows in almost 40% (this high increase explains the lower increase in regular bus service expansion). Mass transit grows 5 fold and is three times the per capita 2010 levels. Overall, total per capita capacity grows 32% by 2050.

In the *Low public transport* scenario, urban buses in Chinese cities grow relative to population following the trend found for the Southern region, if they are below 5 million population, and the trend found for cities in the Northeastern region when they reach 5 million inhabitants. Total vehicle kilometres of bus service grow by 17% between 2010 and 2050. As a consequence, bus service per capita decreases even more, by 28%. Mass transit service grows by 81% in total terms and by 17% in per capita terms. The share of mass transit is slightly lower than in the baseline scenario (21% versus 25% by 2050). Total capacity of public transport service (per capita) is 20% smaller than in 2010.

Road infrastructure scenarios. The variable used for road infrastructure is urban road area per capita. As in the case of buses, we calculate the increase in urban road area relative to population growth based on our data. We calculate a coefficient by region in

China. Agglomerations in the Central region were found to have the highest average growth in urban road area relative to population, while those in the Southern region were found to have the lowest.

In a *Baseline* scenario, urban road area in cities grows relative to population following the average ratio found for the region that each city belongs to. Total urban area grows three times between 2010 and 2050. This is equivalent to an average growth of 58% in the urban area per inhabitant in China.

In the *High roads* scenario, urban road area in cities grows relative to population following the average relation found for cities in the Central region. In 2050, total urban road area is 3.6 times the 2010 level. The average growth in urban area per capita is equal to 91%.

In the *Low roads* scenario, urban road area in cities grows relative to population following the average relation found for cities in the Southern region. In this scenario total urban road area is 26% larger than in 2010. This translates into 40% less average urban area per capita in urban agglomerations.

Car restriction. In addition to differences in the evolution of variables shown in Table 4.5, the three Chinese scenarios incorporate assumptions regarding car ownership restrictions and their evolution. The definition of future restrictions is based on the analysis of seven Chinese cities that had implemented such restrictions by 2010: Beijing, Guangzhou, Guiyang, Hangzhou, Shanghai, Shijiazhuang and Tianjin.

Baseline scenario. Future evolution of car ownership restrictions in this scenario is based on two assumptions. First, the seven cities already restricting car ownership are assumed to maintain their policy in place during the next 40 years. We assume a constant number of licences issued yearly, defined according to official announcements for each city.

Second, a city will impose a restriction if it reaches 2.5 million population coupled with a ratio of cars over road area that the seven cities with car ownership restrictions had in 2010. In that case, the number of licences issued each year is defined applying a constant coefficient relative to the car-road area ratio, extracted from the econometric analysis of permits and congestion on the sample of seven cities. Differently from the case assumed for the *public transport-oriented* scenario with low road infrastructure expansion (see below), licence quotas in this scenario are not adjusted by changes in the population.

Public transport-oriented scenario with low road infrastructure expansion.

In this scenario we assume a stronger willingness to reduce car ownership. Here again, the seven cities with existing restrictions will extend their policy to the end of the period. Additional restrictions will be imposed in cities reaching the same population and road congestion thresholds as above. However, the number of licences issued now also depend on the evolution of population to counter-act the demographic plateauing effect of Chinese cities. In this way, car ownership slow down is maintained despite the marginal growth in population towards the end of the period.

Private transport-oriented scenario with high road infrastructure expansion.

This scenario assumes that there is no expansion of the car restriction policies to other cities in China. Therefore only cities that already had a car ownership restriction by 2010 will continue to do so until the end of the period.

Table 4.4 summarises the number of new cities imposing a restriction in each period. The *Baseline* and the *public transport-oriented* scenarios differ mainly in the timing of the imposed restriction. The two scenarios show the same number of cities imposing a restriction by the end of the period. This shows that despite higher levels of road infrastructure expansion, the *Baseline* scenario results in similar levels of cars relative to road area (due to the higher growth in car motorisation).

Table 4.4. Number of car restrictions imposed in Chinese cities under different scenarios

Scenario	2010	2015	2020	2025	2030	2035	2040	2045	2050
<i>Baseline</i>	7	+0	+35	+6	+0	+4	+0	+0	+0
<i>Public transport-oriented</i>	7	+0	+33	+8	+0	+4	+0	+0	+0
<i>Private transport-oriented</i>	7	+0	+0	+0	+0	+0	+0	+0	+0

Table 4.5. Chinese urban context under different scenarios

			2010	2030	2050
Population			100	154	163
GDP			Baseline	100	592
GDP/Capita			Baseline	100	330
Land use	Urban Density of Average urban agglomeration	Baseline	100	109	110
		High sprawl	100	99	100
		Low sprawl	100	118	121
	Buses vkms	Baseline	100	148	156
		High sprawl	100	126	129
		Low sprawl	100	115	117
	Buses vkms/capita	Baseline	100	96	95
		High public transport	100	82	79
		Low public transport	100	74	72
Public transport	Mass transit vkms	Baseline	100	200	220
		High public transport	100	425	488
		Low public transport	100	168	181
	Mass transit vkms/capita	Baseline	100	134	141
		High public transport	100	284	312
		Low public transport	100	112	117
	Public transport capacity seat.km/capita	Baseline	100	104	105
		High public transport	100	128	132
		Low public transport	100	83	81
Road infrastructure	Total road area (km ²)	Baseline	100	211	304
		High roads	100	232	366
		Low roads	100	188	242
	Road area per capita	Baseline	100	117	158
		High roads	100	129	191
		Low roads	100	105	126
Oil prices		Baseline	100	150	160
		High oil prices	100	253	264
		Low oil prices	100	65	64

Indian cities

Similarly to the case of China, we divided India into four regions: North-West, North-East, Central, and South. Table 4.6 shows the States that are included in each region.

Table 4.6. **Regional division of India**

Region	States and Union territories
North-West	Chandigarh, Delhi, Gujarat, Haryana, Himachal Pradesh, Jammu Kashmir, Punjab, Rajasthan, Uttarakhand
North-East	Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura
Central	Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Orissa, Uttar Pradesh, West Bengal
South	Andaman and Nicobar Islands, Andhra Pradesh, Goa, Karnataka, Kerala, Maharashtra, Pondicherry, Tamil Nadu, Telangana

Note: Only states and union territories with agglomerations above 500 000 population are included.

Land-use scenarios. Land-use scenarios refer again to different evolutions of urban density. In the case of India, no relevant regional trends were found for the relation between population and urban surface expansion. However, significant differences were found in relation to city size. Three sets of coefficients describing growth of urban surface relative to population are computed. Each set applies to cities with population from a certain size interval: below 2 million, between 2 and 8 million, more than 8 million inhabitants.

In the *Baseline* scenario, the coefficients are computed using all cities from each city category. In this scenario the average urban density in Indian cities is 30% higher in 2050 than in 2010.

In the *High Sprawl* scenario, the coefficients are based on the 25% of cities with the highest sprawl in their category. In this scenario the average urban density is reduced by 24% between 2010 and 2050.

In the *Low Sprawl* scenario the coefficients are based on the 25% of cities with the lowest sprawl in their category. In this scenario the average urban density is doubled between 2010 and 2050.

Urban density plays a role in infrastructure development through its impact on road provision (see the road provision scenarios below for more details). Furthermore, load factors of public transport depend on urban density to reflect higher public transport use in denser urban areas. We use the same elasticity than for Latin America and China.

Public transport scenarios. The evolution of public transport is computed in a similar fashion to China. Variables used to describe public transport provision in the Indian module are buses and network length of mass transit per 1 000 population (urban rail and BRT).

The number of buses per 1 000 inhabitants is found to grow with the population, with growth rates depending on the region and also the size of the cities: in small urban areas (under one million inhabitants), growth of public buses with population is almost half of what it is for large metropolises. In addition, in many of the smallest urban centres there is no public provision of buses. This is reflected in the *Baseline* and *Low Public Transport scenarios*. The Indian region found to have the highest growth in the number of buses

relative to population was the Central region. Cities in the North-West region presented the lowest growth in buses relative to population.

Similarly to China, mass transit length grows with population and there are positive correlations between the proportion of urban rail in mass transit and GDP per capita, population density, and urban area size. In the absence of sufficient relevant data for India, the Chinese models were applied to India, controlling for the planned length of mass transit as well as the share of BRT in 2025: in the *High Public Transport* scenario, all planned mass transit projects referenced in the ITDP mass transit database are assumed to be in operation by 2025 (the same trend is continued up to 2050). Finally, buses per capita figure are adjusted to account for the presence of mass transit (including BRT).

In the *Baseline scenario*, buses in cities grow relative to population following the average growth rate found for the region they belong to. Total vehicle-kilometres of bus service double, but don't keep up with urban population growth; per capita service decreases by 17%. This is explained by two phenomena. The first one is the expansion of the mass transit network, with vehicle kilometres of mass transit being multiplied by almost 15. According to our data analysis growth in mass transit tends to slow down growth in conventional buses. The second is the low development of buses in small cities in this scenario. Still, overall capacity of public transport (seat-kilometres per capita) grows by 40% by 2050.

In the *High public transport* scenario, urban buses in Indian cities grow relative to population following the trend found for the Central region. Total vehicle-kilometres of bus service increase by 90%, while per capita service decreases by 26%. There is a strong shift to mass transit as the network length increases: it is multiplied by almost 20 between 2010 and 2050, when 35% of cities above 500 000 inhabitants have developed a BRT and/or subway network (compared to 5% in 2010). Public transport capacity per inhabitant grows 56% from 2010 to 2050.

In the *Low public transport* scenario, expansion of public buses corresponds to that observed in the Northwest region; mass transit networks only develop in the largest cities and many small cities remain without any form of formal public transport. Bus vehicle kilometres double between 2010 and 2050. Mass transit still grows 11 times, but coming from a very low base in 2010. Compared to the *Baseline* and *High Public Transport* scenarios, the number of buses per capita is higher in this scenario. However, mass transit is much less present and the overall quality and quantity of public transport provision is lower. Capacity of public transport per capita only grows in 18% by 2050.

Road infrastructure scenarios. The variable used for road infrastructure is length of road kilometres per capita. In our dataset, road provision grows with population. There are significant differences in the growth rates between regions. Urban density has a negative impact on per capita road infrastructure expansion. Therefore, for each region (except the North East which is more rural and for which no high density city exists) two coefficients linking population and road provision are computed: one for cities with less than 10 000 inhabitants per square kilometre and one for cities above this threshold. This trend creates a link between road development and urban sprawl scenarios.

The *Baseline Road Scenario* assumes road length in each city evolves according to the growth rates of the region it belongs to, with urban sprawl following the *Baseline* sprawl scenario. In this scenario, road length increases by 354% in absolute terms, and by 76% when computed per inhabitant.

In the *High Road Scenario*, urban density evolves according to the *High Sprawl* scenario and road length evolves according to the growth rate of the Central region, which witnesses the strongest relationship between population and urban area in our historical data. The resulting growth in road length is 654% and road provision per capita almost triples.

Finally, in the *Low Road Scenario*, urban density increases according to the *Low Sprawl* scenario and roads expand relative to population according to the coefficients found for the NorthWest region, which has the weakest link between population and road provision in the historical data. In this scenario, road length increases by 168%, but remains stable in per capita terms.

Table 4.7. **India urban context under different scenarios**

			2010	2030	2050
Population			100	200	258
GDP		Baseline	100	356	854
GDP/capita		Baseline	100	291	643
Land use	Urban Density of Average urban agglomeration	Baseline	100	115	130
		High sprawl	100	75	76
		Low sprawl	100	156	204
Public transport	Buses vkms	Baseline	100	214	200
		Low public transport	100	155	206
		High public transport	100	215	190
	Buses vkms/capita	Baseline	100	112	83
		Low public transport	100	87	80
		High public transport	100	121	74
	Mass transit vkms	Baseline	100	391	1 472
		Low public transport	100	313	1 103
		High public transport	100	497	1 971
	Mass transit vkms/capita	Baseline	100	219	570
		Low public transport	100	175	427
		High public transport	100	278	763
	Public transport capacity seat.km/capita	Baseline	100	128	140
		Low public transport	100	99	118
		High public transport	100	145	156
Road infrastructure	Total kms of road	Baseline	100	289	454
		High roads	100	430	754
		Low roads	100	186	268
	Per capita kms of road	Baseline	100	162	176
		High roads	100	241	292
Oil prices		Low roads	100	104	104
		Baseline	100	150	160
		High oil prices	100	253	264
		Low oil prices	100	65	64

Mobility and CO₂ emissions to 2050

Urban agglomerations of above 500 000 population in Latin America, China and India account for about 9% of total world motorised passenger surface transport CO₂ emissions in 2010. In our *baseline* scenario, this share is likely to grow to about 20% in the next 40 years. This means that 38% of the total world growth in CO₂ emissions related to passenger surface transport would stem from these cities.

As will be seen in this section, long-term implementation of alternative policy scenarios can significantly impact the modal shares and CO₂ emission growth in urban agglomerations in the three contexts.

