The Compact City Scenario – Electrified

THE ONLY WAY TO 1.5°C

ITDP

UC DAVIS
UNIVERSITY OF CALIFORNIA

ACKNOWLEDGMENTS

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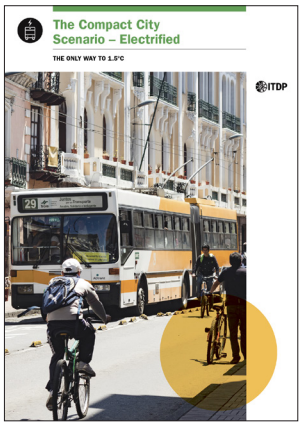

COVER PHOTO:
The Ciclopaseo in Quito, Ecuador, photo courtesy of Ted Timmons.

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INTRODUCTION

Walking and bicycling are emissions-free modes of travel. Photo from Dar es Salaam, Tanzania. **SOURCE:** ITDP Africa

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"Global warming of 1.5⁰ C and 2⁰ C will be exceeded during the 21st century unless deep reductions in CO_2 [carbon dioxide] and other greenhouse gas emissions occur in the coming decades."

— Intergovernmental Panel on Climate Change, Sixth Assessment Report

Over the next 30 years, the way people move around in cities will change. That change could take several forms, and the nature of the change will have extensive impacts on economies, public health, social justice, and the Earth's climate. These changes will be determined by the policies that governments enact now, and their effects will linger for decades or even centuries.

This study models four possible scenarios for change in urban passenger transport. It includes business as usual; extensive vehicle electrification; promotion of compact cities built around walking, cycling, and public transit; and the combination of vehicle electrification plus compact cities and mode shift. We find that neither electrification nor compact cities alone are capable of reducing emissions to a level consistent with limiting global warming to less than 2°C. Only with both vehicle electrification and compact cities together can we limit future global warming to less than 2°C and stand any chance of the climate returning to a warming of less than 1.5°C by the end of the century.

The globe has already measurably warmed. Floods, fires, and hurricanes have already become more common. With anything less than a worldwide effort that reduces carbon emissions to net-zero by 2050, or 2070 at the very latest, the Earth will warm by more than 2°C by 2100. If emissions continue to rise at their current pace, warming could exceed even 5°C. That would be a future of unprecedented and unimaginable human suffering: crops would fail, cities would flood, fires would rage. Many hundreds of millions of people[1] would become refugees or, worse, perish in famine, war, or disaster.

Road passenger transport[2] is responsible for about 10% of humanity's greenhouse gas emissions worldwide. As people in emerging economies become wealthy enough to buy cars, emissions from urban passenger transport are increasing quickly.

One promising approach to reducing emissions from urban passenger transport lies with electric vehicles (EVs). EV technology is improving rapidly, and although market shares are still very low, the right policies could promote rapid electrification of passenger fleets.

Full electrification of all vehicles combined with total grid decarbonization would, in theory, prevent all emissions from passenger transport. However, as this study concludes, even highly ambitious goals for electrification and grid decarbonization are unlikely to entirely displace internal combustion engine (ICE) vehicles by 2050, meaning that electrification alone is not capable of reducing emissions to the level required for warming of less than 2°C.

Another approach to decarbonizing urban passenger transport is the promotion of compact cities built around walking, bicycling, and public transport. Relative to automobile-oriented development, this approach to urban planning can dramatically reduce the demand for car travel.

1 Kanta Kumari Rigaud et al. (2018), Groundswell: Preparing for Internal Climate Migration, World Bank, Washington, DC.
2 Not including freight or aviation. See Hannah Ritchie (2020), Cars, planes, trains: where do CO2 emissions from transport come from?, Our World in Data, October 6; International Energy Agency (2020), Energy Technology Perspectives 2020, IEA, Paris

Cities around the world, from Copenhagen to Bogotá, have already seen great benefits from pursuing this strategy. In addition to reducing carbon emissions, compact cities can reduce the cost of transportation while promoting social inclusion.

Both electrification and compact cities have enormous potential to decarbonize urban passenger transport. But the scale of the challenge is greater than either. As we demonstrate below, neither of those strategies alone is sufficient to reduce emissions to a level consistent with limiting global warming to less than 2°C. For that, electrification and compact cities must be combined.

Because neighborhoods are hard to change after they have been built, it is especially important for today's rapidly growing cities to embrace the growth patterns described in this study. The planning of cities can have impacts that are extraordinarily long-lived: though the buildings have changed, the streets of Xi'an or Rome follow much the same paths they have for millennia. And a city's street network, like its density, is fundamental in determining what kind of transportation system the city will have. It is possible to retrofit sprawling suburbs like those of North America, with their wide roads and large blocks, and make them friendly to bicycling and transit. But it is much easier to prevent such suburbs from ever being built in Africa and India. Over the next 30 years, about 2 billion more people will come to live in our world's cities. By acting today, we can ensure they live in neighborhoods that will be sustainable from the beginning.

1.1A
PREVIOUS STUDIES AND PEER REVIEW

This is the fourth joint research study by ITDP and UC Davis to model the impacts of possible future scenarios in urban passenger transport.[3] Like our previous studies, this research was conducted under the review of a panel of experts representing international organizations specializing in the subject matter. These experts included representatives of:

- International Energy Agency
- International Transport Forum
- ClimateWorks Foundation
- Global Fuel Economy Initiative

They examined the study's assumptions, methodology, and conclusions to ensure the feasibility of the scenarios and, given those scenarios, the accuracy of the conclusions.

1.1B
COVID-19

The COVID-19 pandemic has had an unprecedented effect on worldwide transportation in 2020 and 2021. But the longer-term impacts of the pandemic are not yet clear, so we have chosen to treat COVID-19 as an anomaly and use 2015 as the base year of our analysis.

3 ITDP (2017), Three revolutions in urban transportation, *Transport Matters (blog)*, May 3; ITDP (2015), A global high shift cycling scenario, *Transport Matters (blog)*, November 12; Michael Replogle and Lewis Fulton (2014), A Global High Shift Scenario: Impacts and Potential for More Public Transport, Walking and Cycling with Lower Car Use, ITDP, New York.

MODELING APPROACH

2

2.1 METHODS

This report builds on three previous urban travel studies undertaken by UC Davis and ITDP and uses the same modeling tool: an urban passenger travel model including vehicle sales, stocks, technology and energy types, and travel activity. The modeling tool is calibrated with present-day[4] data. We aggregate detailed figures from the International Energy Agency (IEA) and other sources into eight world regions.[5] At the regional level, we employ the same "ASIF" structure used in many other transportation models:

Activity * Structure * Intensity * Fuel

- **Activity:** travel per capita
- **Structure:** the share of modes used (in turn, a function of vehicle sales and stocks by mode and technology type)
- **Intensity:** the efficiency of modes, measured as fuel use per kilometer
- **Fuel:** the carbon intensity of the fuels and energy carriers used by different types of vehicles, measured in carbon emissions per unit of fuel

We use this approach to model four scenarios for the future of urban passenger transport (described in Section 2.2). We start by projecting the *Business as Usual* scenario for each region to 2050, taking into account population and income growth. Those trends drive car ownership rates and other modal choices. To a large degree, our *Business as Usual* scenario is calibrated to the projections of the IEA Mobility Model.

The three other scenarios model futures in which changes in policy alter the development of urban passenger transport. We do not explicitly link policies to numerical impacts. Rather, we qualitatively envision the policies that will be needed (see Section 4) and quantitatively estimate the effects those policies could have on activity, structure, intensity, and fuel (see Sections 3 and 4). These estimates were informed by scientific literature and industry-standard models and were reviewed by experts from the field's leading international organizations (see Box 1.1A).

4 Actually, 2015 data to avoid anomalies due to COVID-19.
5 USA, OECD Europe, China, India, Brazil, Other Latin America, Middle East / Africa, and Other Europe / Asia.

2.1A
IMPROVEMENTS IN MODELING

The Compact City Scenario—Electrified differs from previous ITDP–UC Davis studies in three key respects:

1 Our scope is not limited to greenhouse gas emissions from the operation of vehicles ("Well-to-Wheel"). Rather, we include emissions from vehicle manufacture and disposal, which is especially important for electric vehicles because of the carbon-intensive processes of creating batteries. We also include emissions from the construction and maintenance of infrastructure, including roads, rails, bicycle lanes, and parking spaces. Recent work by the International Transport Forum[6] and the International Council on Clean Transportation[7] has established a basis for modeling these indirect emissions, which are no less a part of urban passenger transport. For all sources of emissions, there is some uncertainty about how much decarbonization could occur between now and 2050. For electricity generation, we assume deep decarbonization as per the International Energy Agency *Sustainable Development Scenario*. For vehicle production, disposal, and infrastructure, we assume fairly strong decarbonization, on the order of 50–60% between now and 2050, in line with the decarbonization of industry described in the International Energy Agency's more conservative *Announced Pledges Scenario*.

2 We model changes in urban land use and density in detail at the city level, based on high-resolution population density data from 2000 and 2015 published by the European Commission.[8] These projections are aggregated to the regional level to estimate future travel demand. See Section 2.2.3 for more detail.

3 The projected rate of vehicle electrification (in our *High Electrification* and *Electrification+Shift* scenarios) is much higher than ever before. Achieving nearly 100% electric vehicle sales in all regions and modes by 2040 represents a far more aggressive goal than anything we have modeled in past studies. Meanwhile, our projections of potential modal shift have remained generally consistent with previous reports.

2.1B
INTENTIONAL OMISSIONS: BIOFUELS AND AUTONOMOUS VEHICLES

Certain variables, though relevant to the future of urban passenger transport, remain beyond the scope of this study. Two of these are biofuels and autonomous vehicles. Although biofuels will prove critical for decarbonizing the global transport sector more broadly, they are of greater importance in shipping, aviation, and long-distance trucking, which are more difficult to electrify than urban passenger transport.[9]

The potential impacts of autonomous vehicles are discussed in our previous study *Three Revolutions in Urban Transportation*.[10] Since that report was published, industry expectations for the proliferation of autonomous vehicles have become more conservative. To avoid the uncertainty in predicting progress in and uptake of autonomous vehicle technology, we have omitted automation from our study, focusing instead more cleanly on electrification and modal shift.

6 International Transport Forum (2020), Good to Go? Assessing the Environmental Performance of New Mobility, ITF, Paris.
7 Georg Bieker (2021), A Global Comparison of the Life-Cycle Greenhouse Gas Emissions of Combustion Engine and Electric Passenger Cars, International Council on Clean Transportation.
8 European Commission, GHSL – Global Human Settlement Layer, EC, Brussels.
9 International Energy Agency (2021), Net Zero by 2050, IEA, Paris, pp. 134–135.
10 Lew Fulton, Jacob Mason, and Dominique Meroux (2017), Three Revolutions in Urban Transportation, ITDP and UC Davis.

2.2 SCENARIOS

The future of global urban passenger transport is such a massive topic that it can be difficult to imagine. A rough pre-pandemic estimate of passenger travel worldwide in 2020 is provided by the IEA: about 28 trillion kilometers, or about 3,500 kilometers per person per year as a world average. But the future is uncertain. We consider four potential scenarios: simplified narratives that illustrate potential futures in broad strokes.

These are "forecasting" scenarios, rather than the "backcasting" scenarios employed by other modelers. In "backcasting" studies, the authors establish a goal—for example, a net-zero emissions transportation sector—and consider how that goal may be achieved. Our approach starts with feasible, plausible paths for the future of the transport sector, paths that could be accomplished by the promotion of known policies. Then we estimate the passenger and vehicle travel, energy use, emissions and costs that these paths would entail.

While our *Business as Usual* scenario is a straightforward projection of past trends and stated policies into the future, our other three scenarios—*High Shift*, *High Electrification*, and *Electrification+Shift*—are highly ambitious, requiring substantial changes in travel patterns, vehicle adoption, and policy at levels from the international to the local. But these futures are feasible. They can be accomplished with current levels of transport funding, current technologies, and relatively conservative projections of technological trends. Section 4 of this report identifies the key policies that could bring these scenarios to reality.

We focus on three particular years: 2015, 2030, and 2050. We avoid 2020 because data on all needed variables are not yet widely available and because the coronavirus pandemic has made it an anomalous year for transportation. We generally assume a steady set of changes between 2015 and 2030 in these scenarios and that any major deviations from these trends caused by the pandemic are eliminated by 2030 or well before. Trends also are assumed to have strong continuity from 2030 to 2050. However, this does not mean every trend is treated as linear. For example, some changes in sales of different types of vehicles accelerate over time, creating logistic or "S" curves. Stocks of vehicles lag sales as the fleet turns over. We generally assume that deviations from our *Business as Usual* scenario take time to occur, with faster changes after 2030 than before.