Latin American cities

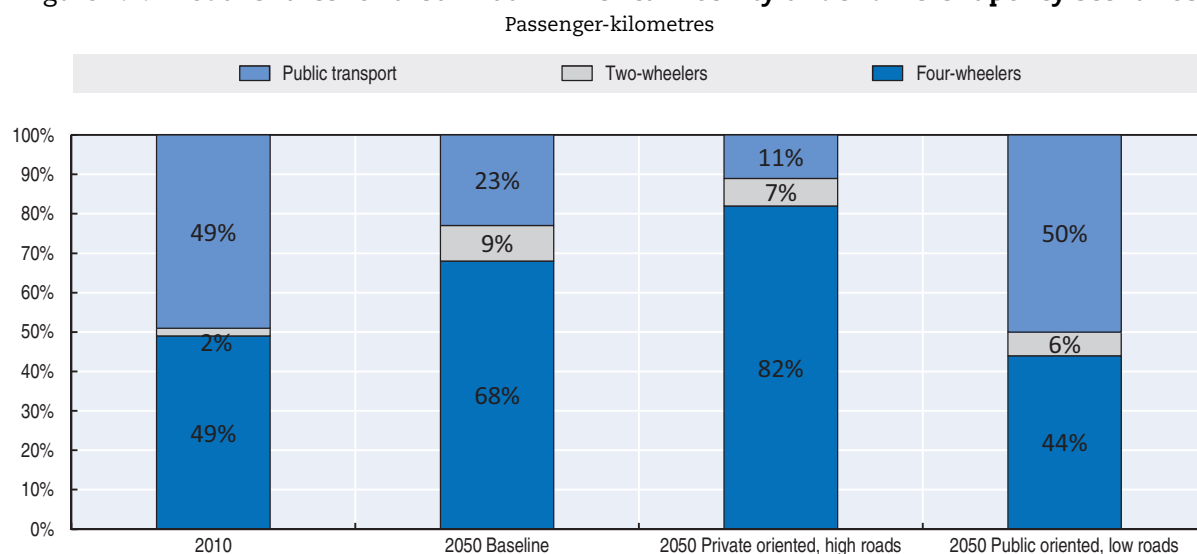
Difference between results shown in this section and the *ITF Transport Outlook 2013* for the Latin American case study are explained by updates in the population and GDP scenarios used within our model.

In the *private-oriented urbanisation* scenario with *high roads* cars and two-wheelers significantly displace public transport in urban mobility by 2050. The rapid expansion of urban road infrastructure delays the build up of congestion and thus slows down the penetration of two-wheelers in the private fleet to a certain extent. At the end of the period, car mobility occupies 82% of motorised transport. This is 30 percentage points more than in 2010 and 14 percentage points more than in the *baseline* scenario in 2050.

Despite the higher expansion in urban roads (which tends to increase attractiveness of cars), with public transport infrastructure expansion lagging behind population growth, the two-wheeler's role in mobility increases significantly in this scenario (from 2% to 7% of total passenger-kilometres). By the end of the period, the share of public transport in mobility is only 11%. This represents a decrease of 38 percentage points with respect to 2010 and 12 percentage points less than in the *baseline* scenario in 2050.

In the *public transport-oriented* scenario with *low roads*, rapid expansion of public transport service per capita and a growing share of services delivered through mass transit prevents high shifts from public to private mobility. Total private mobility is slightly reduced and 2010 public transport participation in total motorised mobility is maintained at similar levels. With urban road expansion lagging behind population growth in cities, congestion pressures increase the competitiveness of motorcycles relative to cars. Car participation in mobility is reduced from 49% to 44% between 2010 and 2050, while the two-wheelers' share in urban mobility grows from 2% to 6%.

Figure 4.7. **Modal shares for urban Latin America mobility under different policy scenarios**



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Mobility-wise the *private-oriented urbanisation* scenario with *high roads* increases total mobility levels throughout the period in comparison to the baseline scenario (+19% by 2050). Much of this is driven by having higher travel per private vehicle as a consequence of low-oil prices.

Total mobility levels resulting from the *public transport-oriented urbanisation* scenario with *low roads* show that the shift in policy strategy will have a certain cost in mobility levels, especially during the first periods. This is due to the increasing costs of driving imposed by high oil prices, while public transport provision remains relatively low and with limited service in mass transit modes. Mobility levels in this scenario catch up with the *baseline scenario* towards the end of the period, when public transport network

Figure 4.8. **Total mobility growth under different scenarios Latin America**
Passenger-kilometres (2010 = 100)

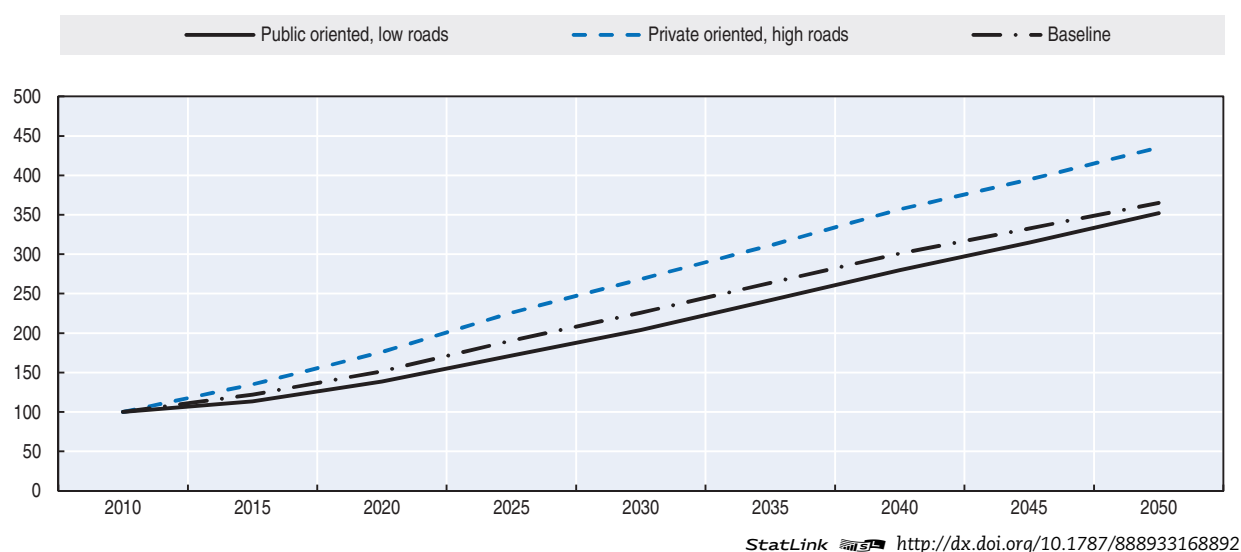
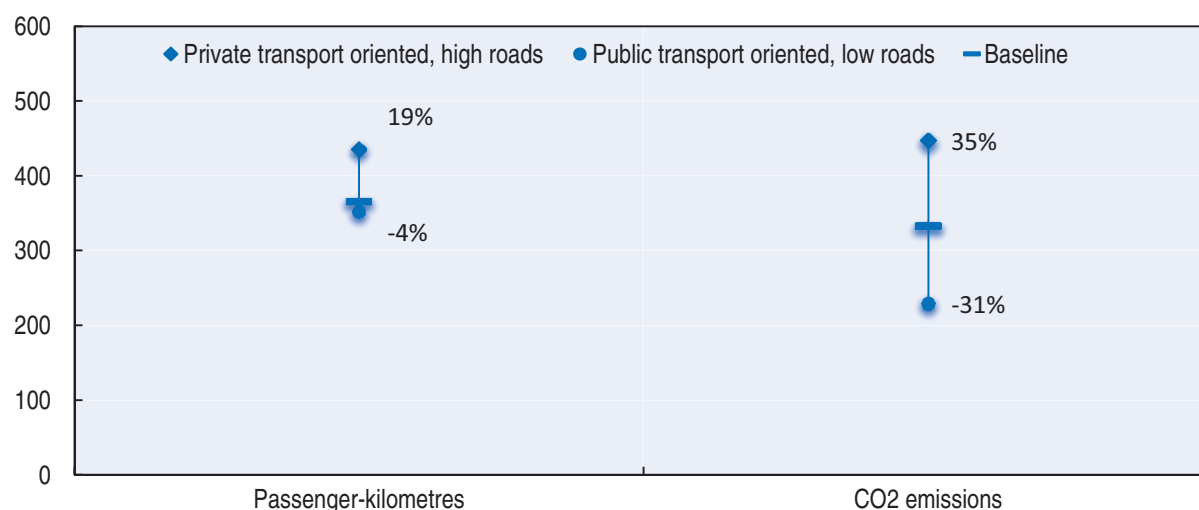


Figure 4.9. **Growth in mobility and CO₂ emissions under different scenarios in Latin American cities**
2010 = 100



expansion and improvement are able to off-set restrictions to private mobility. By 2050, this scenario is only 4% below mobility levels in the *baseline* scenario.

The increase in mobility in the *private transport-oriented urbanisation* scenario with *high roads* generates even higher additional CO₂ emissions (35% higher than in the *baseline* scenario). This implies an increase in the carbon intensity of urban transport relative to the baseline trend. On the other hand, the small reductions in mobility shown by the *public transport-oriented urbanisation* scenario result in significant reductions of CO₂ emissions (31% lower than the baseline). Therefore in this scenario, urban mobility is provided at a lower marginal cost in terms of the external cost of CO₂.

Future perspectives for two-wheelers in the Latin American region

Until recently, motorisation in the Latin American region had been almost entirely characterised by the growth in cars. Recent trends however show that two-wheelers are an important player in mobility in the region, and suggest that their role will increase in the future. Globalisation in the production of two-wheelers has allowed the introduction of low-price models in the Latin American markets. Countries like Brazil, Colombia and Argentina have also developed their own motorcycle production industry, which has further reduced costs and increased supply (Montezuma 2012). Added to the low purchasing costs, inexistent or lax regulation also account for the low relative cost of owning and using two-wheeler vehicles.

The response of demand to decreasing prices has been very high in most countries in the region, despite the fact that both average income and motorisation are already at middle level stages. A possible explanation is that high levels of congestion in many cities have increased the competitiveness of two-wheelers. Another important driver has been the conjunction of the very high income inequalities in the region and the deficient quality and insufficient supply of public transport in urban centres. Two-wheelers have therefore become first stage motorisation vehicles for the many captive users of public transport. Box 4.3 illustrates the reliance of a high proportion (especially in the poorest segments) of the population on inferior modes of public transport in the metropolitan region of Mexico City.

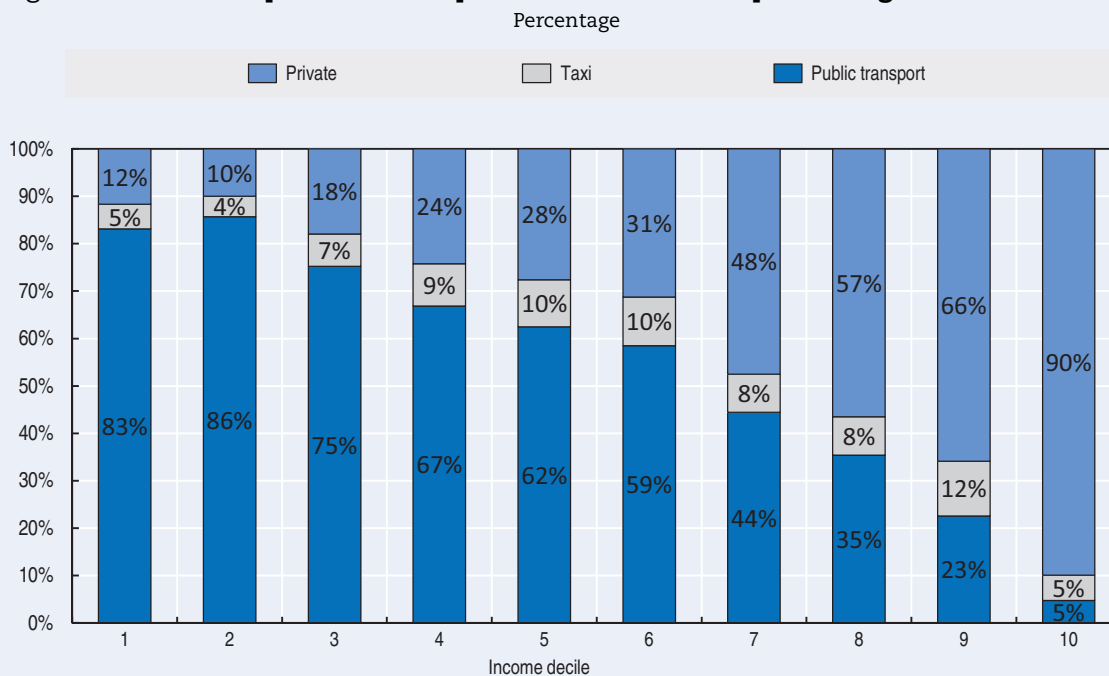
Box 4.3. Transport expenditure by income decile in the metropolitan region of Mexico City

Figure B.4.3.a below shows the percentage of transport related expenditure in public and private modes in the metropolitan region of Mexico City by income decile of the population. As can be seen, public transport expenditure (without taxis) makes up more than 1/3 of total expenditures on transport for people in deciles one through eight. In the first two deciles it accounts for 80% of total transport related expenditure.

Disaggregating this expenditure by mode of public transport (Figure B.4.3.b) it is evident that the highest share of public transport expenditure is allocated to “colectivos”, combis, and minibuses. This type of vehicle is the most available throughout the city, and the only available services in many of the suburban areas. Nonetheless, these are low capacity vehicles characterised by old fleets that are far from meeting with safety standards. Because these services are mixed with all other traffic, their travel times are also affected by the growing congestion levels in the city. It can also be seen that only higher income deciles allocate a significant share of total expenditure on public transport to mass transit. At the same time these segments of the population rely very little on public transport, contrasting with the poorest segments, which rely heavily on public transport and meet a large part of their demand for these services with poor quality modes.

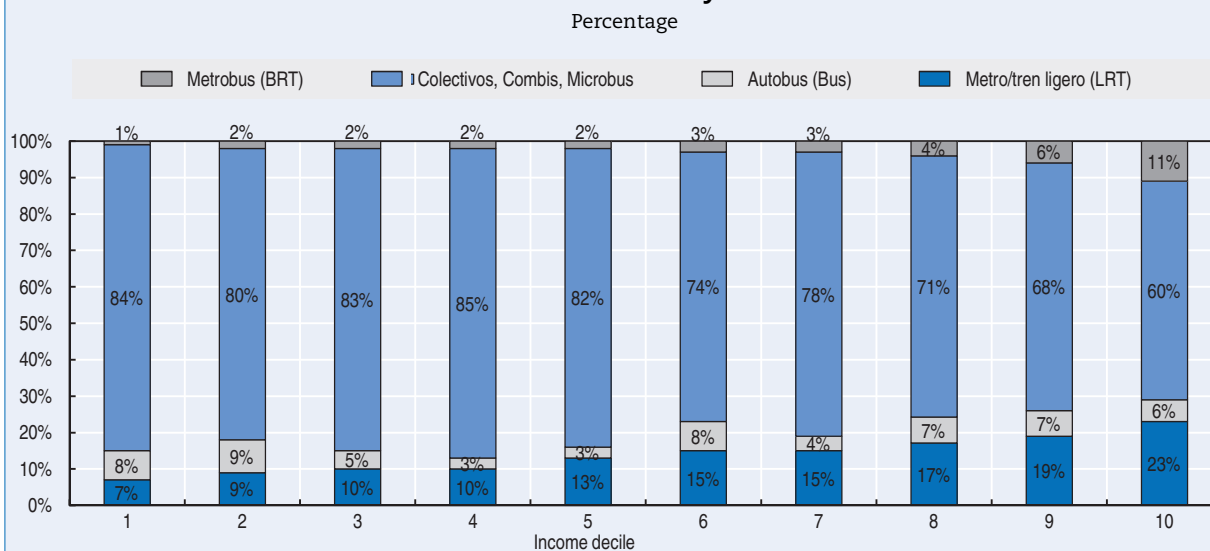
Box 4.3. Transport expenditure by income decile in the metropolitan region of Mexico City (cont.)

Figure B.4.3.a. Transport related expenditure in the metropolitan region of Mexico City



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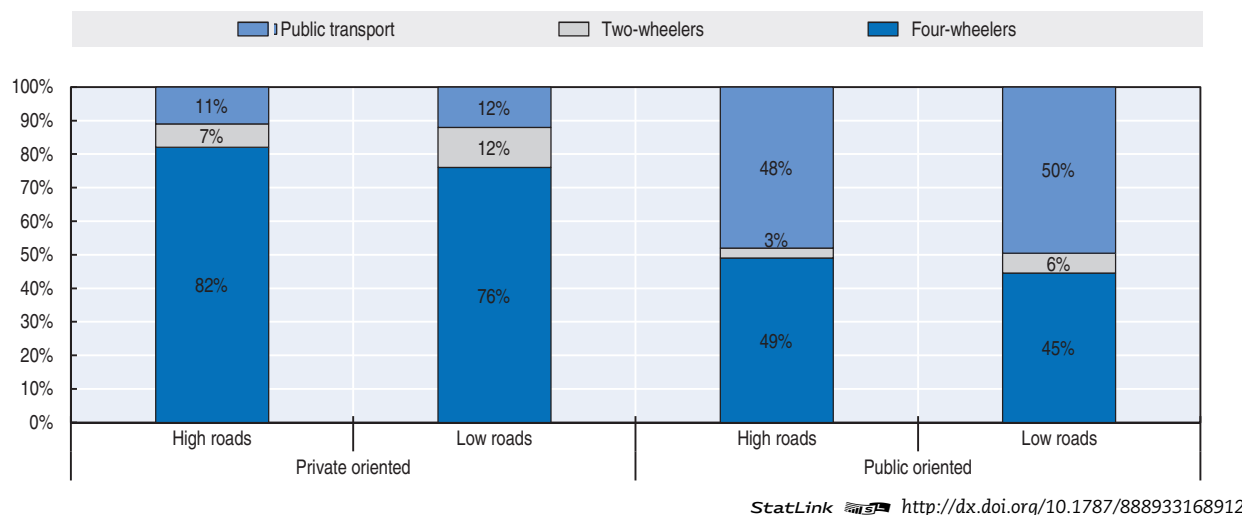
Figure B.4.3.b. Transport related expenditure by mode in the metropolitan region of Mexico City



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In order to further explore the future perspectives of two-wheelers in the region, we compare the *public transport-oriented* and *private transport-oriented* urbanisation scenarios under *high* and *low* road infrastructure perspectives. As shown by Figure 4.10, in the private transport-oriented urbanisation scenario, with low roads, a higher share of mobility

Figure 4.10. **Modal shares for urban Latin America under different policy scenarios, 2050**
 Passenger-kilometres, alternative road scenarios



transferring from public to private modes is captured by two-wheelers (relative to the same scenario with high roads expansion). Under this scenario two-wheeler participation in urban mobility is higher than in all other scenarios. In the public transport-oriented urbanisation scenario with rapid expansion of road infrastructure, two-wheelers participation in urban mobility only grows from 2% in 2010 to 3% in 2050.

In terms of private fleet growth, Figure 4.11 shows the growth (index) of car and two-wheeler fleets during the 40 year period in the baseline and the four scenarios modelled. In the baseline scenario, the car fleet in urban centres with more than 500 000 population in Latin America grows 5.1 times, while the two-wheeler fleet grows 21 times. This represents an average annual growth rate of 4% and 8% for cars and two-wheelers respectively.

Figure 4.11. **Private fleet growth by 2050 (2010 = 100) Latin America**

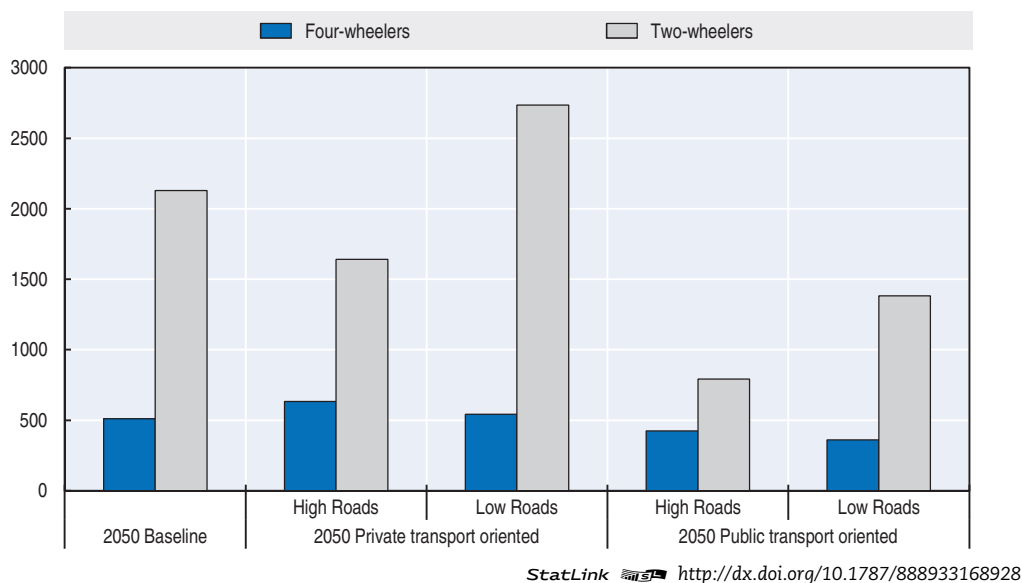
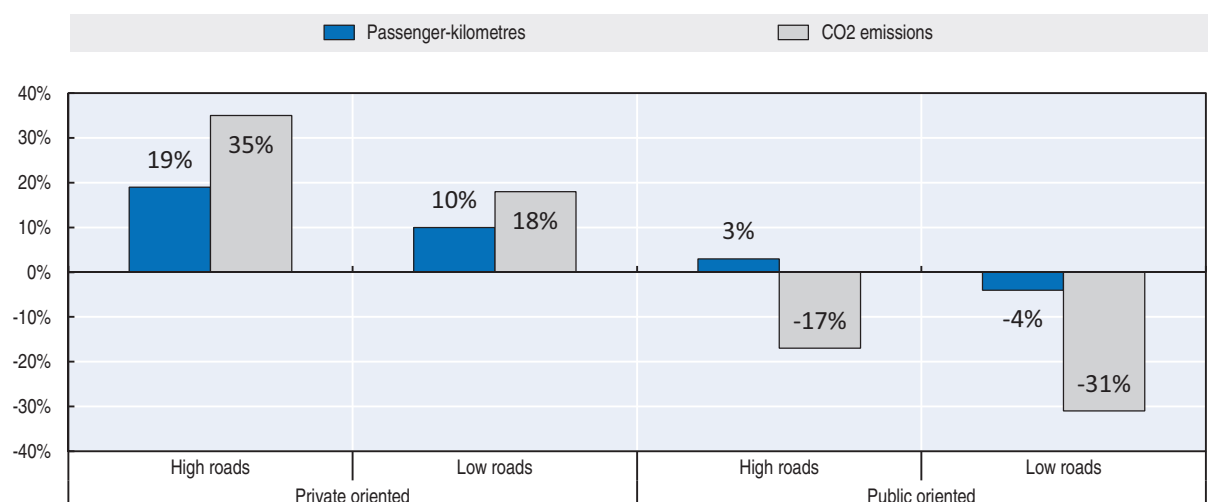


Figure 4.12. **Mobility and CO₂ emissions in Latin American cities, compared to Baseline scenario**
Alternative road scenarios



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In the *private transport-oriented* scenario with *high roads* the car fleet grows 24% more than in the baseline scenario (5% average annual growth). This is due both to the delay in congestion (caused by the rapid expansion of urban roads) and the slow expansion of public transport services and moderate quality improvements. The relative alleviation of congestion levels slows down private vehicle demand shift towards two-wheelers. As a consequence, growth in the fleet of two-wheelers is only 77% of their growth in the baseline scenario. In this scenario, the two-wheeler urban fleet grows 16 times (7% average annual growth).

In the *private transport-oriented* scenario with *low road* expansion the car fleet expands slightly above baseline levels. This means that due to congestion pressures generated by slow road expansion, a large part of the growth in the private fleet (which is accelerated by the lower expansion of public transport in this scenario) comes from two-wheelers. In this scenario the two wheeler fleet expands 28% more than in the *baseline* scenario (9% average annual growth).

Both *public transport-oriented* scenarios show slower fleet growth relative to baseline levels for both cars and two-wheelers. This is the consequence of significant expansion and improvement of public transport service. In the case where this scenario is combined with a high road expansion scenario, car and two-wheeler fleets are 20% and 60% smaller than in the baseline scenario. In the case where urban roads lag behind urban population growth, the car and two-wheeler fleets are 30% and 40% less than in the baseline scenario.

Just as in the case of the *private transport-oriented* urbanisation scenario with high road infrastructure expansion, the case under *low road* infrastructure yields higher increments in CO₂ emissions than mobility (relative to baseline levels). In the case of the *public transport-oriented* mobility scenario with *high road* infrastructure, total mobility is slightly higher than in the baseline scenario. CO₂ reductions in this scenario amount to 17% relative to baseline scenario levels. Again, this shows a lower marginal cost of mobility in terms of CO₂ emissions than results in the *baseline* scenario.

Chinese cities

The *Baseline* scenario for China assumes a business-as-usual evolution in car ownership restrictions over the 2010-50 period, as described in Table 4.4, with 52 cities imposing a restriction by 2050. Despite these restrictions, car share grows by 33 percent points and total private vehicle share by 35 percent points.

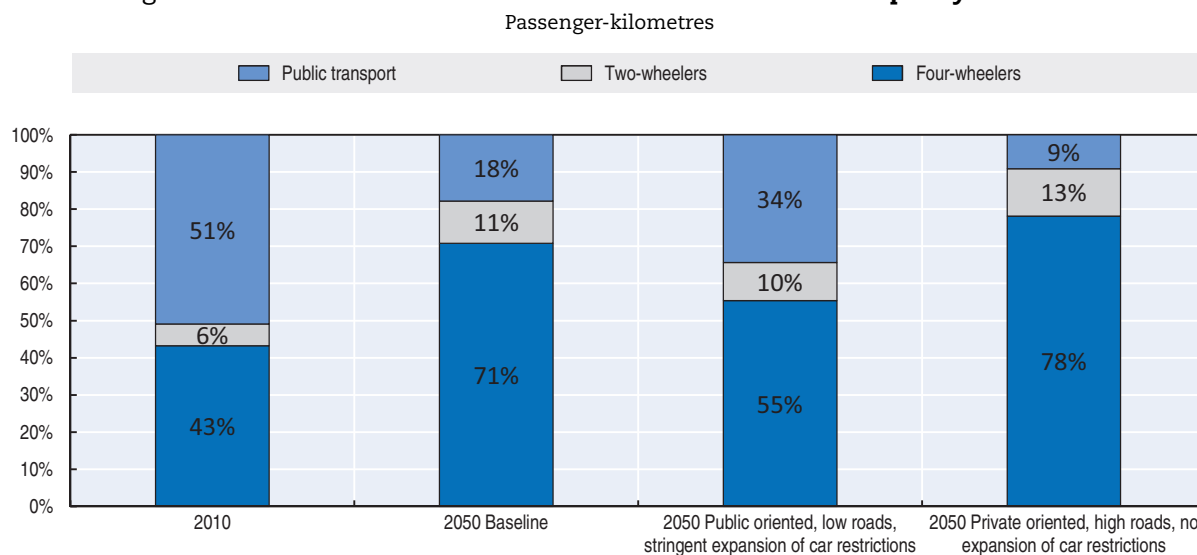
The *public transport-oriented* scenario corresponds to a higher public transport expansion and a higher mass transit share, coupled with a stronger car restriction policy (adapted to the evolution of population), and high fuel prices. In this case, car participation only grows by around 12 percent points. This scenario also reduces the extent of growth in two-wheeler participation compared to the *Baseline* scenario. However, as congestion pressures related to a slower urban road expansion tend to slow down the transition from two- to four-wheelers, there is still a significant increase in participation of two-wheelers compared to 2010.