2.2.1 BUSINESS AS USUAL SCENARIO

The *Business as Usual* scenario reflects current trends in urban passenger transportation. It is a future that looks a lot like the present—only on a larger scale.

This is a future defined by rapid proliferation of private cars powered by ICEs in low- and middle-income countries. In the Africa–Middle East region, for example, the number of such vehicles grows by a factor of five between 2015 and 2050, reaching 224 million cars by 2050—significantly more cars than are in urban areas of the United States today. Meanwhile, high-income countries see expansion of both automobile fleets and public transit service, but the vast majority of motorized travel remains dependent on fossil fuels.

The *Business as Usual* scenario relies on the IEA projections, as presented in the *Energy Technology Perspectives 2020* report,[11] and as contained in the IEA Mobility Model used for that report. This model provides the basis for the growth in travel by mode and region, and the growth in vehicle sales and stocks by vehicle and technology type, through 2050.

In this scenario, travel patterns are dominated by increases in personal vehicle travel, including two-wheelers and light-duty vehicles (cars, SUVs, pickup trucks, minivans). This growth comes at the expense of public modes, such as buses and rail systems, which grow only slowly in most parts of the world. EV market shares also grow slowly, reaching about 10% of global car sales by 2050.

11 International Energy Agency (2020), Energy Technology Perspectives 2020, IEA, Paris.

FIGURE 2.2.1
A car-oriented street in Cairo represents the future for much of the world under Business as Usual.
SOURCE: Friedrich Stark via Alamy Stock

EQUITY IMPACTS OF *BUSINESS AS USUAL*

The *Business as Usual* world is a world of widening gaps between the wealthy and the poor. As cities become ever more car dependent, it becomes increasingly difficult for those outside of cars to get around. The negative externalities of car use fall disproportionately on the poor: air pollution, noise pollution, and traffic fatalities most affect those who can afford no choice but to live near highways. Urban highways cut through urban neighborhoods. In some places, low-density suburbs sprawl into agricultural and natural areas; in others, car-oriented high-rise housing subjects inhabitants to high levels of noise and air pollution from traffic. In this scenario, people drive more and walk and bicycle less, resulting in mental and physical challenges to public health.

2.2.2 HIGH ELECTRIFICATION SCENARIO

Today, battery technology is improving rapidly and the purchase price of new EVs is falling. In all major world markets, the lifetime emissions of EVs are considerably lower than those of vehicles powered by fossil fuels. The market share of EVs in most countries is still low, but rising. Over the coming decade, EVs could significantly displace sales of ICE vehicles. This could occur in concert with grid decarbonization efforts. As an added benefit, vehicle electrification would reduce not only the emission of greenhouse gases but also the emission of local air pollutants.[12] Air pollution is a major cause of death in much of the world, so electrification will save lives in the short as well as long term.

The *High Electrification* scenario considers a world in which EVs are pursued intensely and almost exclusively as a strategy to decarbonize urban passenger transport. In this scenario, policymakers commit wholeheartdly to electrification but do not attempt to significantly change the paradigm by which our cities are planned or the modes by which people travel, relative to the *Business as Usual* scenario. We assume ongoing progress in EV technology (longer driving ranges and ongoing drops in battery cost) such that EVs become mainstream and cost competitive by 2030 in most countries. We also assume that the worldwide electricity grid has been largely decarbonized by 2050, consistent with the IEA *Sustainable Development Scenario*.[13]

The *High Electrification* world superficially looks a lot like the *Business as Usual* world. There is the same quintupling of African passenger cars, the same relative status quo of modal splits in higher-income countries. But in this scenario, most of those cars are electric by 2050.

This scenario relies on projections of vehicle electrification adapted from the recent COP26 declaration of a goal to end the sale of fossil-fuel-powered cars and vans worldwide by 2040.[14] It meets or exceeds the electrification rates of ambitious electrification scenarios recently proposed by the United Nations Framework Convention on Climate Change, the IEA, BloombergNEF, and the Global Fuel Economy Initiative. Under this scenario's projections, 84% of the world's motorized passenger vehicle fleet (including cars, buses, and two- and three-wheelers) is electrified by 2050.

FIGURE 2.2.2
This photo from Los Angeles shows the kind of car-centric infrastructure that will be prevalent in a High Electrification future.
SOURCE: GaudiLab via Shutterstock

12 Some local air pollutant emissions are still caused by tire and brake lining abrasion. See Francesco Cetta et al. (2008), Comment on "Emissions from brake linings and tires: Case studies of Stockholm, Sweden 1995/1998 and 2005", *Environmental Science & Technology* 42(7), 2708–09.

13 *The Sustainable Development Scenario* projects a future of warming below 2°C. For simplicity's sake, we assume this level of grid decarbonization in all four scenarios.

14 UN Climate Change Conference UK 2021 (2021), COP26 declaration on accelerating the transition to 100% zero emission cars and vans, 10 November

EQUITY IMPACTS OF *HIGH ELECTRIFICATION*

High Electrification entails many of the same inequitable impacts as *Business as Usual.* Public health suffers as people walk and bicycle less. Low-income people who cannot afford cars find that their access to opportunities is curtailed by car-dominated urban planning. Suburbs expand into farmland. However, the population does not suffer from increased air pollution as in the *Business as Usual* scenario. The worst impacts of climate change, which disproportionately impact more vulnerable populations, are mitigated.

2.2.3 HIGH SHIFT SCENARIO

Cities around the world have begun embracing compact land-use policy and redesigning their transportation systems with the goal of enabling residents to travel as easily by transit, bicycle, or walking as they can by car. This decreases the demand for car ownership and use, reducing emissions even if cars remain powered by fossil fuels.

Compact, mixed-use, transit-oriented land-use policies can reduce the overall demand for urban travel by making people's trips shorter. Bus lanes, bicycle lanes, rail transit, and pedestrian sidewalks can also make those modes more inviting than driving, encouraging modal shift. Like electrification, modal shift also brings benefits besides decarbonization. Because modal shift improves mobility for poorer people especially, cities become more equitable. Because people walk and bicycle more, public health improves, which reduces healthcare costs.

The *High Shift* scenario describes an ambitious yet plausible future in which governments at all levels commit to building more and better public transit, bicycling, and pedestrian infrastructure while pursuing sustainable land-use policies and traffic reduction strategies. The scenario presumes only a very limited increase in overall transport funding, but rather the political will to direct that funding toward proven multimodal strategies.

In this scenario, cities around the world grow to look more like Barcelona than Atlanta. There is an overall decrease in driving in high-income countries, while low- and middle-income countries see a much slower growth in driving than they do in *Business as Usual* or *High Electrification*. Rapid transit networks expand quickly, and electric bicycles become particularly widespread. Electric cars and buses, however, are not common. Funding to build transit and bicycle infrastructure comes at least partly from reduced spending on road and parking construction and maintenance. Tax policies may need to change, but the revenues required should not cause undue burden on taxpayers; the public will also save enormous amounts of money on vehicle- and fuel-related costs.

The compactness of cities, measured by their urban density, is a key factor in determining the feasible extent of shift from cars to other modes of travel. Unlike previous ITDP–UC Davis reports, this study made an in-depth examination of urban densities and used the findings to inform projections of modal shift.

First, we used the European Commission's Global Human Settlement Layer,[15] available for 2000 and 2015, to understand current conditions and trends in urban density for every city on Earth with a population greater than 300,000. We then aggregated these city-level projections into regional-level summaries.

The *Business as Usual* density projections extend the trends identified from the Global Human Settlement Layer. The *High Shift* projections imagine that cities allocate new population growth to densify as many neighborhoods as possible to the threshold of 4,000 people per square kilometer. This number is meant as an approximation of the density at which transit, walking, and cycling can feasibly replace driving for most daily needs. New greenfield development is only permitted once the entire city reaches that threshold, and that greenfield development is assumed to be at least 16,000 people per square kilometer.

15 European Commission, GHSL – Global Human Settlement Layer, EC, Brussels.

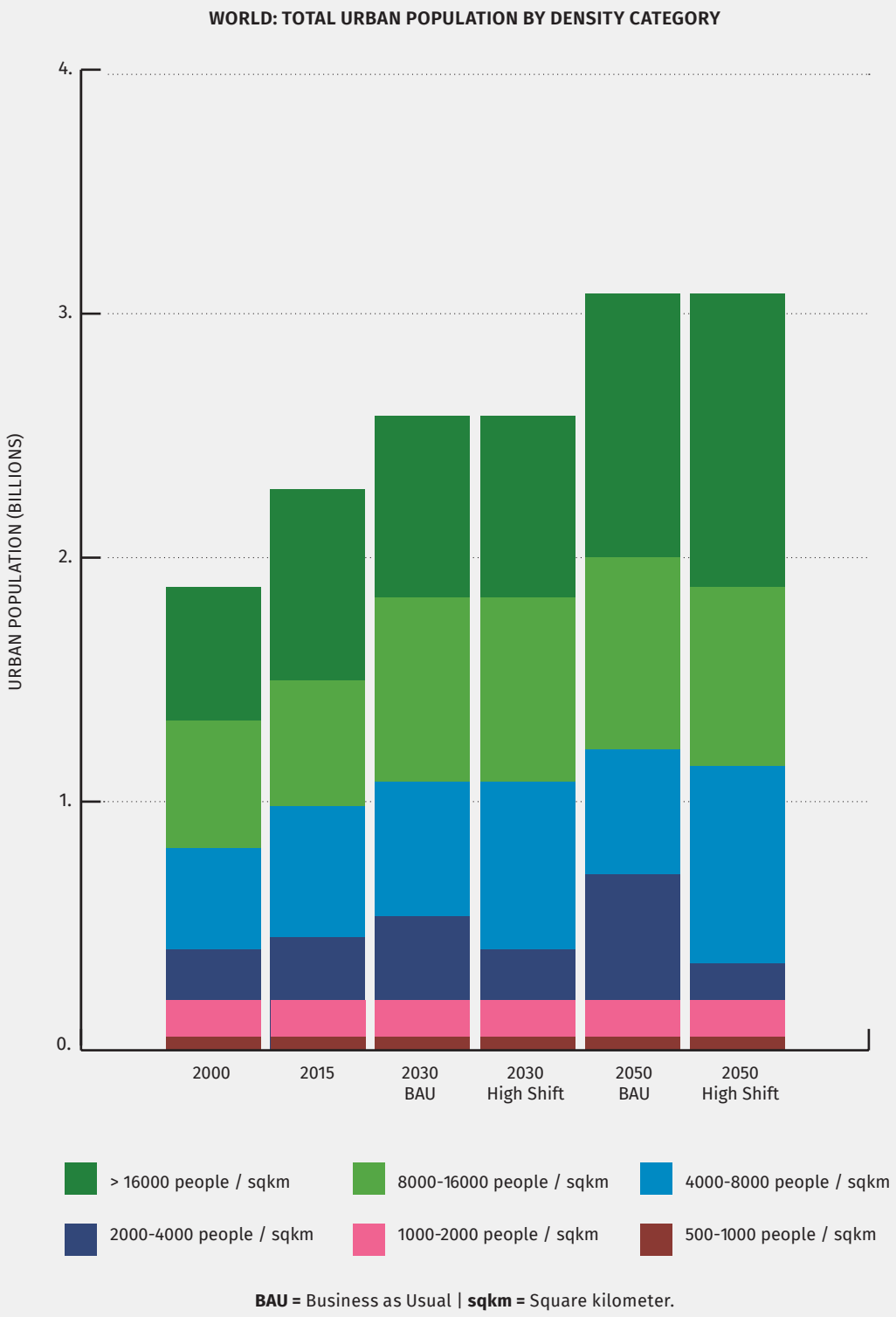


TABLE 2.2.3.A
The greatest difference between Business as Usual and High Shift is the reduction in the number of people living in urban neighborhoods of fewer than 4,000 people per square kilometer.

TABLE 2.2.3.A
Although city populations grow at the same rate in all scenarios, sprawl is much more limited in the *High Shift* than the *Business as Usual* scenario.

	2000–2015	*Business as Usual*, 2015–2050	*High Shift*, 2015–2050
Growth in urban population	400 million people (23% relative to 2000)	800 million people (34% relative to 2015)	800 million people (34% relative to 2015)
Growth in urban extent	51,000 km^2 (13% relative to 2000)	110,000 km^2 (24% relative to 2015)	13,000 km^2 (3% relative to 2015)

We recognize that density is not the only land-use factor to influence travel demand and that the mixing of land uses is also particularly important. However, with no reliable global data available on land-use mix, that topic is outside the scope of this study.