The shift to align policies towards the most public oriented trends in the country, taking into account mass transit construction according to the future plans, limits the loss of public transport participation between 2010 and 2050 compared to the *Baseline* scenario. However, it does not allow 2010 levels to be maintained as in Latin America.

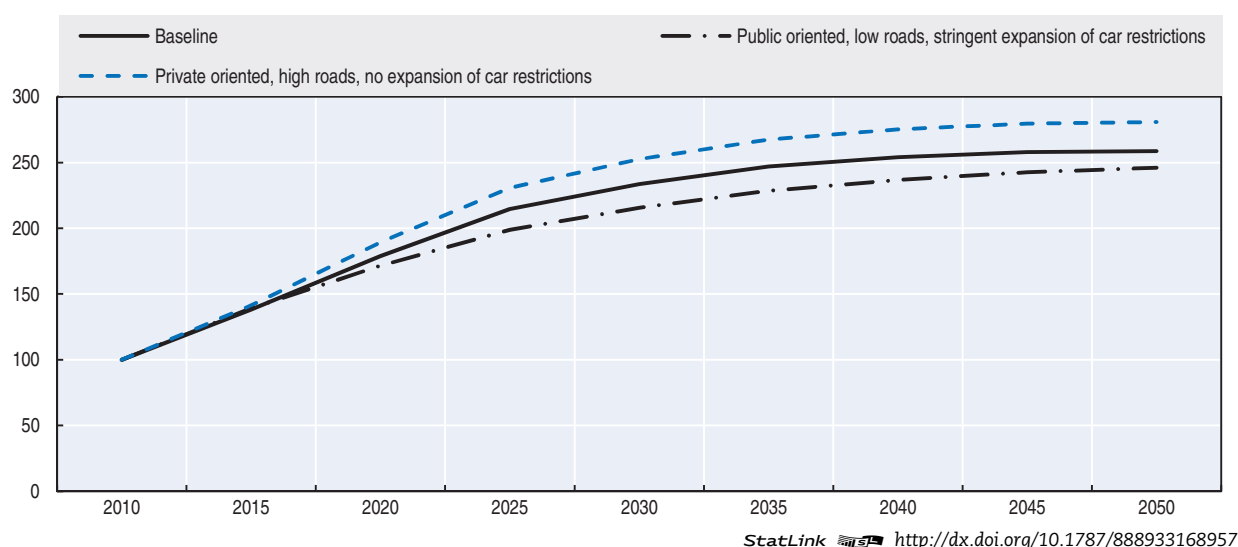
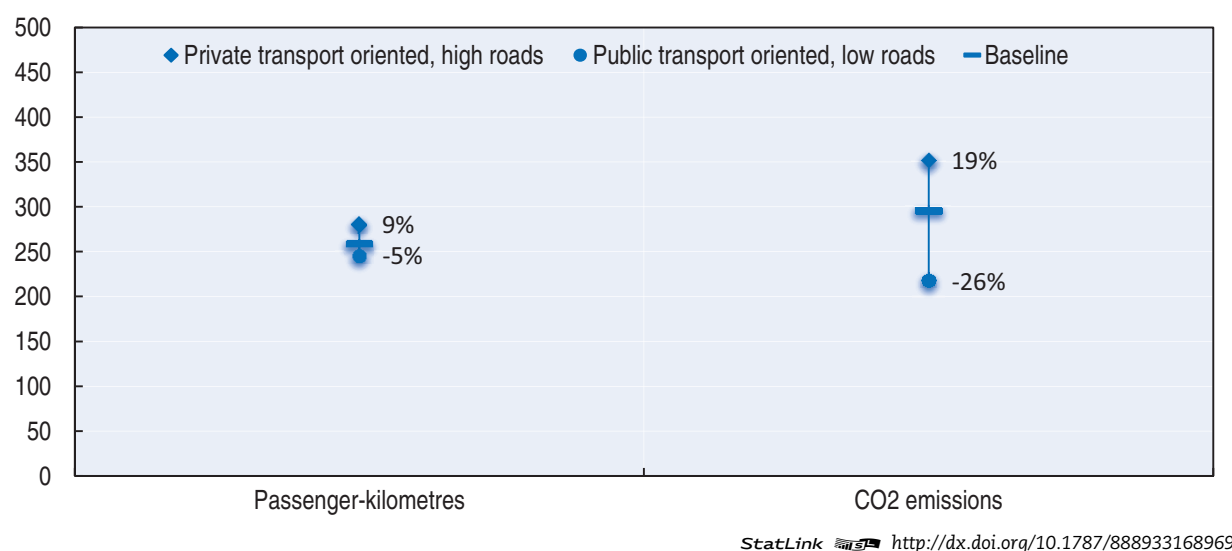
The *private transport-oriented* scenario significantly reduces the participation of public transport in urban mobility in China. The decrease of public transport service per capita, coupled with a higher road expansion, a lower oil price and a less restrictive car ownership policy, explains the participation of cars in urban mobility doubling compared to 2010. Compared to the *Baseline*, the increase is 11 percent points for total private participation, while the share of two-wheelers remain the same between the two scenarios.

In the *private transport-oriented urbanisation* scenario, total mobility levels increase 9% over the period in comparison to the baseline scenario by 2050. Most of this growth is driven by higher travel per vehicle, as a consequence of low-oil prices.

Figure 4.13. **Modal shares in Chinese cities under different policy scenarios**



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Figure 4.14. **Mobility in Chinese cities under different policy scenarios (Index, 2010 = 100)**Figure 4.15. **Growth in mobility and CO₂ emissions under different scenarios in Chinese cities**

Total mobility levels resulting from the *public transport-oriented* urbanisation scenario show a similar evolution to that of the Latin American case, with the shift towards a public transport strategy imposing some mobility costs in the beginning of the period but then catching up towards the end of the period. By 2050 the gap in mobility between these scenarios is only 5%. This shows that long-term shift to the public transport-oriented policy allows to overcome the mobility costs arising from private travel restrictions coupled with the most stringent car ownership restriction policy. Stabilisation of mobility levels towards the end of the period in all scenarios is explained by the plateauing of the population.

Regarding CO₂ emissions, results for the Chinese case study provide similar conclusions to those for Latin America. The *private transport-oriented* scenario generates an increased carbon intensity of urban transport relative to the baseline trend: in the Chinese

case, the *private transport-oriented* scenario results in 19% higher CO₂ emissions compared with the baseline. As for Latin America, the *public transport-oriented* scenario results in a significant reduction in CO₂ emissions (26% lower than the baseline). Here again, urban mobility is provided at a lower marginal cost in terms of CO₂ emissions.

Effect of car ownership restrictions in China under different urban scenarios

Car ownership restriction policies are likely to be adopted in a growing number of cities in order to deal with the fast growing CO₂ and pollution emissions and congestion issues Chinese cities are facing.

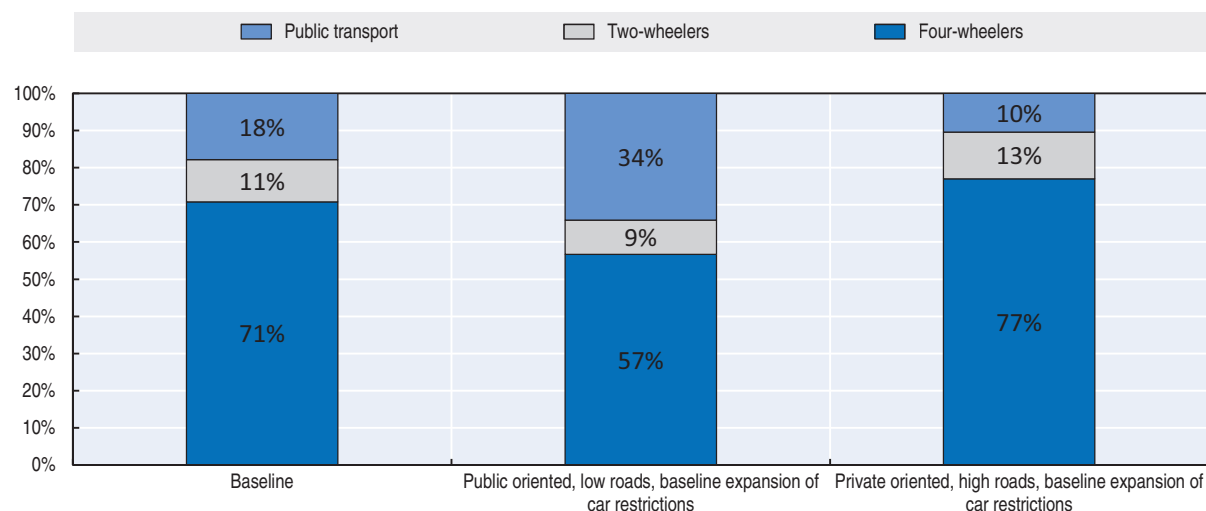
In order to investigate the potential impacts of restrictive measures on car ownership under different policy frameworks, we define two intermediate scenarios, using the same assumption for car ownership restrictions. We use the baseline assumption as we consider this a more plausible scenario. Under this assumption medium and large cities with high ratios of car to road area impose a car ownership restriction. Quotas are not adjusted to account for changes in population growth. The two scenarios then differ in the orientation of the urban policy, with one using the *public transport-oriented* urbanisation scenario with low road expansion while the other uses the *private transport-oriented* urbanisation scenario with high road expansion.

Figure 4.16 shows that the car restriction, without population adjustment, coupled with the public oriented scenario with low road expansion, reinforces the impact of car restrictions, as the participation of cars is 14 percentage points lower compared to the baseline. The participation of two-wheelers is also less due to the high public transport expansion, the low road infrastructure growth (which increases congestion pressures) and the high oil prices. The scenario based on the same assumptions about car ownership restriction development but coupled with the private oriented scenario with high road expansion shows only a slight increase in two-wheelers participation. The bulk of increase in car participation is driven by low oil prices and a high road expansion. Notice that in this scenario, two-wheelers account for a higher participation in urban mobility than public transport.

Figure 4.17 compares the evolution of total urban mobility under the three scenarios. Expanding car ownership restrictions to medium and large cities that have severe congestion problems will end in higher than baseline mobility whether implemented under a *public transport-oriented* urbanisation scenario with low road expansion, or under a *private transport-oriented* urbanisation policy with high road expansion. However, the reasons behind the gains in mobility compared to the baseline scenario differ between the two settings, as do the environmental consequences. The private oriented urbanisation policy with high road expansion results in more private vehicles in cities that do not have a restriction. Also, cities that implement car restrictions under this scenario do it after arriving at higher car ownership levels than in the *public transport-oriented* scenario since expansion of road infrastructure will generate similar congestion levels at higher vehicle ownership.

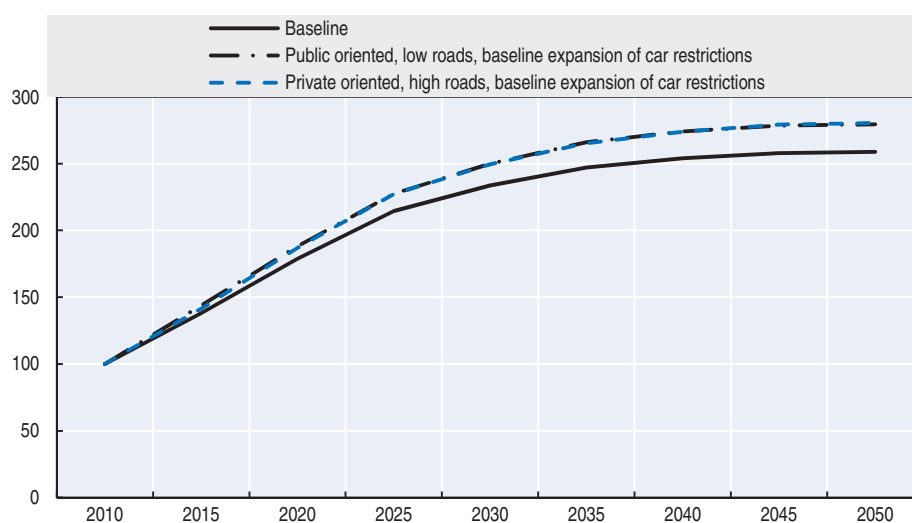
Finally, all vehicles travel more in this scenario because of the low oil prices assumed in this scenario. Contrastingly, the *public transport-oriented* urbanisation scenario with low road expansion gives similar levels of mobility under the same car restriction assumption, due to the increase in public transport provision. The growth in public transport capacity counterbalances the lower level of private mobility generated.

Figure 4.16. Modal shares in urban China, 2050
 Passenger-kilometres, baseline expansion of car ownership restriction



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Figure 4.17. Mobility in urban China under different policy scenarios
 Baseline expansion of car ownership restrictions

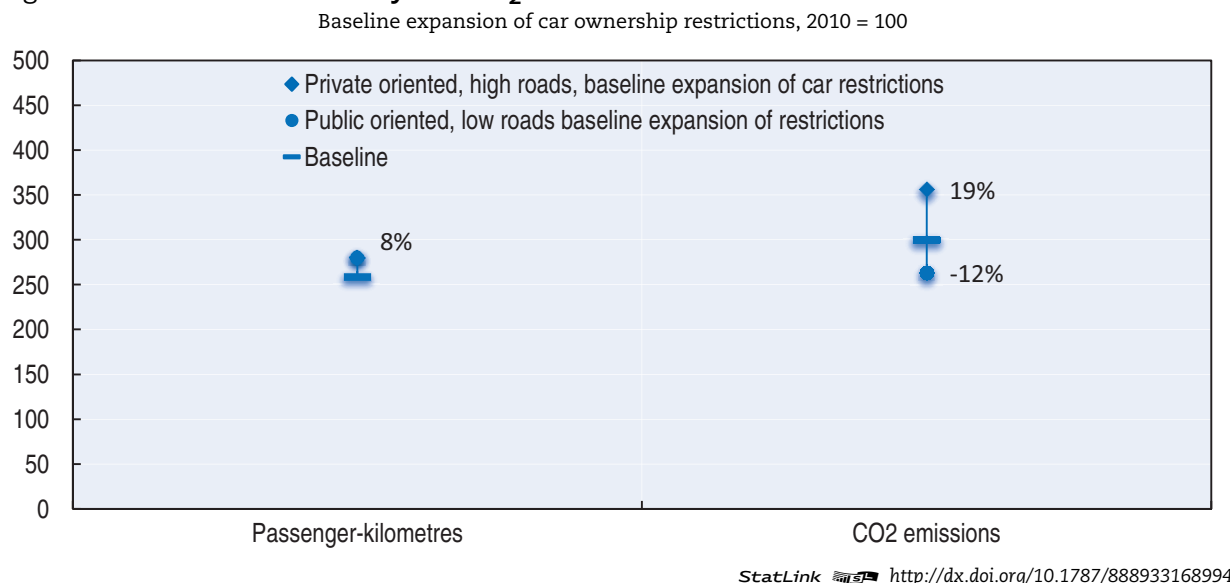


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Figure 4.18 illustrates the differences in environmental consequences of the three scenarios and highlights the beneficial impact of coupling car ownership restriction with a policy shift towards public transport. The figure shows that the gain in mobility under this scenario translates into significantly less CO₂ emissions compared to baseline (-12%), while the increased mobility resulting from the same car restriction assumption but associated to a private oriented scenario creates additional CO₂ emissions (+19%). These results emphasise that a car restriction implemented without an adequate setup for public transport would still produce more CO₂ emissions. Notice that the private transport scenario with high roads generates the same level of CO₂ emissions when coupled with the baseline expansion of car ownership restrictions and when such policies were assumed to

be implemented only in seven cities. The reason for this is that other policies assumed in this scenario significantly accelerate car ownership growth. As cities approach high ownership levels elasticity of motorisation relative to income decreases significantly. Under this context car ownership restrictions have a marginal impact in car travel and related externalities.

Figure 4.18. **Growth in mobility and CO₂ emissions under different scenarios in Chinese cities**



Indian cities

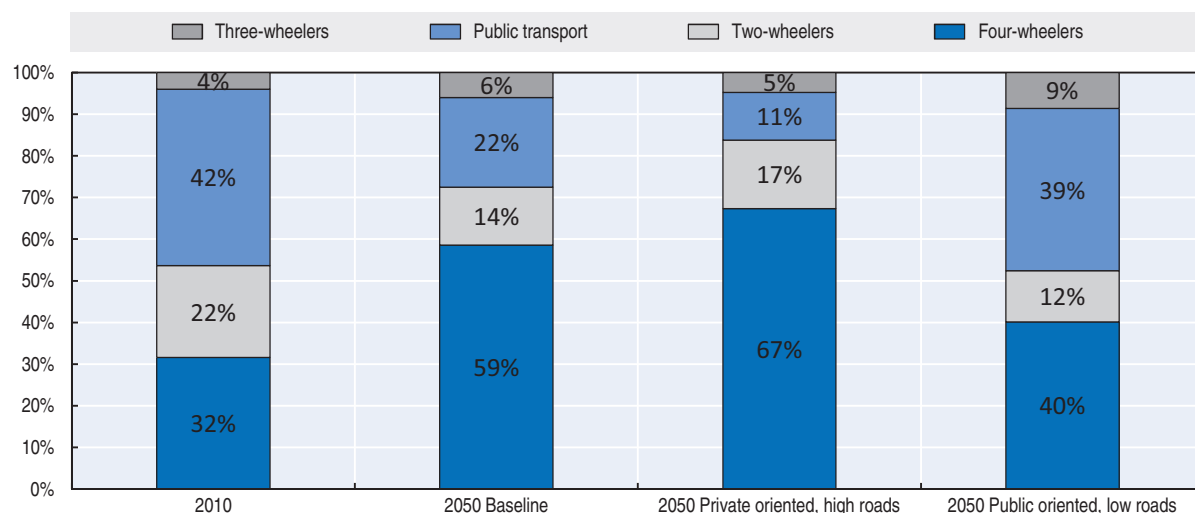
As for Latin America and China, we examine the outcomes of the urban scenarios through modal shares, total mobility (passenger-kilometres) and CO₂ emissions.

The outcomes in terms of modal shares show very contrasting trends for the different scenarios (Figure 4.19). In the *Baseline* scenario, the modal share of private cars increases from 32% in 2010 to 59% in 2050, to the detriment of public transport (from 42% to 22%). This shows that the natural evolution of mobility patterns in urban India is towards private mobility.

The *public transport-oriented* scenario with low roads maintains public transport shares at 2010 levels. This however will require a very significant enhancement, in quantity and quality, of public transport provision. Resulting modal shares is enough to significantly reduce CO₂ emission growth, which is 37% (Figure 4.21) less in the *public transport-oriented* scenario than in the *Baseline* scenario. However, total growth in mobility in this scenario is 29% smaller than in the *Baseline* (Figure 4.20).

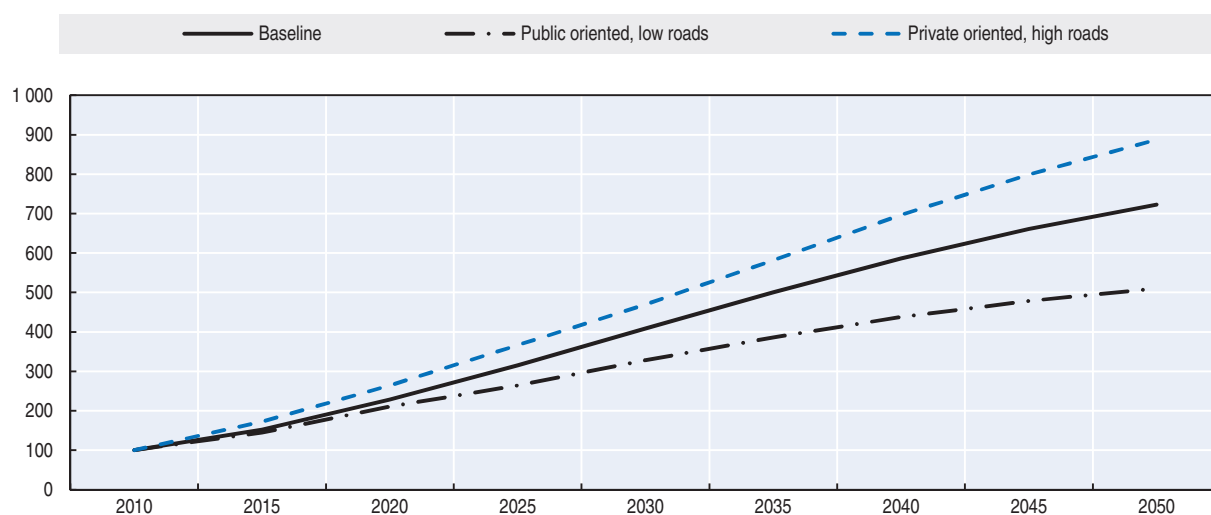
In the *private transport-oriented* scenario with *high road* expansion, public transport develops slowly and this accelerates private vehicle ownership. As a consequence, the modal share of four-wheelers more than doubles, and that of two-wheelers only marginally decreases, from 22% to 17%. The modal share of public transport is four times smaller than in 2010. Because of these new modal shares, the 23% increase in mobility compared to the *Baseline* scenario result in CO₂ emissions that are 47% higher than in the *Baseline* scenario. The additional passenger-kilometers of the *private transport-oriented* scenario are thus more CO₂ intensive.

Figure 4.19. **Modal shares under different policy scenarios in Indian cities, 2010 and 2050**
Passenger-kilometres



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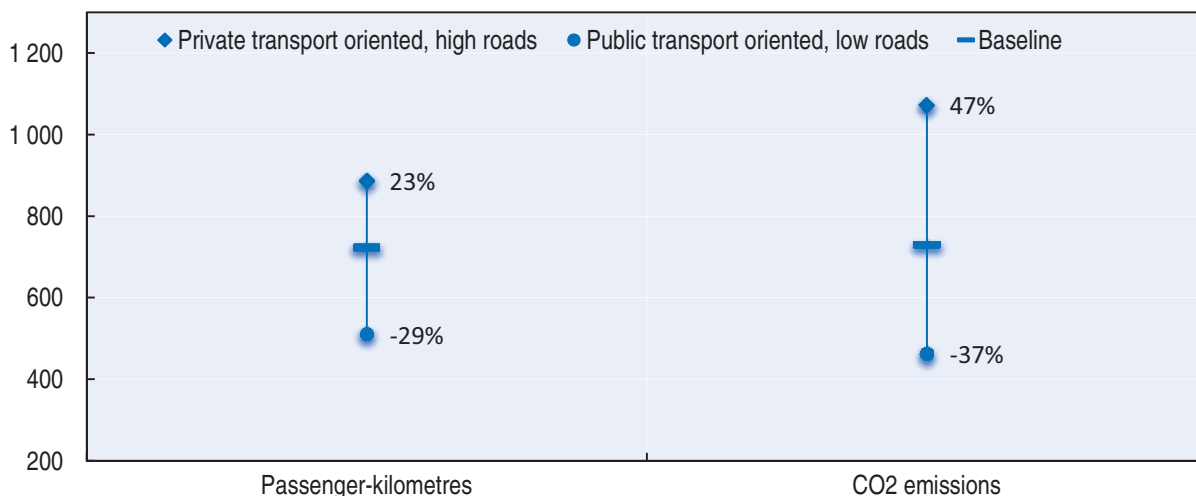
Figure 4.20. **Evolution of urban mobility in Indian cities under different scenarios**
2010 = 100



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As said before the three scenarios differ significantly in terms of mobility. The lower cost of fuel and the positive effect of high road provision on private vehicle fleet explain the relatively high growth in the *private transport-oriented scenario with high roads*. Contrary to Latin America and China, the *public transport-oriented scenario with low roads* does not converge with *Baseline* mobility levels during the studied period. One possible explanation is the limited capacity offered by public transport in India, which cannot accommodate all the private mobility of the *private transport-oriented scenario* (even when expansion of public transport is high in the *public transport-oriented scenario*, the starting point is low relative to the levels of Latin America and China). Limited road expansion delays growth of both four-wheelers and two-wheelers in this scenario, which also increases the mobility

Figure 4.21. **Growth in mobility and CO₂ emissions under different scenarios in Indian cities**
2010 = 100



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gap. One challenge for Indian cities thus lies in the development of public transport at a pace that does not hinder mobility.

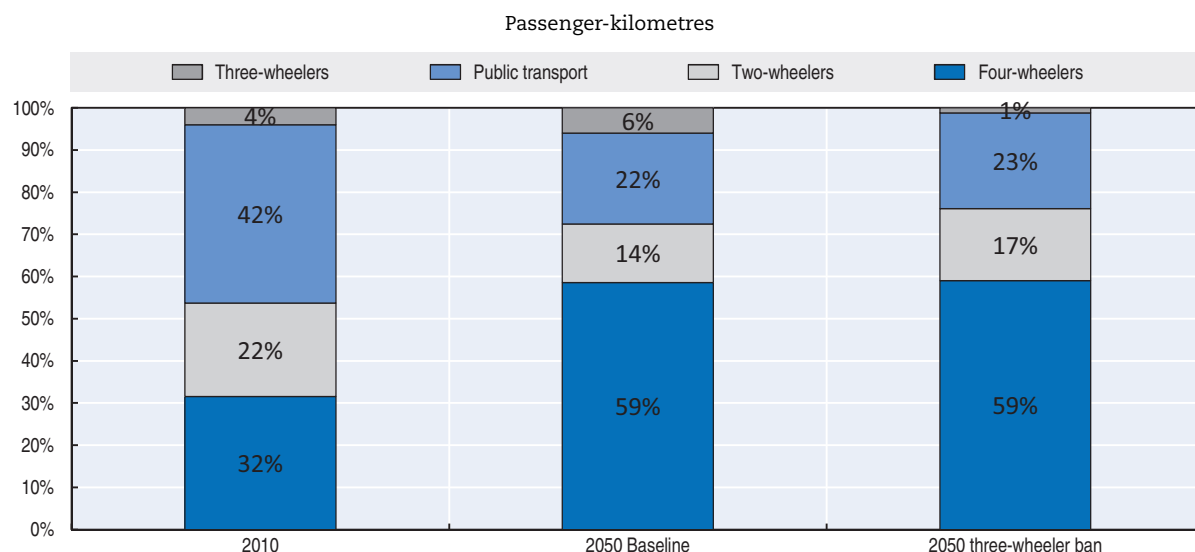
Three-wheeler ban in large Indian cities

Three-wheelers are an important part of the mobility mix in Indian cities. However, legislation banning some forms of three-wheelers in city centres are gaining momentum in India, with bans already in place in the central part of Mumbai and in Pune and a few municipalities considering the introduction of at least a limited (i.e. two-stroke three-wheelers) ban. Locally, the objectives of such policies are twofold: to reduce congestion on the small roads of city centres, and limit CO₂ and other pollutants.

To assess the impact of such a policy on a larger scale, a fourth alternative urban scenario is tested in India. In the *three-wheeler ban* scenario, cities above two million inhabitants gradually ban three-wheelers from 2015. All other variables remain at their baseline values.