After projecting future densities (Fig. 2.2.3A), we combined the *Business as Usual* region-specific density distribution with a formula adapted from the gravity model of human mobility,[16] relating density to relative travel demand. This allowed us to project overall person-kilometers traveled per year for the Business as Usual and High Shift scenarios, independent of mode; we project a roughly 11% reduction in travel activity in the latter scenario (see Section 3.1).

Our second step was to estimate the modal shift that would result only from a change in density. If a city grows denser, we assume that its modal split will change to be more like the modal split of other dense cities in its region, even without any policy shift toward transit, walking, or cycling beyond the construction of proportionate infrastructure.

Third and finally, we applied a mode shift factor representing the impacts of transportation policies associated with a *High Shift* scenario (Table 2.2.3B). This factor reallocated travel activity from cars to other modes (and to telecommuting) in a way dependent on the density distribution of each region. For example, in very low-density areas, such as suburban parts of the United States, only a minority of driving can be shifted to other modes by 2050. But in dense and rapidly growing areas, like many Indian cities, a much greater shift is possible: a regionwide reduction of driving by about 60% relative to *Business as Usual*.

TABLE 2.2.3.B
Modal shift factors: Percentages of travel by private car, ride-hailing, and motorcycle that shifts to other modes in the *High Shift* scenario due to policy and infrastructure change, by density category.

	500–1,000 people/km^2	**1,000–2,000 people/km^2**	**2,000–4,000 people/ km^2**	**4,000–8,000 people / km^2**	**8,000–16,000 people / km^2**	**>16,000 people / km^2**
2030	3%	6%	10%	17%	20%	23%
2030	10%	20%	30%	50%	60%	70%

By 2050, relative to Business as Usual, the High Shift scenario projects a reduction of about 52% in person-kilometers traveled by car and motorcycle worldwide.

Changes on this scale are ambitious, but not unprecedented. Paris decreased car travel by almost 50% in 30 years by investing in other modes and traffic control strategies.[17] Jakarta built a mass transit system with nearly a million riders a day in only 15 years.[18] We do not anticipate massive shifts in the most mature markets, such as the US and European Union, but shifts in these regions are still significant. Fast-growing countries experience much bigger changes relative to Business as Usual, as they shift growth patterns and avoid building car-centric infrastructure.

16 Markus Schläpfer et al. (2021), The universal visitation law of human mobility, *Nature* 593, pp. 522–27.
17 Frédéric Heran (2017), Á propos du report modal, les enseignements du cas parisien, *Les Cahiers Scientifiques du Transport* 71/2017, pp. 99–124. See this article for English language coverage.
18 ITDP (2019), A dignified ride, *Transport Matters* (blog), 15 November.

FIGURE 2.2.3
In certain parts of Mexico City, improved infrastructure for public transit and bicycling has already led to the kinds of modal shifts projected in High Shift.

EQUITY IMPACTS OF *HIGH SHIFT*

In a world of diminished driving, the poor enjoy improvements to personal mobility. Living in compact, mixed-use cities with bicycle lanes and rapid transit, they find it easier to attend to their daily needs in less time. Increased rates of bicycling promote cardiovascular health, decreased driving improves air quality, and pedestrian-friendly streets reduce traffic violence (today, the seventh-highest cause of death in low-income countries)[19]. *High Shift*'s walkable cities are also more resilient, better able to withstand disasters such as fuel crises.

19 World Health Organization (2020), The top 10 causes of death, WHO, December 9.

2.2.4 ELECTRIFICATION +SHIFT SCENARIO

The *Electrification+Shift* scenario is a combination of the *High Electrification* and *High Shift* scenarios. It is a world of modal shift away from cars toward walking, bicycling, and public transit—and of massive electrification of motorized vehicles.

Although the *Electrification+Shift* future may seem to require even more governmental initiative than either High Shift or High Electrification alone, it is in fact facilitated by substantial synergies between those scenarios.

One of the greatest obstacles to achieving the *High Electrification* scenario is being able to meet the staggeringly high demand for new EVs, including their batteries, and providing the clean electricity needed to power them. By decreasing the demand for driving overall, *High Shift* combined with *High Electrification* lowers that obstacle (see Section 3.3).

Another synergy lies in the cost of realizing these futures. Because private cars are so expensive to operate on a per-passenger-kilometer basis, the *High Shift* scenario entails a massive reduction in the direct private and public costs of urban passenger transport (see Section 3.6). In the *Electrification+Shift* scenario, these savings can be channeled into programs to support electrification.

FIGURE 2.2.4
The electric buses of the bus rapid transit system in Nanning, China, exemplify the *Electrification+Shift* future.
SOURCE: ITDP China

EQUITY IMPACTS OF *ELECTRIFICATION+SHIFT*

This scenario brings all the benefits of the High Shift scenario, combined with a much greater reduction in air and noise pollution due to vehicle electrification.

RESULTS

3

The modeling approach allowed us to compare the Business as Usual, High Electrification, High Shift, and Electrification+Shift scenarios according to several of their impacts. These measurements were all taken at the level of the eight major world regions and aggregated to the global scale.

Our key findings include the following:

- Even the *High Electrification* scenario, aligning with the most ambitious goals stated by any major international organization, is incapable of fully electrifying all motor vehicle fleets by 2050.
- Although both *High Electrification* and *High Shift* could result in major greenhouse gas reductions by 2050, neither scenario alone is capable of reductions sufficient for consistency with possibly limiting anthropogenic global warming to 1.5°C. That extent of decarbonization can only be achieved by combining *High Electrification* with *High Shift*.
- If decarbonization of electric grids is slowed, greenhouse gas reductions from *High Electrification* will be attenuated, but reductions from *High Shift* will not be.
- The *High Shift* and E*lectrification+Shift* scenarios could reduce the direct public and private costs of urban passenger transport by as much as a third: about US $5 trillion annually.

3.1 TRAVEL ACTIVITY

Over the next 30 years, the world's population will grow larger and more urban. With those increases in population and resources, global urban passenger travel activity will roughly double.

In different scenarios, the growth in travel activity is accommodated differently (Fig. 3.1A). *Business As Usual* handles the increased travel demand the same way we handle most urban passenger transport today: with ICE cars. There is some increase in transit, walking, bicycling, and EV use in wealthier countries, but it is dwarfed by the massive increase in ICE cars in middle-income and, especially, low-income countries. In the Africa–Middle East region, for example, car fleets increase by a factor of five.

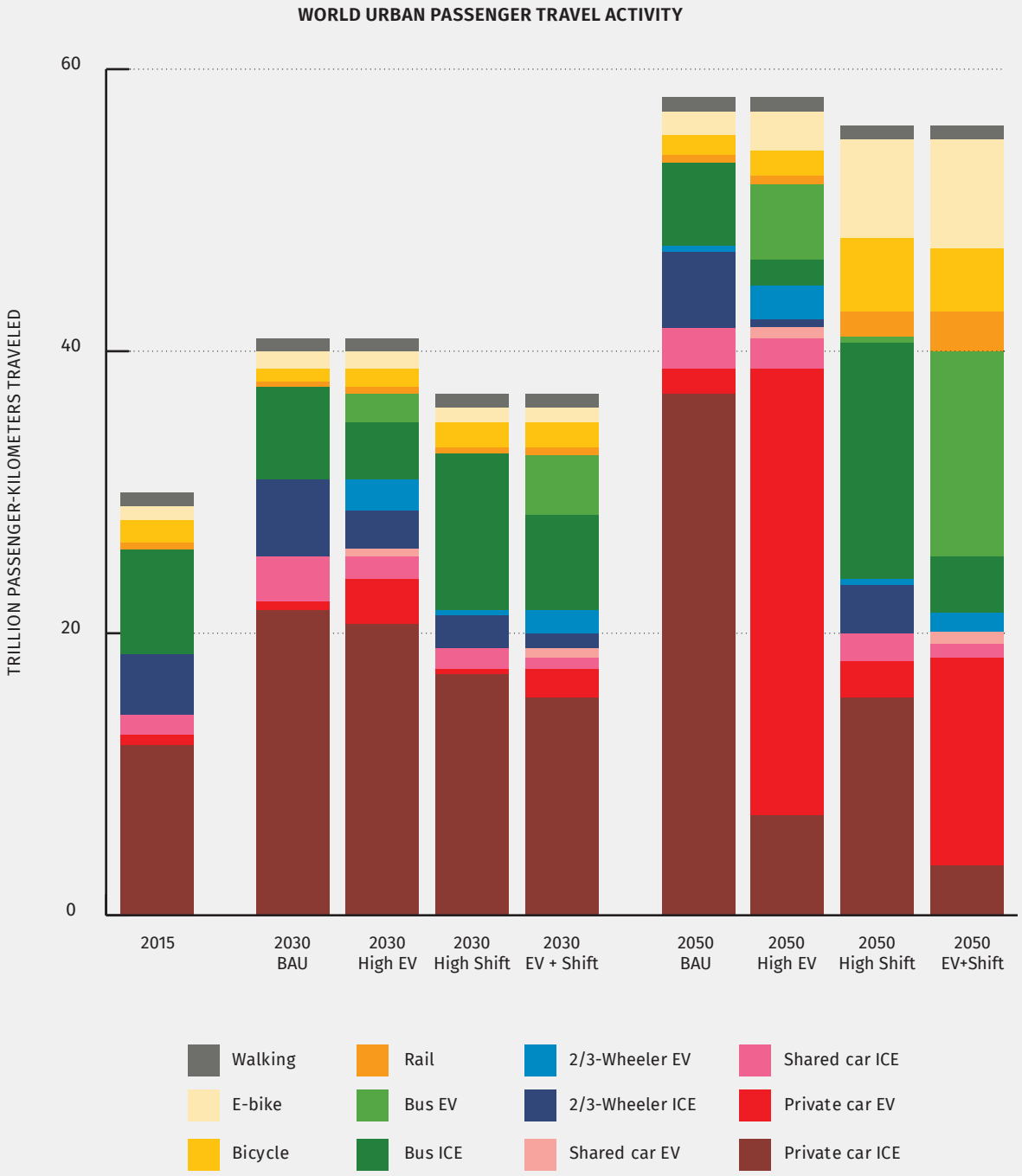
High Electrification exhibits the same general modal split as *Business as Usual*, but the source of power within each mode changes. Instead of ICE, the majority of bus, motorcycle, and car travel is by EV by 2050. The small fraction of motorized vehicle travel that remains ICE-powered in 2050 is due mostly to older vehicles that are still on the road, and after 2050 that fraction may be expected to diminish quickly.