Under this scenario, results show that under these assumptions, a ban on three-wheelers is in place in one third of all cities above 500 000 inhabitants in 2050, and that the total number of three-wheelers in India is reduced by 80% compared to the *Baseline* scenario (the last 20% remain in cities below 2 million people therefore not targeted by the ban). The absence of three-wheelers in the case of a ban will be compensated by an increase of 18% in the number of two-wheelers in urban areas compared to baseline. However, there will be no increase in cars. All in all, the total number of both two- and three-wheelers is higher in this scenario than in the *Baseline* scenario.

As auto-rickshaws are usually very CO₂ intensive compared to two-wheelers, CO₂ emissions decrease by 4% in the *three-wheeler ban* scenario. In terms of health impacts from local air pollutants, banning three-wheelers would have a marginal effect when compared to the baseline scenario (see pollution and health impacts section). Another alternative to the ban on three-wheelers to reduce emissions could be the replacement of conventionally fuelled three-wheelers by electric auto-rickshaws (see also Box 4.4).

Figure 4.22. **Modal shares in Indian cities, 2010 and 2050 for the Baseline and three-wheeler ban scenarios**

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Box 4.4. **Emergence of electric rickshaws in India**

Electric auto-rickshaws (e-rickshaws) are three-wheeled rickshaws powered by electric batteries. They emerged in 2011, mainly in Delhi, and the number of e-rickshaws rocketed to reach an estimated 100 000 units in mid-2014, overtaking CNG-powered auto-rickshaws – around 55 000 in the capital city (Pai, 2011) – in only a few years. The reasons for such growth are threefold: a general lack of feeder transport modes in the capital city such as conventional auto-rickshaws, despite a recent increase in the licences issued by the Delhi government; the absence of regulation for such vehicles which are not regulated by the Motor Vehicle Act of India, and therefore do not require any licence; they are around four times cheaper than conventional auto-rickshaws to own and run due to the absence of licences and the relatively low price of electricity (Harding and Rojesh 2014).

The sudden and massive expansion of these last mile connectivity e-vehicles created intense debate in the media, mainly because of poor quality construction (resulting in numerous road accidents) and the absence of regulation. In mid-2014, Delhi's High Court of Justice pronounced a ban on e-rickshaws that is meant to last until the Motor Vehicle Act is amended to regulate them.

It is currently difficult to say what the future of electric three-wheelers will be. If e-rickshaws were regulated and controlled, without making them entirely uncompetitive, they could represent around 60% of the three-wheeler fleet in 2050, a proportion similar to that predicted for electric two-wheelers in India and China in 2050. This could contribute between 7 and 11 MtCO₂ mitigation per year at the national level (depending on assumptions for the fuel mix for the rest of the fleet). This figure only represents around 1% of total urban CO₂ emitted by private and public transport. However in very dense areas, where auto-rickshaws are generally concentrated, significant reductions in air (Aggarwal and al. 2012) and noise pollution would be achieved, with a direct positive impact on health.

The results from the *three-wheeler ban* scenario show that the analysis of local policies limiting the use of three-wheelers should consider the effects on two-wheeler growth, and related externalities. Although not in our model, the impact of banning three-wheelers in terms of mobility also needs to be considered carefully. This policy would need to be accompanied by significant reinforcement of other forms of transport, such as buses or mass transit. In the controversial debate about the ban on auto-rickshaws, the introduction of e-rickshaws within a regulated framework on a large scale, in India, could be a better alternative and provide the last mile connectivity that remains vital for millions of commuters. It can help to slow down the increase in two-wheelers and contribute to emission reduction in urban transport.

Pollution and health impacts

In addition to the climate change impacts due to emissions of CO₂ and short-lived climate pollutants, urban transport is also an important contributor to local air pollution, leading to severe health problems such as cardiovascular, respiratory diseases and numerous cancers. Exposure to outdoor air pollution is one of the main causes of premature mortality, leading to 3.2 million early deaths globally in 2010 (Lim et al., 2012). On-road vehicles are a major contributor to outdoor air pollution, in particular in urban areas where population will grow most rapidly.

OECD estimated the health impact costs of outdoor air pollution in OECD countries at about USD 1.7 trillion in 2010, suggesting that road transport is responsible for close to USD 1 trillion (OECD, 2014). While the number of deaths from outdoor air pollution fell by 4% in OECD countries between 2005 and 2010, partly due to stricter vehicle emission controls, China and India have seen increases of 5% and 12%, respectively. Health impact costs of outdoor air pollution in China and India in 2010 were estimated at USD 1.4 trillion and 0.5 trillion, respectively, but sufficient evidence was not available to determine road transport's contribution. The cost of air pollution in developing countries represents a heavy burden on national budgets in addition to its dramatic consequences on public health.

In addition to providing future perspectives on CO₂ emissions for different urban policy scenarios, it is important to estimate their effects on local air pollutants and health impacts. NO_x, and PM_{2.5} emissions as well as health impacts from primary PM_{2.5} in urban areas resulting from urban transport scenarios in Latin America, China and India, were calculated by the International Council for Clean Transportation (ICCT). See Box 4.5 for additional details on the emissions and health impacts calculation methodology.

Even in the most optimistic scenario of motorisation rates, passenger vehicle activity and CO₂ emissions will increase in Latin America, China, and India. Although increased vehicle activity typically degrades air quality, stringent vehicle emission and fuel standards in place in many developed countries have decoupled the relationship between vehicle activity and emissions since the most advanced emission controls can effectively eliminate over 99 percent of local air pollutants from engines (Chambliss et al., 2013). As a result, the impacts of different urban scenarios on emissions of local air pollutants and health impacts are highly dependent on national standards for vehicle emissions. In addition to alternative policy scenarios, this analysis therefore considers two scenarios for

Box 4.5. The International Council on Clean Transportation Global Transportation Roadmap model

The International Council on Clean Transportation (ICCT) is a non-profit research organisation dedicated to improving the environmental performance and efficiency of transportation to protect public health, the environment, and quality of life. The ICCT provides national and local policymakers with sound technical analysis of regulations, fiscal incentives, and other technology-based measures for clean vehicles and fuels. The ICCT works across modes including passenger cars, light commercial vehicles, heavy-duty trucks and buses, two- and three-wheelers, international aviation and marine, conducting global outreach with a focus on major and growing vehicle markets. The ICCT maintains a staff of about 40 technical and policy experts, and a network of council participants who provide input on regulatory and research priorities.

The analysis of health impacts from different urban activity scenarios was developed by the International Council on Clean Transportation (ICCT). The analysis estimates premature mortality from primary fine particulate matter (PM_{2.5}) emitted by on-road vehicles in urban areas. In addition to the urban activity scenarios, this analysis considers two technology scenarios: a baseline scenario that includes currently adopted vehicle emission standards, and an accelerated scenario that assumes all countries adopt the most stringent vehicle emission standards currently adopted by most developed countries (i.e., equivalent to Euro VI/6 standards adopted in Europe).

The emissions and health data presented in this chapter are produced by the ICCT using the Global Transportation Roadmap model, which captures well-to-wheel (WTW) transportation sector emissions from 2000 through 2050 (ICCT, 2014). In this analysis, the model calculates tank-to-wheel (TTW) emissions of local air pollutants – fine particulate matter (PM_{2.5}), nitrogen oxides (NO_x), nonmethane hydrocarbons (HC), etc. – as the product of vehicle activity and fleet-average emission factors. Average emission factors for each region and on-road mode (light-duty vehicles, 2-wheelers, and buses) are calculated based on the share of the fleet meeting various vehicle emission standards using a fleet turnover algorithm and a policy implementation timeline, a method consistent with that described in previous work by the ICCT on vehicle and fuel standards impacts (Chambliss et al., 2013).

This analysis is specific to transportation activity, emissions, and health impacts within urban areas. The emission factors reflect a mix of low-, mid-, and high-speed driving conditions experienced in downtown high-traffic areas, on highways through cities, and in the urban periphery. The model employs a global set of emission factors (expressed in grams of pollutant per kilometer traveled) for multiple local air pollutants that are specific to vehicle type, fuel type, and emission certification level (e.g., Euro 1/I through Euro 6/VI). Emission factors are derived from COPERT, an emissions model developed for official road transport emission inventory preparation in European member countries and widely adopted by research and academic institutions (EMESIA, 2009). In regions that follow United States standards, those certification levels are mapped to equivalent European emission standards and assigned appropriate Euro-level emission factors. PM_{2.5} emission factors are further adjusted to account for the effect of diesel sulfur content using a mass-balance (or conservation of mass) approach, assuming a 2 percent conversion of fuel sulfur to sulfates. The calculation of vehicle emissions for this analysis did not include evaporative emissions, cold-start emissions, or brake-, tire-, and road-wear emissions.

Total premature mortality and years of life lost are estimated from exposure to primary PM_{2.5} from on-road vehicles in urban areas. The Roadmap model produces an aggregate total of PM_{2.5} emissions across all urban areas within a region. Urban PM_{2.5} exposure, translated from aggregate emissions by intake fractions, is expressed in terms of pollutant concentration—micrograms per cubic meter (µg/m³)—and is assumed to be equal across the urban population in each city. The impacts of exposure to this concentration are then calculated using a set of concentration-response functions from published literature documenting the increased risk of death from cardiopulmonary disease, lung cancer, and acute respiratory infections due to PM_{2.5} exposure (Krewski et al., 2009; Cohen et al., 2004). Years of life lost are calculated by comparing the number of premature mortalities in 5-year age categories against a standardized life expectancy table (Murray et al., 2012). The estimation of health impacts from urban

Box 4.5. The International Council on Clean Transportation Global Transportation Roadmap model (cont.)

emissions follows a standard methodology described previously by Chambliss et al. (2013), and appendix III of that report includes further details of these calculations.

This methodology results in a conservative estimate of premature mortality from on-road vehicle emissions. It is limited to exposure to tailpipe emissions of primary $PM_{2.5}$, and excludes the additional impact of secondary $PM_{2.5}$ formed in the atmosphere from vehicle emissions. It also omits the impacts of exposure to ozone, which forms from other chemicals emitted by vehicles and is also known to have adverse health effects (Jerrett et al., 2009). In addition, this method does not quantify the broader non-fatal effects of vehicle pollution on the population ranging from an increase in asthma attacks and chronic bronchitis to greater numbers of hospital visits for lung and heart disease. These estimates of premature mortality indicate the overall trends in the health impacts of vehicle emissions, but these results should be considered a highly conservative assessment of the overall benefits of clean fuel and vehicle policies.

vehicle emission standards to account for the level of emission control technology adoption:

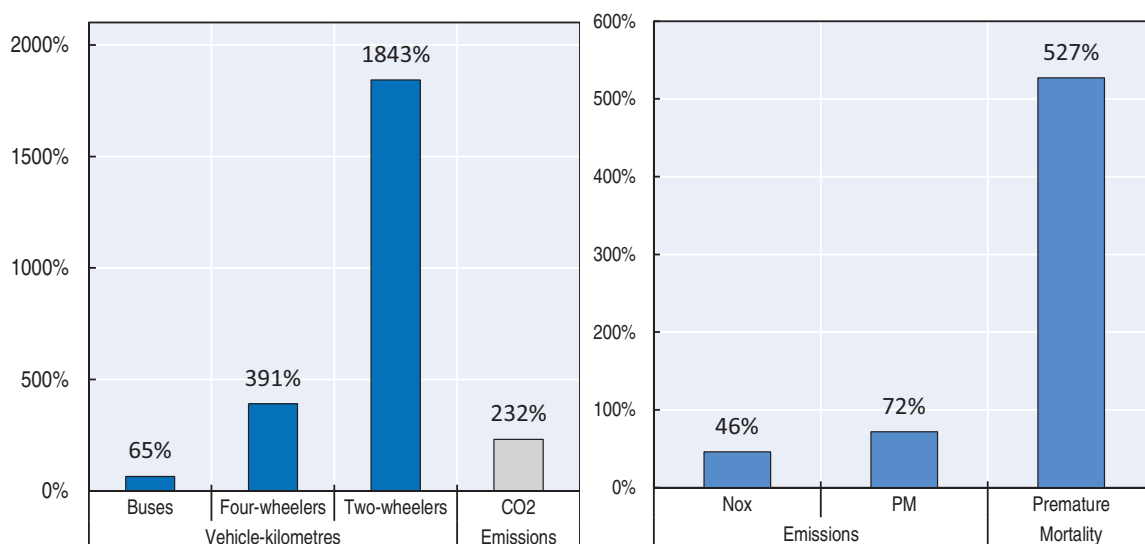
- *Reference scenario*: assumes that no additional progress is made beyond current vehicle emission standards;
- *Accelerated scenario*: assumes that world-class standards equivalent to Euro 6/VI are implemented based on a policy roadmap established by the ICCT (Chambliss et al., 2013).

Because emissions of local air pollutants and health impacts are strongly influenced by the level of emission control technology, vehicle type, and fuel type, the effects of urban activity scenarios on CO_2 , local air pollutants and health impacts are not always correlated.

Latin American Cities

Figure 4.23 illustrates the growth in vehicle activity, emissions of CO_2 , NO_x , and $PM_{2.5}$, and health impacts in the baseline activity scenario in Latin America between 2010 and

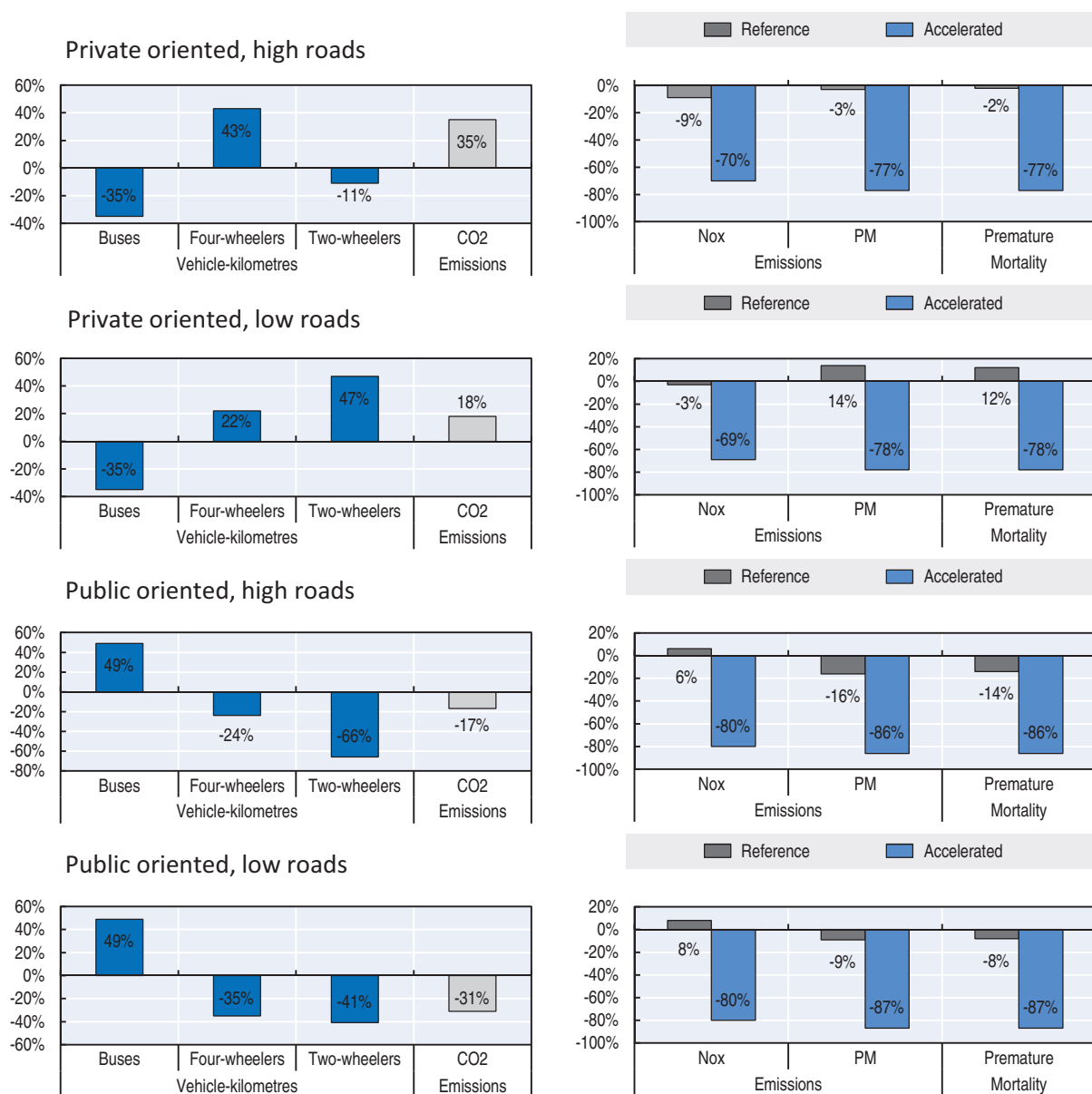
Figure 4.23. **Growth in activity, emissions, and health impacts in Baseline scenario in Latin American cities**



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2050 assuming current vehicle emission controls (reference scenario). CO₂ emissions related to urban transport in Latin American cities above 500 000 will grow by 232% between 2010 and 2050. Growth in CO₂ emissions will be less than total growth in motorised vehicle travel due to a significant improvement in CO₂ intensity of cars and more moderate improvement in CO₂ intensity of buses and two-wheelers. Overall CO₂ intensity of motorised travel will also be reduced due to a higher share of two-wheelers. NO_x and PM_{2.5} emissions will grow by 46% and 72% in the same time period, respectively, primarily stemming from the growing share of two-wheeler travel. Higher PM_{2.5} emissions and increasing population exposed to PM_{2.5} concentrations in urban centers will generate an increase of over 500% in premature deaths during the 40 years.

Figure 4.24. **Changes in activity, emissions and health impacts from Baseline scenario in Latin American cities, 2050**



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Figure 4.24 compares vehicle activity, emissions of CO₂, NO_x, and PM_{2.5}, and health impacts between the alternative activity scenarios and the baseline activity scenario in 2050 in Latin America.

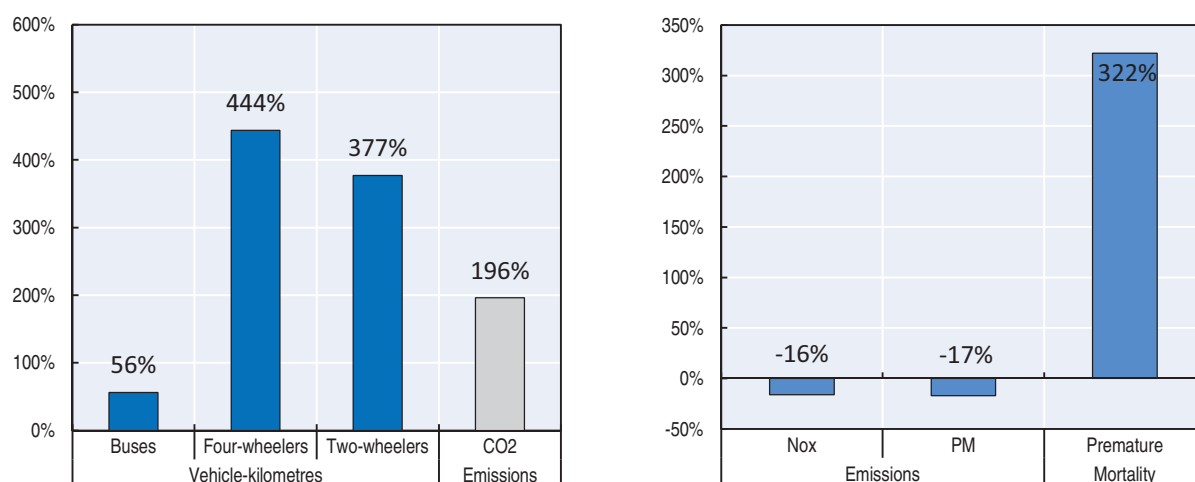
As highlighted previously, the private high road scenario results in the highest growth in CO₂ emissions (35% more than in the baseline scenario). On the other hand, the public low roads scenario would generate 30% less growth in CO₂ emissions compared with the baseline.

Without additional emission control technologies (*reference scenario*), PM_{2.5} emissions and premature mortality are the highest in the *private low road* scenario as more activity is shifted to two-wheelers, which emit considerably more than automobiles. Despite decreases in vehicle activity in public-oriented scenarios compared to the *baseline*, relative NO_x emissions increase more than in the baseline because diesel buses without additional emission control technologies emit considerably more than gasoline automobiles. Compared to the baseline, the *private low road* scenario results in higher pollution growth than the *private high road* scenario because of the increased of two-wheeler travel. By introducing advanced emission control technology (*accelerated scenario*), emissions of PM_{2.5} and NO_x, and premature mortality could be largely avoided (i.e., 70-90% reduction from the baseline), with the *public low road* scenario achieving the highest reductions from baseline levels in 2050.

Chinese Cities

Figure 4.25 illustrates the growth in vehicle activity, emissions of CO₂, NO_x, and PM_{2.5}, and health impacts in the baseline activity scenario in China between 2010 and 2050 assuming current vehicle emission controls (*reference scenario*). CO₂ emissions grow in 200% from 2010 to 2050. As in the case of Latin America, CO₂ emission growth is limited to a certain extent by significant improvements in the car fleet (which in the case of China has an important penetration of gasoline hybrid vehicles). Also buses will reduce their CO₂ intensity, although to a less extent than cars. The shift from two-wheeler to car travel is an element delaying reduction in carbon intensity of total motorised travel. Total emissions of NO_x and PM_{2.5} decrease by 16% and 17% during the 2010-50 period in Chinese cities. The

Figure 4.25. **Growth in activity, emissions, and health impacts in Baseline scenario in Chinese cities**

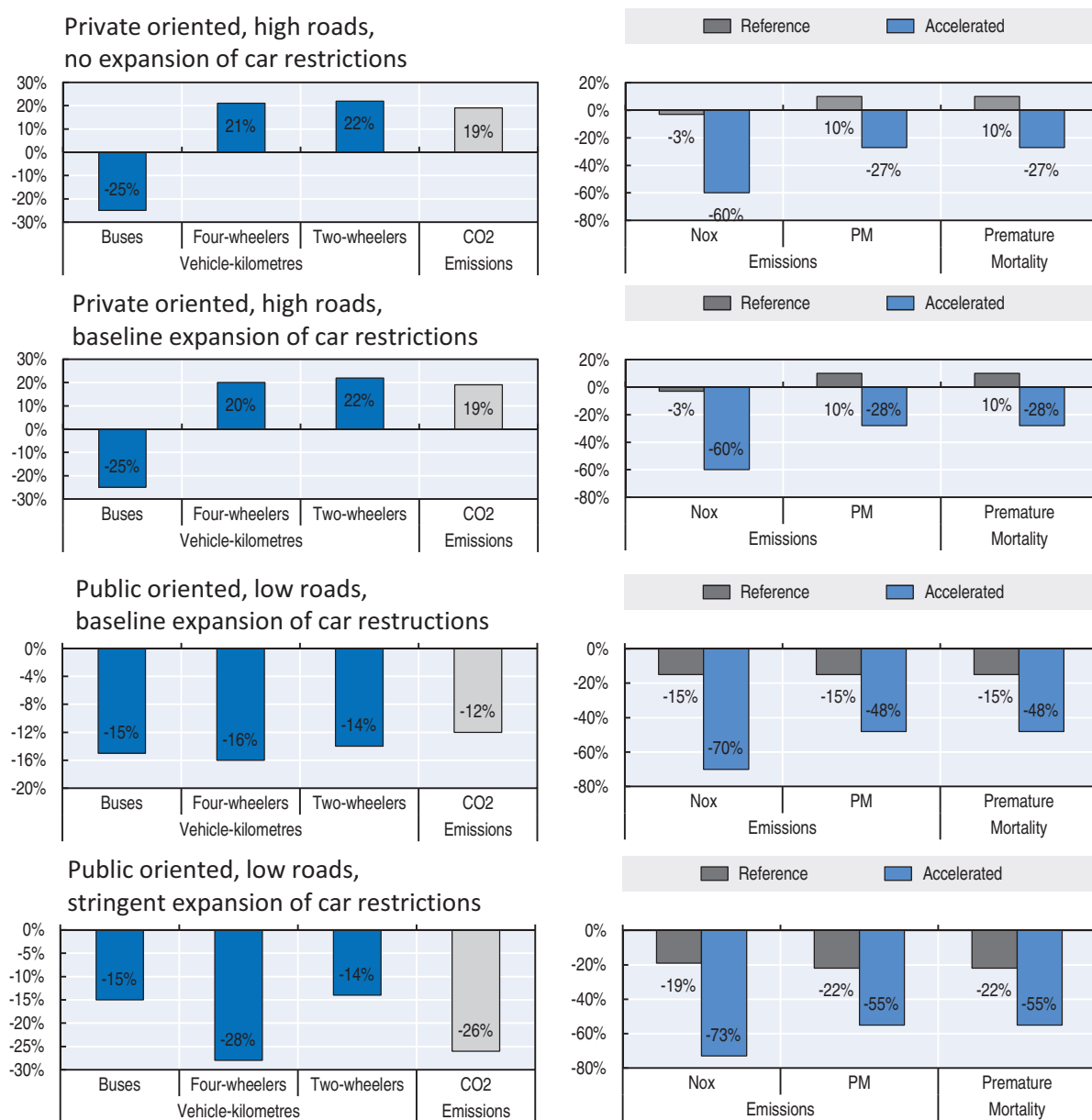


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main drivers for this reduction are the shift from two-wheeler to car travel, the high penetration of electric two-wheelers (since two-wheeler travel maintains a significant share of total motorised travel), and significantly higher reductions in NO_x and PM_{2.5} intensity of buses than in Latin America. Despite the lower overall levels of PM_{2.5}, increasing numbers of urban population exposed to such concentrations by 2050 translate into a 300% increase in premature deaths compared to 2010.

Figure 4.26 compares vehicle activity, emissions of CO₂, NO_x, and PM_{2.5}, and health impacts between the alternative activity scenarios and the baseline activity scenario in 2050 in China.

Figure 4.26. **Changes in activity, emissions, and health impacts from Baseline scenario in Chinese cities, 2050**



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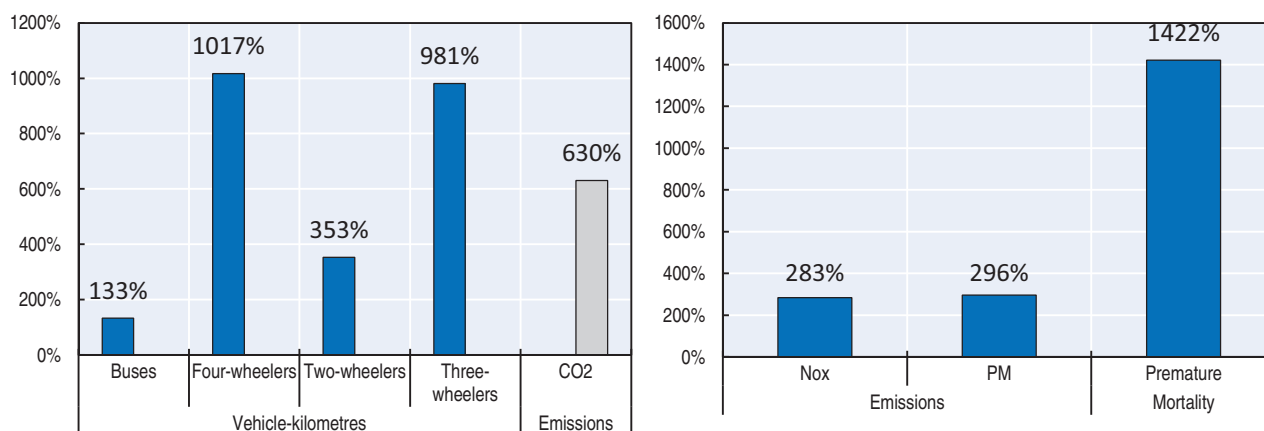
As for Latin America, the *public transport-oriented* scenario results in a significant reduction in CO₂ emissions compared with the baseline. The impact of coupling car ownership restriction with a policy shift towards public transit translates into significantly less CO₂ emissions compared to the baseline, while the increased mobility resulting from the same car restriction assumption but associated to a private oriented scenario creates additional CO₂ emissions.