High Shift illustrates a future of two key changes in urban passenger travel activity. First, transit-oriented development and other policies promote compact, mixed-use cities. Combined with rapid growth in telecommuting, especially in wealthier countries, this results in a reduction in global urban travel demand of about 6.5 trillion passenger-kilometers annually (11% of the *Business as Usual* total). Second, a great amount of the travel that would be done by car under *Business as Usual* is done by walking, bicycling (particularly e-bicycling), and

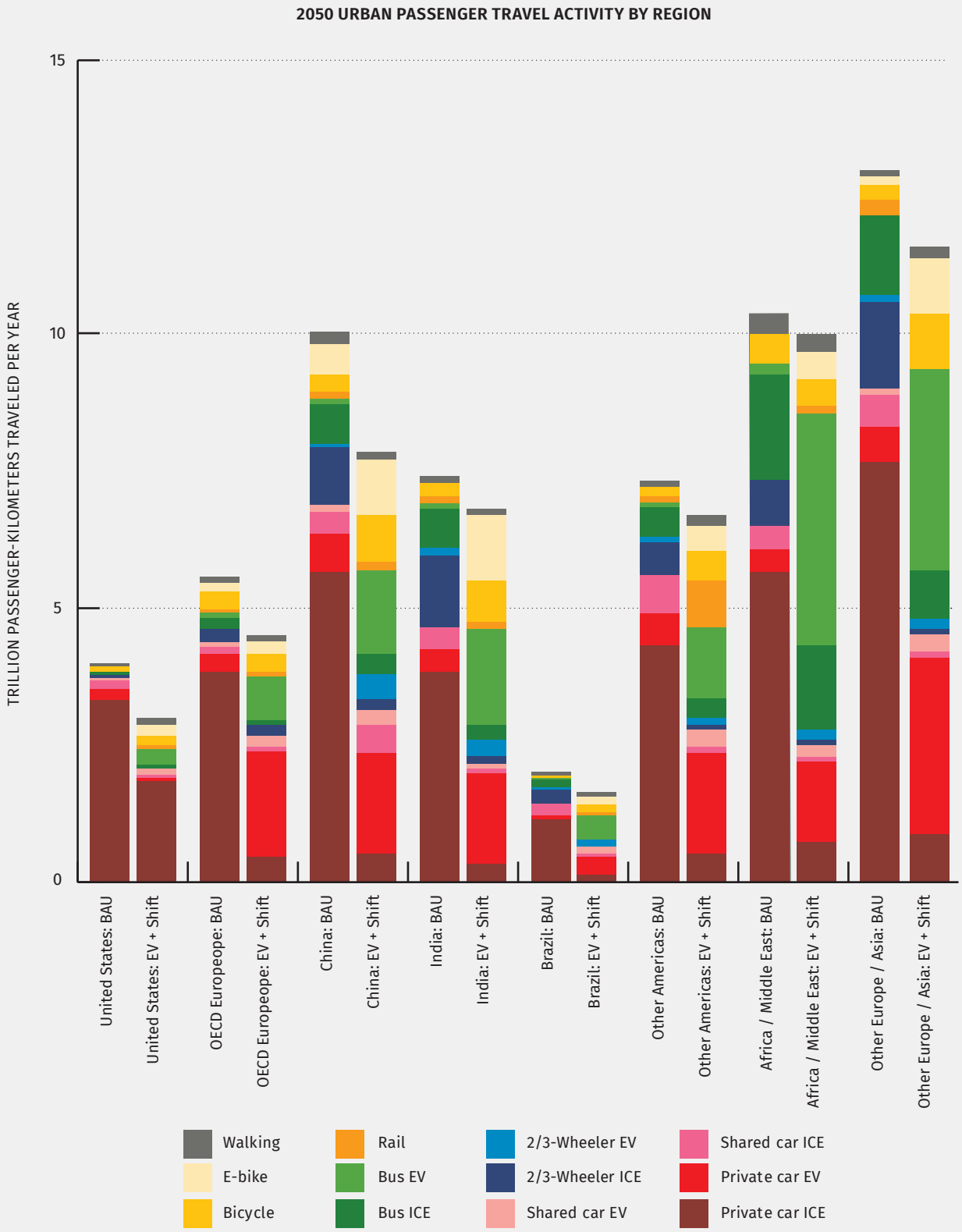
especially by public transit under *High Shift*. Wealthier regions see an absolute decline in driving relative to 2015, while low- and middle-income countries see a much slower increase. However, the powertrains of these vehicles are proportionately the same as they are in *Business as Usual*, meaning that the great majority of the buses and cars remaining on the road are still powered by fossil fuels

FIGURE 3.1.A
Urban passenger travel activity is lower and less car dominated in the Shift scenarios.

The *Electrification+Shift* scenario projects a future in which the modal splits from *High Shift* are combined with the electrification rates of *High Electrification*. This scenario has by far the lowest extent of ICE car travel by 2050: only 3 trillion passenger-kilometers per year, compared with *Business as Usual*'s 37 trillion (Fig. 3.1A).



BAU = Business as Usual | **EV** = Electric vehicle | **EV+Shift** = Electrification+Shift | **High EV** = High Electrification
ICE = Internal combustion engine.



BAU = Business as Usual | **EV** = Electric vehicle | **EV+Shift** = Electrification+Shift
ICE = Internal combustion engine | **OECD** = Organisation for Economic Co-operation and Development.

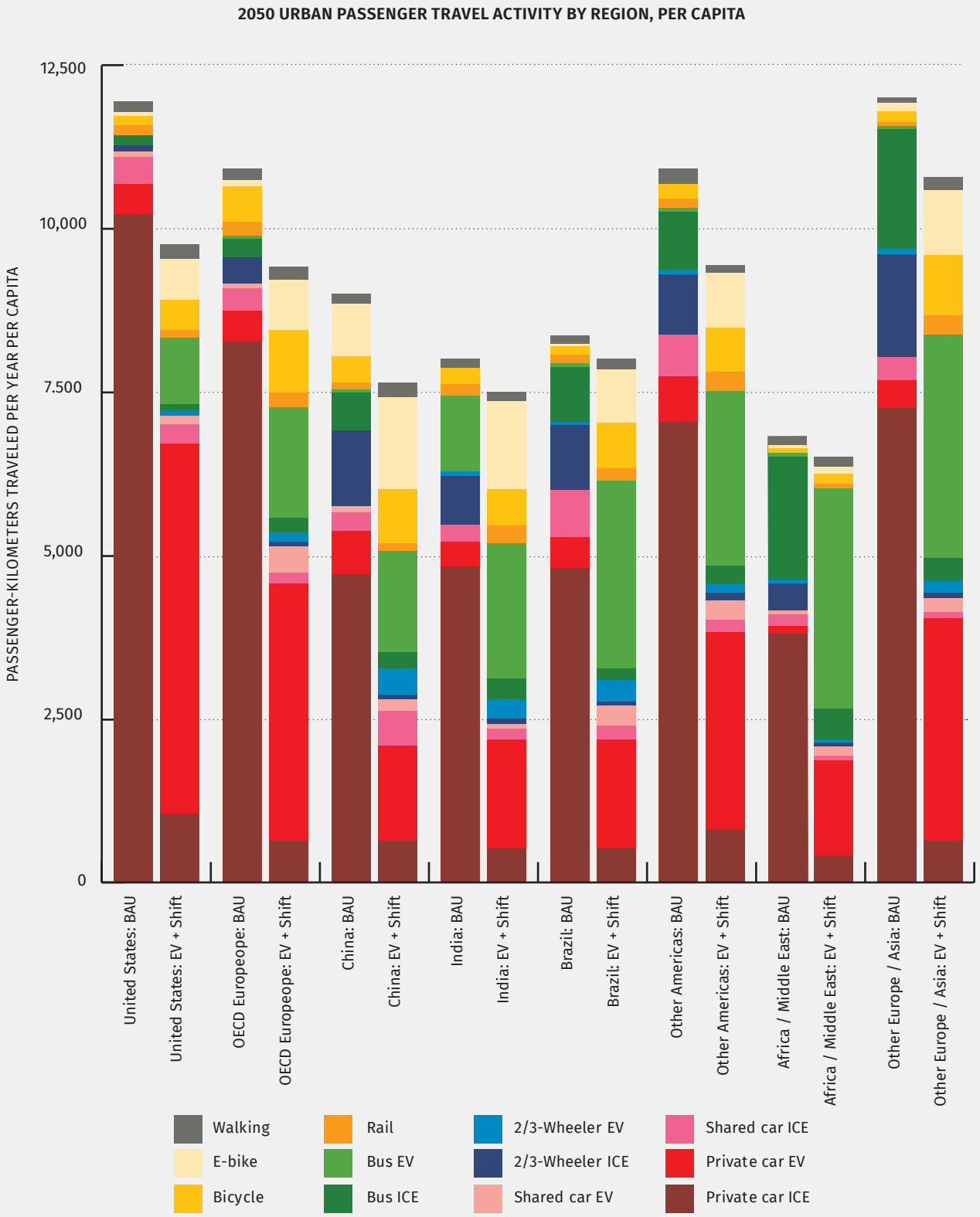
FIGURE 3.1.B
All regions could see major shifts from private ICE car travel to electric cars, transit, and bicycling.

The *Electrification+Shift* scenario sees the greatest gains from electrification in the wealthiest regions, including the United States and the European members of the Organisation for Economic Co-operation and Development, and the greatest gains from mode shift in the fastest-growing regions, including India, Africa and the Middle East, and other European countries and Asia (Figs 3.1B and 3.1C).

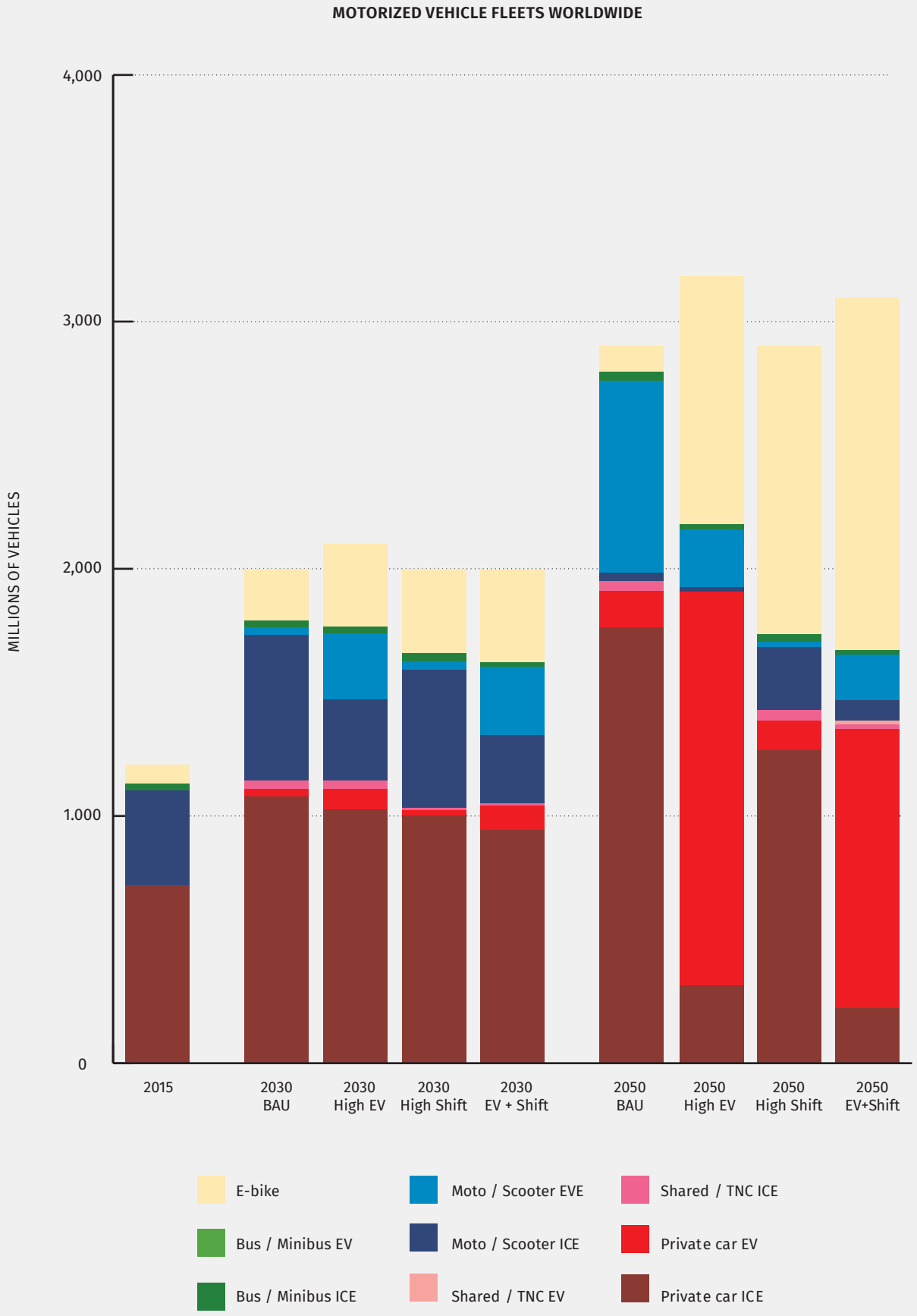
3.2
FLEET COMPOSITION

FIGURE 3.1.C
Wealthier regions could see a greater reduction in travel activity per capita and more extensive electrification, while less wealthy regions could see a greater shift to bicycling and public transit.

Across all four scenarios, the world will witness roughly a doubling in the size of urban passenger vehicle fleets by 2050. In all scenarios except *Business as Usual*, a substantial amount of this growth is accommodated by electric bicycles. In the *Electrification* scenarios, by 2050, the majority of car, bus, and motorcycle fleets are electric. And in the *High Shift* scenarios, growth in car and motorcycle fleets is substantially slowed by modal shift to public transit (Fig. 3.2).



BAU = Business as Usual | **EV** = Electric vehicle | **EV+Shift** = Electrification+Shift
ICE = Internal combustion engine | **OECD** = Organisation for Economic Co-operation and Development.

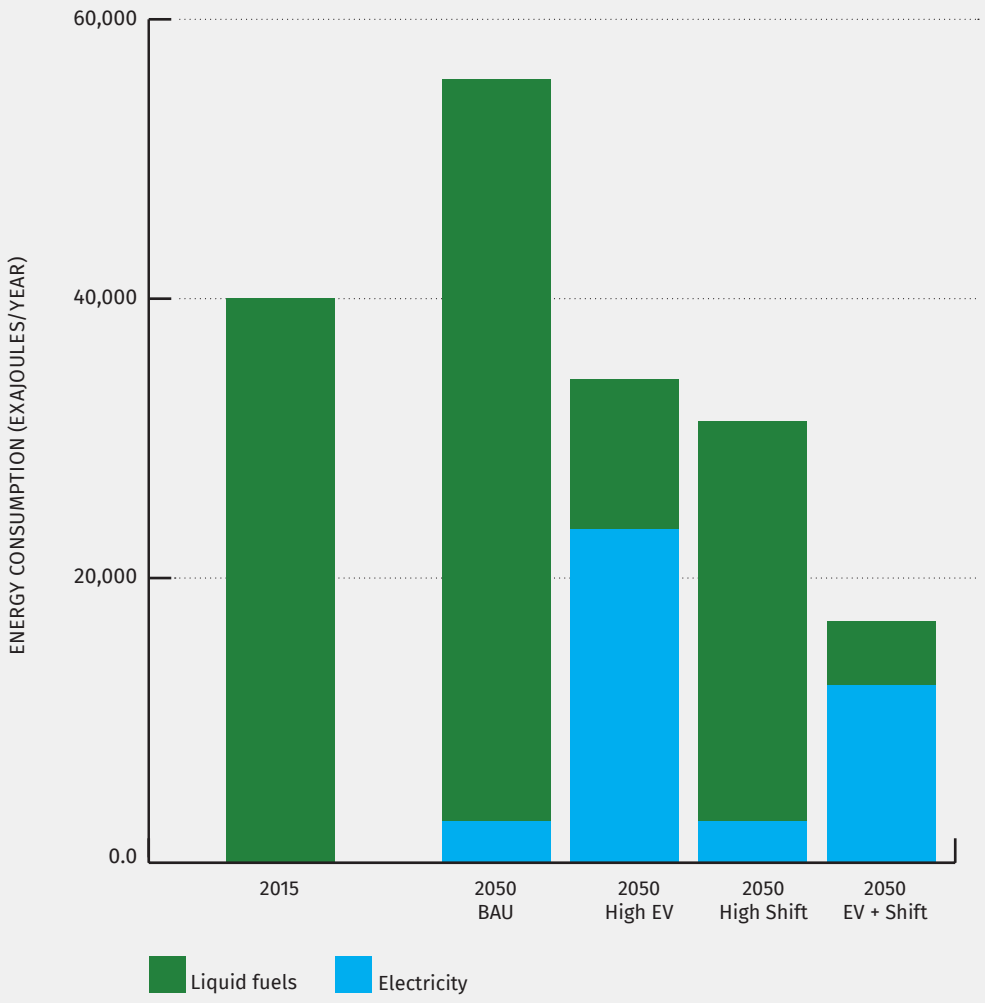


BAU = Business as Usual | **EV** = Electric vehicle | **High EV** = High Electrification (horizontal axis)
EV+Shift = Electrification+Shift | **ICE** = Internal combustion engine | **TNC** = Transportation Network Companies (ridehailing).

3.3
ENERGY CONSUMPTION

One of the major prerequisites for large EV fleets, of cars or of buses, is an expanded electrical power supply. If electrification is to result in the greatest greenhouse gas emission reductions, that power supply must be from renewable energy. Although the overall demand for energy drops by a similar extent in both *High Electrification* and *High Shift*, the *High Electrification* scenario represents a massive, unprecedented increase in demand for electricity for urban passenger transport.

ANNUAL GLOBAL ENERGY CONSUMPTION FROM URBAN PASSENGER TRANSPORT, BY ENERGY SOURCE



BAU = Business as Usual | **EV+Shift** = Electrification+Shift | **High EV** = High Electrification.

PREVIOUS PAGE
FIGURE 3.2
Extensive e-bicycle fleets are an essential element of transport decarbonization.

RIGHT
FIGURE 3.3
The High Electrification scenario creates a large demand for sustainable electricity, which is lessened by Electrification+Shift.

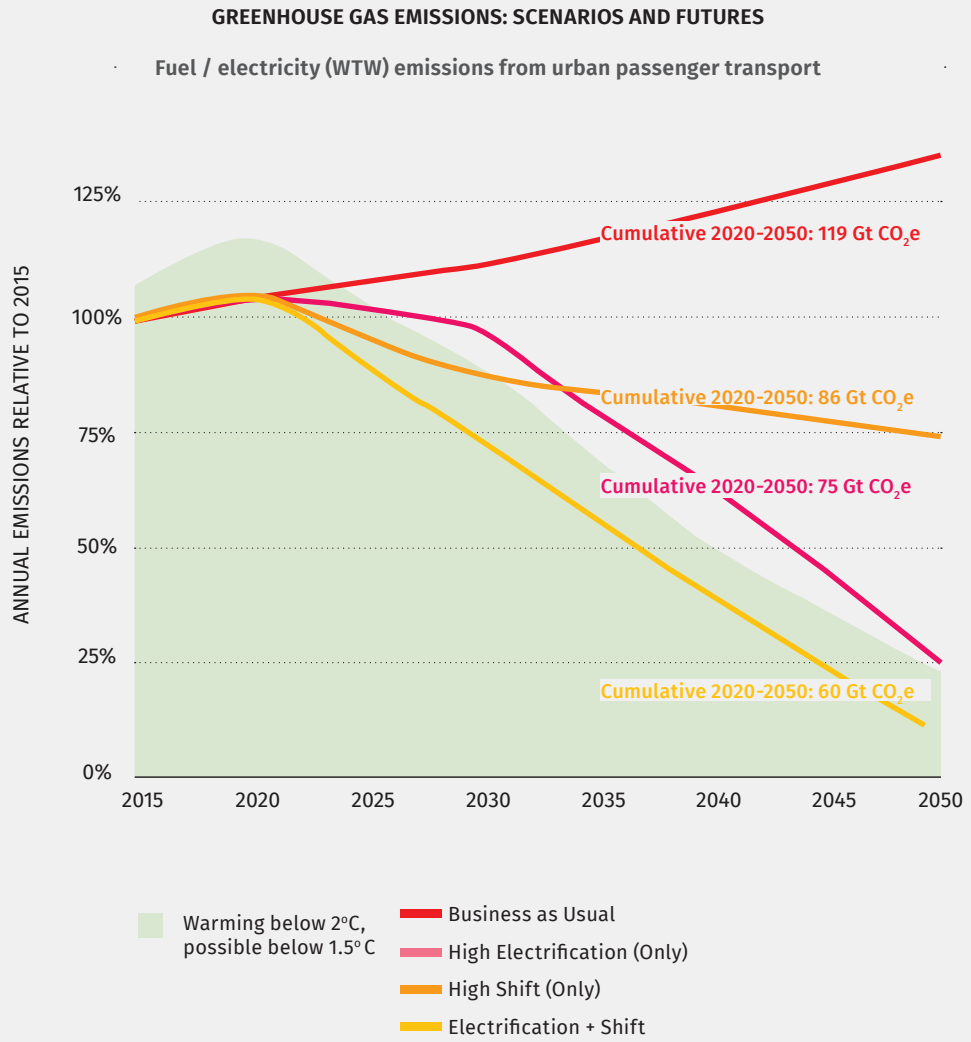
The reduced demand for driving because of *High Shift* means that about 300 million fewer electric cars are required and about 9,000 fewer exajoules of electricity are needed to power them per year (about 40% less than in *High Electrification*, Fig. 3.3). Synergy in the *Electrification+Shift* scenario makes both EV manufacturing and the energy transition more feasible.

3.4
GREENHOUSE GAS EMISSIONS

To limit global warming to less than 2°C, carbon emissions from most world energy sectors must fall to less than about 20% of their 2015 levels by 2050. We treat urban passenger transport as having to meet this level of reduction, along with other sectors. This possible future—described as the Sustainable Development Scenario by the IEA—is expected to maintain global warming to less than 2°C of pre-industrial levels throughout the twenty-first century, with an expected global warming of 1.6°C by the century's end.[20] The Sustainable Development Scenario shows about a one-in-three chance of limiting global warming to less than 1.5°C by 2100.

Among the four scenarios for urban passenger transport examined in this report, only one—*Electrification+Shift*—will achieve greenhouse gas reductions consistent with the *Sustainable Development Scenario* during the study's entire timespan from 2015 to 2050. Only *Electrification+Shift* is consistent with this pathway to limit global warming to less than 2°C and stand a chance of limiting it to less than 1.5°C (Fig. 3.4A).

By 2050, the *High Electrification* scenario comes close to the *Sustainable Development Scenario*, but for most of the period of 2015–2050 it is clearly outside the bounds of that future. *High Electrification* and *High Shift* may be consistent with warming of less than 2°C, but it is very unlikely to limit warming to less than 1.5°C by 2100.



APS = Announced Pledges Scenario | **BAU** = Business as Usual | **EV+Shift** = Electrification+Shift
GHG = Greenhouse gas | **High EV** = High Electrification | **IEA** = International Energy Agency
NZE = Net Zero Emissions by 2050 Scenario | **SDS** = Sustainable Development Scenario
STEPS = Stated Policies Scenario | **WTW** = Well-to-Wheel.

FIGURE 3.4.A
Only the Electrification+Shift scenario is consistent with a chance of limiting global warming to less than 1.5°C by the end of the century, and no scenarios guarantee that outcome.

20 The data for the *Sustainable Development Scenario*, as well as the *Stated Policies Scenario*, the *Announced Pledges Scenario*, and the *Net Zero Emissions by 2050 Scenario*, are adapted from International Energy Agency (2021), World Energy Outlook 2021, IEA, Paris. Our adaptation assumes that necessary emission reductions from urban passenger transport (by all modes) follow the same curves relative to 2015 as necessary reductions from road passenger transport using light-duty vehicles (urban or nonurban). This approach to understanding consistency with future extents of global warming is more sophisticated than the approach described in the pre-publication brief that was circulated in early November, 2021; but the conclusion is unchanged: *Electrification+Shift* is the only scenario consistent with possible global warming of less than 1.5°C.

For the sake of clarity, this discussion of our scenarios' consistency with certain emissions thresholds, illustrated in Fig. 3.4A, only includes emissions from fuel and electricity.[21] It does not include emissions from the manufacture and disposal of vehicles nor from the construction and maintenance of infrastructure. However, these latter sources of emissions are not to be ignored: by 2050, under *EV+Shift*, vehicles and infrastructure may account for the majority of emissions related to urban passenger transport (Fig. 3.4B).