Public-oriented scenarios result in larger reductions of emissions of local air pollutants and premature mortality. The *public transport-oriented* scenario, coupled with low road expansion results in the largest reductions when congested cities adopt stringent car ownership restrictions especially when advanced vehicle emission controls are considered (*accelerated* scenario). Meanwhile, expansion of car restriction policies has a marginal effect on car travel when these are implemented under a private-oriented scenario (since many cities approach saturation in any case, due to accelerated car ownership growth). For this reason both private scenarios show the same results in terms of the growth in CO₂, pollution and premature mortality. As it was the case in Latin America, advanced emission control technologies (*accelerated* scenario) could reduce a large share of emissions of PM_{2.5} and NO_x, and premature mortality, up to 73% in NO_x emissions and 55% of PM_{2.5} and premature mortality when compared to the baseline scenario in 2050.

Indian Cities

Figure 4.27 illustrates the growth in vehicle activity, emissions of CO₂, NO_x, and PM_{2.5}, and health impacts in the baseline activity scenario in India between 2010 and 2050 assuming current vehicle emission controls (reference scenario). Total CO₂ emissions will grow over 600% between 2010 and 2050 in Indian cities of above 500 000 population. To a certain extent, CO₂ emission growth will be slowed down by more significant shares of diesel cars (around 35% on average). However, overall reductions in CO₂ intensity of cars will be smaller than in Latin America and China. The shift from two-wheelers to car travel will still increase carbon intensity of the overall private travel. NO_x and PM_{2.5} emissions will grow nearly by a factor of four in urban India between 2010 and 2050 in the baseline scenario. High growth in car travel will be an important driver for this growth since

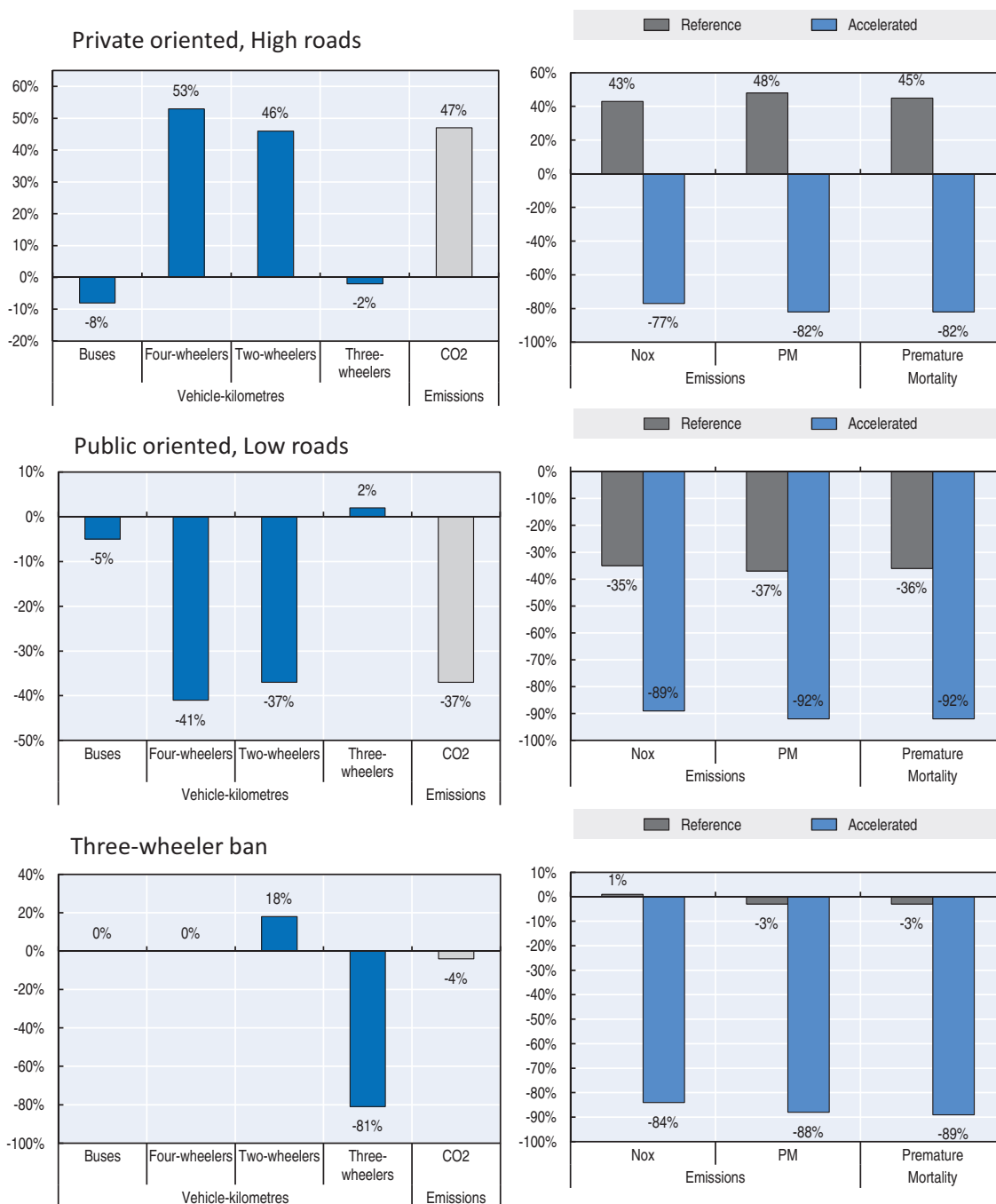
Figure 4.27. **Growth in activity, emissions, and health impacts in the Baseline scenario in Indian cities**



StatLink  <http://dx.doi.org/10.1787/888933169088>

pollution generated by these vehicles is significantly higher than in Latin America and China (per kilometer of travel). Three-wheeler and two-wheeler vehicle growth will also contribute to the high increases in pollution. The very high growth in PM_{2.5} emissions and increasing urbanisation rates in Indian cities will generate 1422% more premature deaths by 2050 compared to 2010.

Figure 4.28. **Changes in activity, emissions, and health impacts from Baseline scenario in Indian cities, 2050**



StatLink  <http://dx.doi.org/10.1787/888933169095>

Figure 4.28 compares vehicle activity, emissions of CO₂, NO_x, and PM_{2.5}, and health impacts between the alternative activity scenarios and the baseline activity scenario in 2050 in India. With the quick expansion of the vehicle market, transport activity in India is expected to increase most rapidly among the three regions evaluated. Under a *private transport-oriented* high roads scenario, the impacts on PM_{2.5} and NO_x emissions, and premature mortality will grow substantially if India remains at its current emission control level (reference scenario), but the public low scenario can reduce these impacts even with current vehicle controls. By adopting world-class emission control standards in the accelerated scenario, PM_{2.5} and NO_x emissions could be largely reduced in the long term compared to the baseline in 2050, by about 90% in the best case (public low scenario). Banning three-wheel vehicles in India shows very slight improvements on all metrics evaluated (CO₂, PM_{2.5}, NO_x, and premature mortality) compared to the baseline scenario.

Figure 4.28. Changes in activity, emissions, and health impacts from Baseline scenario in Indian cities, 2050

Conclusions: Implications for urban transport policies

Long-term urban transport planning decisions and choices in the alignment of policies towards promoting private transport or public transport-oriented urbanisation will translate into significant differences in the modal composition of urban mobility in Latin America, China and India.

In a scenario where urban policies promote private transport use, and in particular car use, by permitting sprawl, letting public transport expansion lag behind population growth, heavily investing in urban road infrastructure expansion and maintaining low fuel prices, public transport accounts for only 11% of urban mobility in Latin America and India, and 9% in China by 2050.

In contrast, alignment of policies that contain sprawl, set higher fuel prices, and prioritise expansion of public transport infrastructure over urban road infrastructure can maintain current shares of public transport in Latin American and Indian cities, and significantly limit the reduction of public transport participation in China (with public transport's participation being twice what it would be in 2050 in a baseline scenario).

The set of policies modelled in the *private transport-oriented* urbanisation scenarios increase mobility levels relative to baseline mobility in the three cases. An important driver is the increase in travel per private vehicle as a result of low oil prices. Additional mobility is in the three cases more carbon intensive and therefore generates even higher CO₂ emissions than the respective baseline scenarios. Under this policy framework CO₂ emissions related to urban transport in Latin American, China and India grow 35%, 19%, and 47% more than in the baseline scenario respectively.

Alignment of policies toward *public transport-oriented* urbanisation reduces the carbon intensity of urban mobility. This cuts transport related CO₂ emission growth by 31%, 26%, and 37% in urban Latin America, China, and India. When combined with world-class standards for vehicle emission controls, *public transport-oriented* urbanisation can reduce premature mortality caused by urban transport emissions by 87%, 55%, and 92% in urban Latin America, China, and India.

The shift to *public transport-oriented* urbanisation has certain mobility costs, as significant public transport expansion with major extensions of mass transit systems needs to be carried out before public transport systems can absorb the mobility displaced

by higher costs for private mobility. For Latin America and China, mobility under the *public transport-oriented* scenario with low road expansion infrastructure would catch up with baseline levels towards the end of the period, with a gap of only around 5% of growth in passenger-kilometres. In the case of India, despite the lower initial private mobility shares, the relatively poor public transport infrastructure has more difficulty in expanding sufficiently to meet growing mobility needs. Therefore, mobility in the *public transport-oriented* urbanisation scenarios with low roads remains below the levels delivered under baseline and *private transport-oriented* urbanisation policy frameworks in India.

Public transport and urban road investments will be a key determinant of the speed and magnitude of future two-wheeler development in Latin America. A scenario where policies are oriented towards significantly expanding and improving the public transport system can effectively limit the shift of public transport users towards these vehicles. In combination with higher fuel prices and containing sprawl this will lead to more moderate growth of two-wheelers in the region (5% average annual growth). In contrast, a scenario that aligns urban policies towards private transport use, but sees road infrastructure expansion lagging behind population growth, would generate the highest expansion of two-wheelers (9% average annual growth).

Our analysis shows that the growing share of two-wheelers in Latin American cities could be associated with CO₂ emission reductions. However, higher participation of two-wheelers in urban mobility generates major increases in pollution with negative health impacts. Effective regulation of two wheelers is critical to avoid severe damage to the health of the population.

Car ownership restrictions implemented by Chinese cities will have to be put in place with a *public transport-oriented* urbanisation policy framework in order to bring about a reduction in negative externalities. Our projections show that implementing car ownership restrictions while permitting urban sprawl, letting public transport expansion lag behind population growth and continuing to invest in urban road infrastructure expansion would generate 19% higher CO₂ emission growth than the same restriction under baseline policies. In contrast, combining car restrictions with *public transport-oriented* urban policies with low road expansion would generate 8% more mobility growth and 12% less growth in CO₂ emissions. Electric two-wheelers have a positive impact on CO₂ emissions and local air pollution but do not solve congestion issues.

India is at the beginning of its motorisation process for private cars. Under the *private transport-oriented* scenario, modal share of private cars could double by 2050. While efforts are being made to improve public transport in larger cities, several medium and small size cities do not have bus service or mass transit systems. To compensate the lack of public transport provision, Indian urban population relies on two-wheelers which explain the high motorisation rate for scooters and motorcycles. It is expected that with income growth the share of private cars will increase especially in the *private mobility-oriented* scenario.

Private transport-oriented urbanisation in all three regions could lead to significant increases in vehicle activity compared to other scenarios. On the other hand, *public transport-oriented* scenarios could slow growth in urban vehicle activity. By shifting activity from private to public transportation, CO₂ emissions growth is expected to be reduced between 26% and 37% depending on the region. However, benefits in terms of local air pollutants and health impacts are very limited without stringent vehicle emission controls

(reference scenario for technology adoption). For Latin America, largely promoting public buses could result in an increase in NO_x emissions relative to baseline growth, which can contribute to smog and secondary PM in urban areas. This is mostly a result from higher emission rates from diesel buses without advanced emission control technologies. By implementing advanced standards for emission control (accelerated scenario for technology adoption), emissions growth of local air pollutants and health impacts could be reduced by up to 87%. With world-class standards for vehicle emission controls equivalent to Euro 6/VI standards, a move towards higher rates of public transit and less reliance on private automobile could bring substantial climate and health benefits.

This analysis illustrates the potential pitfalls of considering policies targeting climate while disregarding local air pollution and health impacts. It also shows that integrated policies aiming at climate and health objectives work best, and it is possible to achieve substantial climate change mitigation, less reliance on private car and lower health impacts by promoting low sprawl and road development, and higher rates of public transit alongside more stringent controls for vehicle emissions. More specifically, results also show that for all regions analysed, increasing the share of public transport in urban mobility will only bring significant health benefits if coupled with regulations that assure improvement in emission control technologies for buses. They also show that the increasing role of two-wheelers in urban mobility can be positive in terms of CO₂ reduction, congestion and affordable mobility, but adequate regulations for motorcycle emissions are critical to avoid additional public health impacts.

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