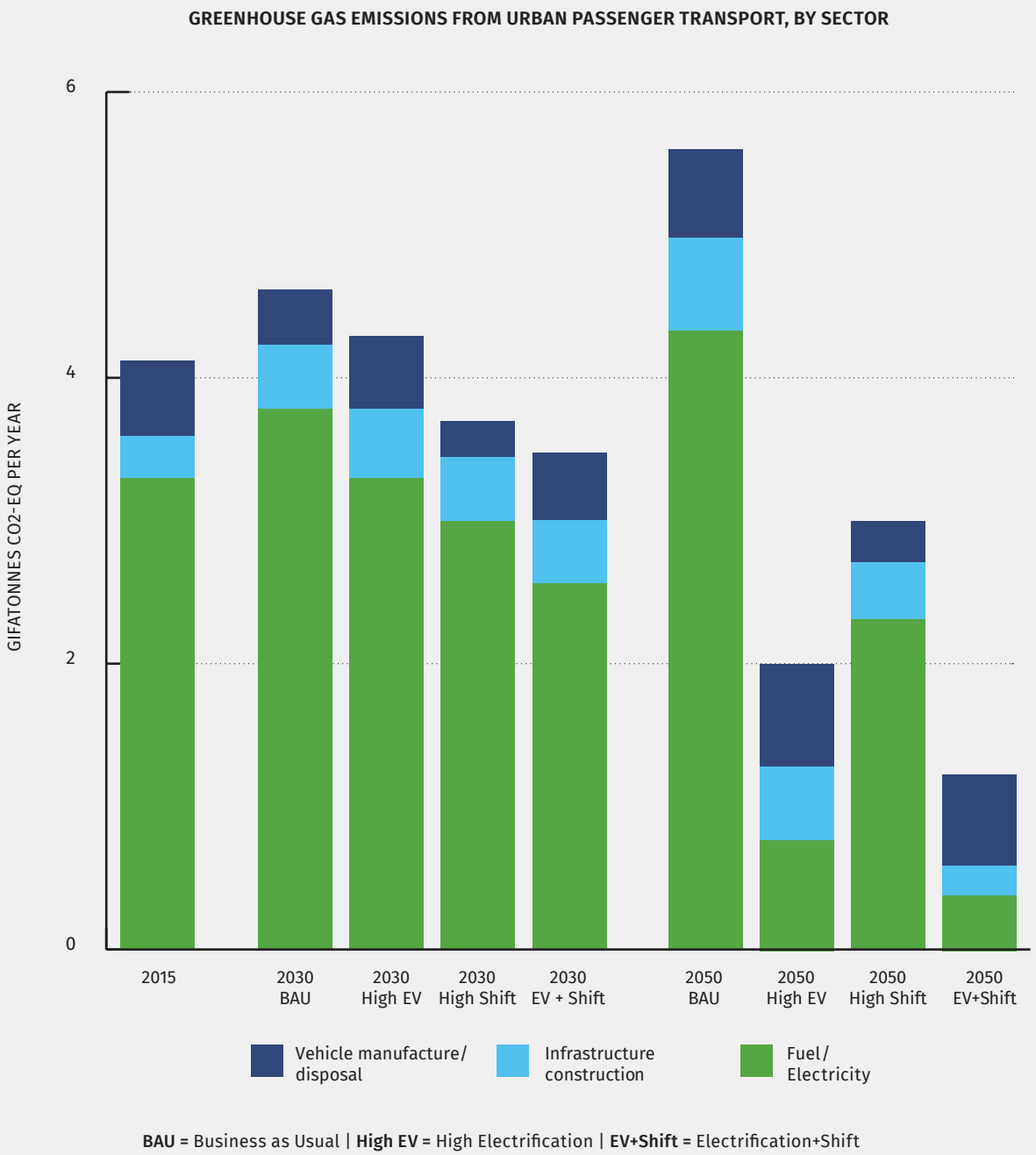


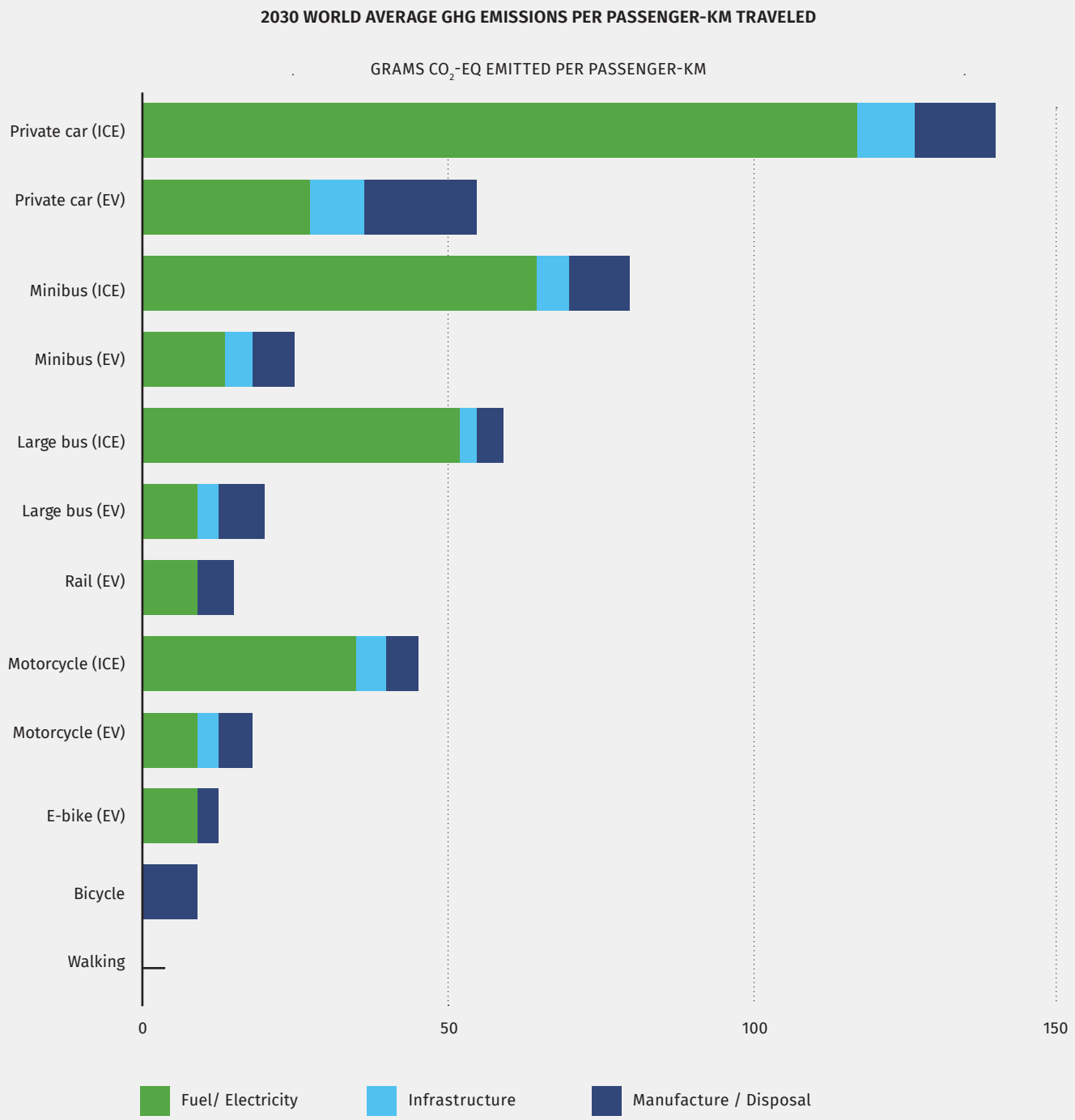
FIGURE 3.4.B
By 2050 in the High Electrification and Electrification+Shift scenarios, emissions from infrastructure and vehicles are greater than emissions from fuel and electricity.

21 The intersectoral implications of including vehicles and infrastructure in estimates of consistency with the IEA's scenarios, especially given our relatively rough approximations of potential decarbonization of industry, are beyond the scope of this study.

In the *Business as Usual* and *High Shift* scenarios, as today, the majority of urban passenger transport emissions are from fuel and electricity. In the *High Electrification* and *Electrification+Shift* scenarios, most vehicles run on clean electricity by 2050, resulting in a major reduction in emissions from fuel and electricity. That reduction, however, is attenuated by an increase in emissions from vehicle manufacture, especially the production of batteries.

Viewing these emissions on a per-passenger-kilometer basis (Fig. 3.4C) lets us see that the majority of emissions from EVs are emissions from battery and vehicle manufacture and from the construction of roads. Decarbonization of those processes is not impossible, and we have made relatively aggressive predictions of technical progress. But even if all vehicles were electric and the grid were fully decarbonized, per-kilometer emissions from travel by car would still be several times higher than emissions from travel by transit, bicycle, or walking.

FIGURE 3.4.C
ICE-powered cars emit far more greenhouse gases than any other mode per passenger-kilometer

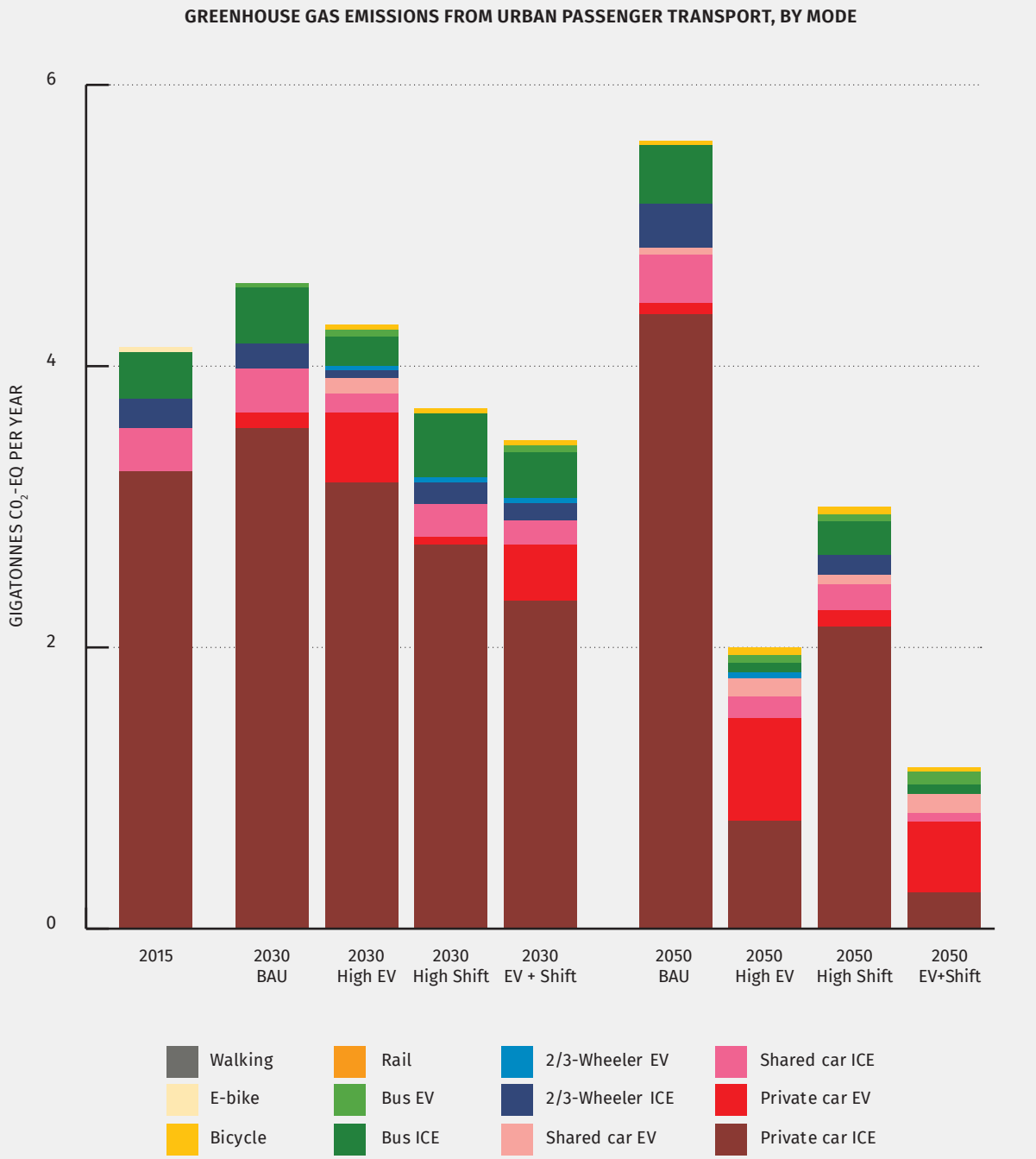


EV = Electric vehicle | **GHG** = Greenhouse gas | **ICE** = Internal combustion engine.

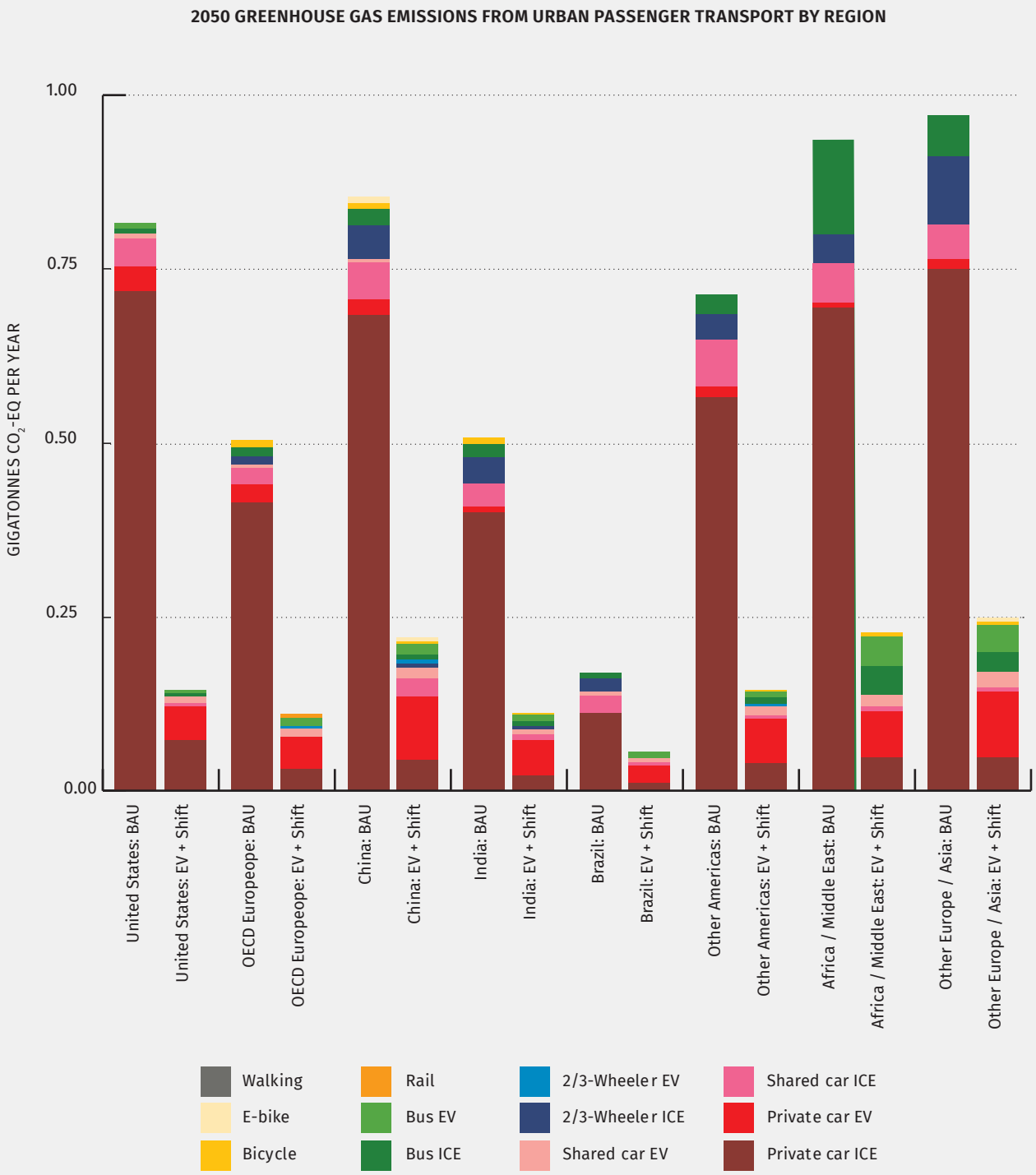
Based on our research and that of the IEA and the International Council on Clean Transportation, we conclude that ICE cars are by far the most emissions-intensive common form of urban passenger travel. Electric cars offer enormous carbon savings in comparison, as do ICE-powered buses and motorcycles. Even greater reductions are offered by electric buses, rail, electric motorcycles, and bicycles. The least emissions-intensive mode, of course, is walking.

Taking all sources of emissions into account, and looking across all regions, years, and scenarios, private cars are responsible for the vast majority of the world's greenhouse gas emissions from urban passenger transport. Even in a scenario as ambitious as the 2050 *Electrification+Shift*—in which cars carry less than 40% of the world's urban passenger travel (Fig. 3.1A) and in which a large majority of cars are powered by renewable electricity—cars are still responsible for 80% of the sector's emissions (Fig. 3.4D).

FIGURE 3.4.D
In all scenarios and at all time points, the vast majority of emissions are from cars.



BAU = Business as Usual | **EV** = Electric vehicle | **EV+Shift** = Electrification+Shift | **High EV** = High Electrification | **ICE** = Internal combustion engine.



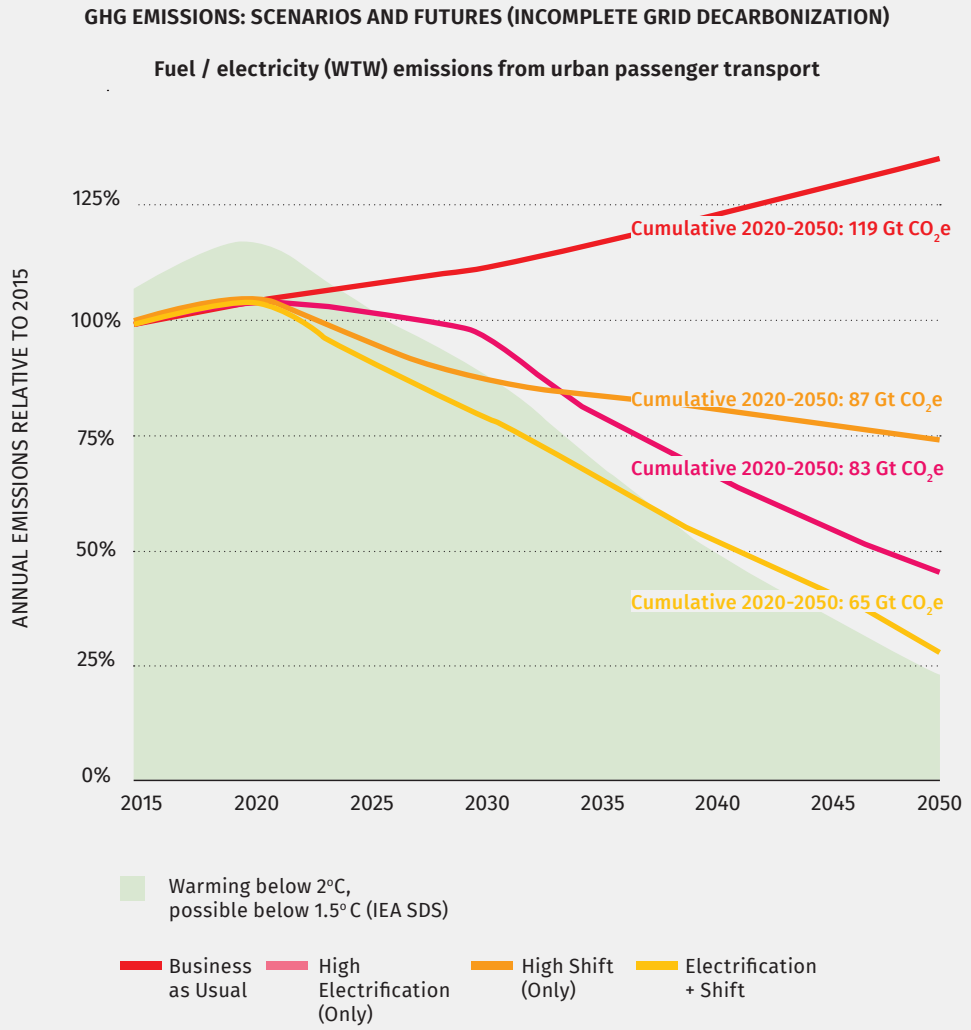
BAU = Business as Usual | **EV** = Electric vehicle | **EV+Shift** = Electrification+Shift | **ICE** = Internal combustion engine
OECD = Organisation for Economic Co-operation and Development.

FIGURE 3.4.E
All regions can see major emissions reductions from Electrification+Shift.

Each of the eight world regions sees a similar reduction in carbon emissions from the *Electrification+Shift* scenario relative to *Business as Usual* (Fig. 3.4E).

3.5
GREENHOUSE GAS EMISSIONS: SENSITIVITY CASE

The results presented above are based on an ambitious assumption: that worldwide electricity grids will almost entirely transition to renewable power by 2050, following the IEA's *Sustainable Development Scenario*,[22] which is consistent with less than 2°C degree warming. But grid decarbonization should not be taken for granted, and so we have completed an alternative modeling of the four urban transport scenarios using the electricity carbon intensities described in the IEA's *Stated Policies Scenario*.[23] The *Stated Policies Scenario* does not assume any policy goals beyond what countries have already adopted, though it does assume that those stated goals are met. It is a much more conservative projection than the *Sustainable Development Scenario*, but hardly a worst-case scenario.



APS = Announced Pledges Scenario| **BAU** = Business as Usual | **EV+Shift** = Electrification+Shift
High EV = High Electrification | **GHG** = Greenhouse gas | **IEA** = International Energy Agency
NZE = Net Zero Emissions by 2050 Scenario | **SDS** = Sustainable Development Scenario
STEPS = Stated Policies Scenario | **WTW** = Well-to-Wheel.

FIGURE 3.5
If grid decarbonization follows a more moderate trajectory, only Electrification+Shift approaches the decarbonization required to limit global warming to less than 2°C.

22 International Energy Agency (2021), World Energy Model, IEA, Paris.
23 International Energy Agency (2021), Stated Policies Scenario in World Energy Model, IEA, Paris.

Assuming only these more limited levels of sustainable electricity, we find that the High Electrification and High Shift scenarios achieve comparable levels of cumulative carbon reductions over the 2015–2050 timeframe, and the Electrification+Shift scenario approaches but does not quite pass the threshold needed to ensure that global warming will be limited to 2°C by 2100 (Fig. 3.5).

The success of a *High Electrification* scenario depends on a decarbonized electricity grid. If we adopt electrification as the transport sector's sole strategy in mitigating climate change, we are gambling with the planet's future. By combining electrification with compact cities, transit, bicycling, and walking, we ensure a redundant strategy that will reduce carbon emissions as much as possible even if other sectors —like power generation— fail to decarbonize in time.

A TransOeste BRT bus in Rio de Janeiro, Brazil. **SOURCE:** Stefano Aguilar / ITDP Brazil, Flickr.

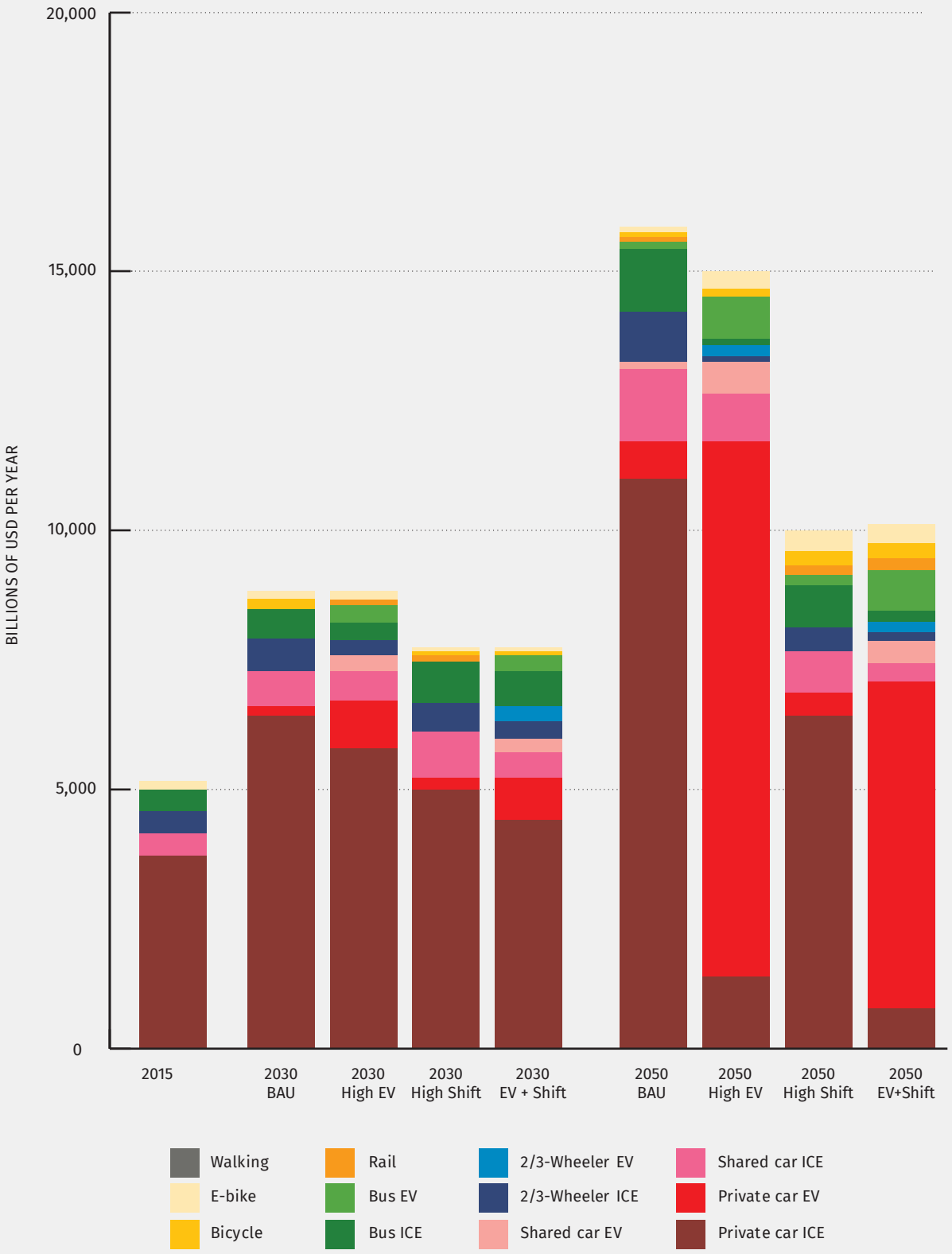
3.6
DIRECT PUBLIC AND PRIVATE COSTS

In the wake of the coronavirus pandemic, the budgets of cities and nations, like those of individuals and families, are limited. For nations, cities, individuals, and families alike, urban passenger transport is a major expense.

In the car-oriented United States, for example, people in the lowest-income section of the population spend as much as 30% of their income on transportation. In the more compact, transit-friendly European Union, people in that same section only spend about 7% of their income on transportation.[24] Transportation can be affordable or expensive, depending on how a city's mobility system is structured.

24 ITDP (2019), The high cost of transportation in the United States, *Transport Matters* (blog), May 23.

DIRECT PUBLIC AND PRIVATE COSTS OF URBAN PASSENGER TRANSPORT, BY MODE



BAU = Business as Usual | **EV** = Electric vehicle | **High EV** = High Electrification | **ICE** = Internal combustion engine.

In the *Business as Usual* and *High Electrification* scenarios, the direct public and private costs of urban passenger transport total about US $15 trillion per year by 2050 (Fig. 3.6A). In the *High Shift* and *Electrification+Shift* scenarios, that cost is only US $10 trillion per year. The largest contributor to this expense is the cost of vehicle manufacture (~53%), followed by the cost of infrastructure (~28%), system operations (~10%), and fuel and electricity (~9%).

Cars, whether powered by fossil fuels or by renewable electricity, are the least cost-effective common mode of urban transport. Cars account for a minority of travel activity in the 2050 *High Shift* and *Electrification+Shift* scenarios, yet they are responsible for a clear majority of the expenses related to urban travel, even in those scenarios.

Compact mixed-use cities, public transit, bicycle infrastructure, and traffic control measures could save the world US $5 trillion in direct public and private costs every year by 2050. This $5 trillion could instead be invested in healthcare, education, or other sectors of the world's effort to mitigate climate change.

These figures are limited to direct costs. They do not encompass indirect costs associated with urban transport, which include:

- The value of time lost due to traffic congestion
- The value of lives lost in traffic collisions or to air pollution
- The expense of healthcare for lung conditions caused by air pollution or for ailments caused by lack of physical exercise
- The costs of supplying electricity, water, and sewer systems to houses in low-density suburbs subsidized by urban highways

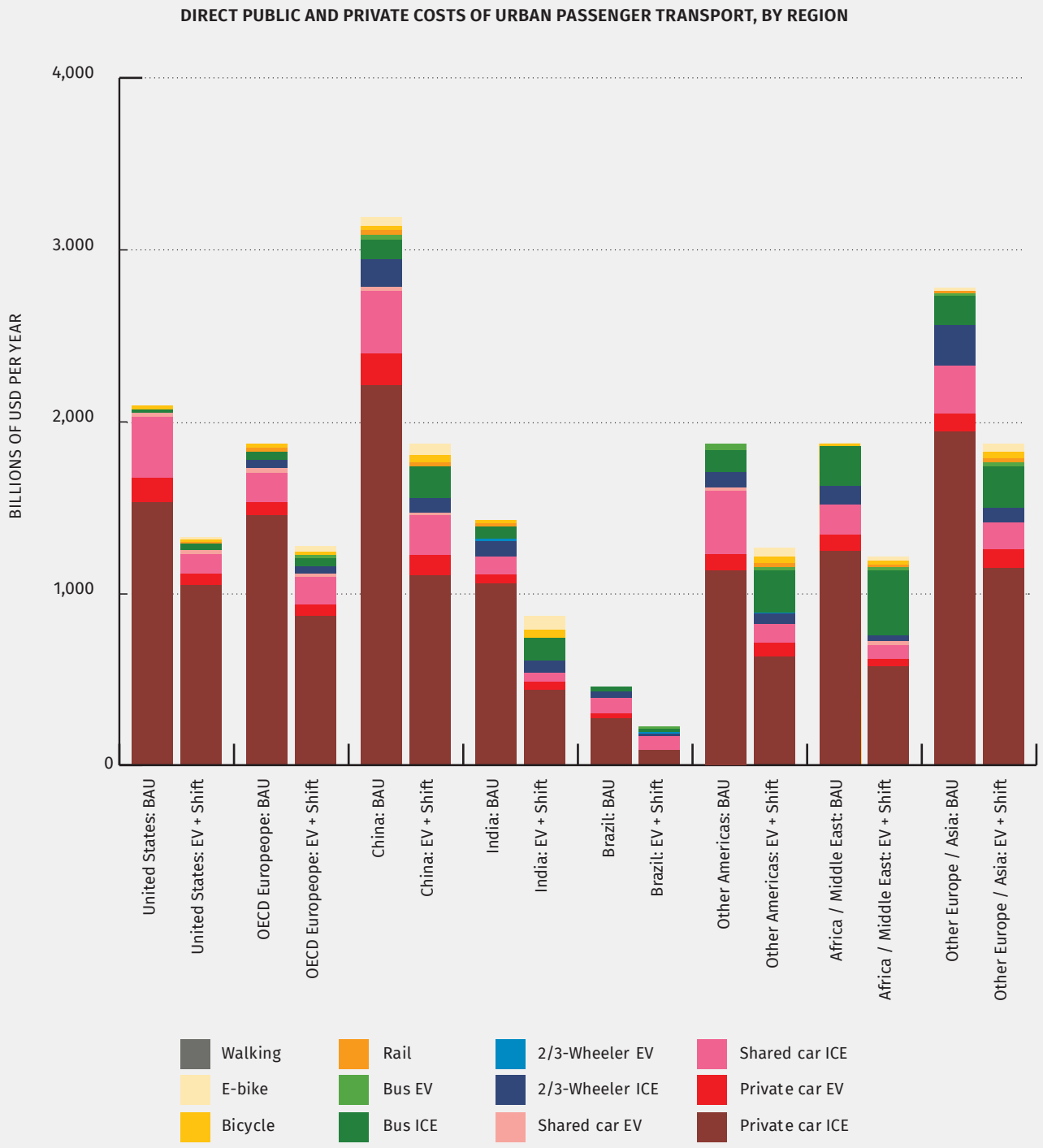
These are major expenses to society and are intensified by car-centric urban mobility systems.[25]

Large cost savings are possible in every world region but are slightly more pronounced in regions experiencing quick economic growth (Fig. 3.6B). China alone could save US $1 trillion per year by 2050 by embracing compact cities, walking, bicycling, and transit.

The source of these cost savings is not economic recession, nor is it a degraded quality of life. On the contrary, our model assumes the same pace of economic growth in each of the four scenarios, and the *High Shift* scenario does not prevent people who want cars from buying them. It only imagines that walking, cycling, and transit become more efficient ways of traveling in cities than driving, removing much of the incentive for car ownership.

OPPOSITE PAGE
FIGURE 3.6.A
High Shift reduces the direct costs of urban passenger transport by about a third.

25 Victoria Transport Policy Institute (2002), The Costs of Automobile Dependency, VTPI, Victoria, BC, Canada.



BAU = Business as Usual | **EV** = Electric vehicle | **HS** = High Shift | **ICE** = Internal combustion engine
OECD = Organisation for Economic Co-operation and Development.

FIGURE 3.6.B
Cost savings are possible worldwide.

POLICY GUIDANCE

4

Decarbonizing urban passenger transport will require many policies enacted at many levels over many years. There is no single solution, but there are various proven approaches that can be scaled up and combined.

This study forecasts future scenarios at a high level, imagining the kinds of futures that could be achieved through committed, broad-based reform rather than simulating the specific impacts of particular policies. The scope—30 years and the entire globe—is so large that we cannot speak quantitatively about individual measures. But we can offer guidance about the types of policies that have already achieved effects of this kind in individual cities—policies that can be spread and adopted around the world.

Many expert organizations have issued clear, thorough, and up-to-date policy guidance on vehicle electrification. Such reports include:

- Cleaner Vehicles (International Transport Forum, 2021)
- Electrifying Transportation in Municipalities (Electrification Coalition, 2021)
- Policies to Promote Electric Vehicle Deployment (IEA, 2021)

We have summarized some of the key recommendations of this guidance in Section 4.1. In Section 4.2, we draw on the experience of ITDP's seven regional offices and the success of many other cities around the world in promoting compact cities built around walking, bicycling, and public transit.

4.1 HOW TO ACHIEVE HIGH ELECTRIFICATION

In our *High Electrification* and *Electrification+Shift* scenarios, we consider a rapid increase in the uptake of EVs around the world, phasing out the production of ICE vehicles by 2040. This is a very challenging yet feasible projection. It is technically achievable, but there will need to be strong policies in every country to achieve this rapid transition. To realize these EV market shares, committed policies must achieve the following:

- As soon as possible, EVs of all types, in all countries, must be **no more expensive to purchase**, and **less expensive to operate**, than their closest ICE competitors. For example, large electric SUVs must be cost competitive with large ICE SUVs on both total ownership cost and purchase price. This is expected to happen naturally as battery prices continue to drop but may not occur until the late 2020s or later. To reach parity sooner, **vehicle purchase subsidies**, on both the supply and demand side, will be required through the 2020s.

- **Home charging** (or something close to it) must be available for all EV owners. For those without access to their own parking space and charger at home, low-cost, reservable overnight charging must be available close to home. Workplace charging is also important for many drivers, especially those with longer commutes. Governments must strongly encourage and support the widespread development of this infrastructure.

- **Public charging infrastructure** must be widely available. Public infrastructure will make drivers confident that they can recharge when and where they need, and drivers will be able to store EVs overnight with a charger. The cost of charging must be low enough that the overall operational cost of EV ownership remains lower

than ICE car ownership. The infrastructure must include some "fast" charging stations, but "medium" (level 2: 220 volt) charging can play a large role. Governments need to ensure that investments are made and that viable business models are created to encourage private investment, while keeping prices affordable.

• Vehicle **purchase opportunities** and **repair infrastructure** must be adequate. Consumers must be able to purchase EVs easily, and repairs must be convenient and affordable. This means training thousands of technicians and ensuring a strong supply of vehicles by manufacturers.

• There must also be a **wide selection of EV models**, competitive with the selection of ICE models available. In advanced markets, these issues must be solved by 2025; in all other world markets, they must be solved by 2030.

• Consumers must be made aware of and comfortable with the new technology. Manufacturer-led advertising campaigns and government-led **information campaigns** can play a crucial role in increasing awareness.

• Other policies, such as requirements for manufacturers to produce a certain number of zero-emission vehicles, increasing over time, and other market development policies, will also be very important and are proving successful in places like California, Norway, and Germany.

4.2 HOW TO ACHIEVE HIGH SHIFT

The *High Shift* scenario considers a major modal shift away from cars and toward walking, bicycling, and public transit. Most of this shift is not a net decrease in car travel, but rather a lack of increase relative to *Business as Usual*. Although this scenario is ambitious, it is not unprecedented. Successfully achieving *High Shift* will require an array of complementary policies, enacted by governments at every level, from international to local. But it is possible. These policies will apply to four key areas:

- Land use
- Walking and bicycling
- Public transit
- Car control

Policies in each area are valuable, but they will combine to have a compounding impact. For example, policies that create density near public transport stations lead to more financially sustainable public transport systems by increasing ridership, but that density also supports increased walking and bicycling.

LAND USE

The principles of land use for sustainable mobility are **compactness** and **mixed-use** planning. In compact, mixed-use cities, people live within a short distance of their daily needs, meaning they can walk or cycle to them. Compact, mixed-use cities also make public transit more efficient by having more destinations around stations and shorter distances between stations.

Techniques for promoting sustainable land use	Successful implementations
15-minute neighborhoods. Everybody lives within a short walk of their daily needs: food, healthcare, education, transit, childcare, and park space.	Paris, France Singapore
Zoning reform to permit and encourage high-density development on any property, especially with provisions for affordability.	Portland, USA
Transit-oriented development strategies to concentrate population, jobs, and services near rapid transit.	Curitiba, Brazil

WALKING AND BICYCLING

Walking and bicycling are the most energy-efficient modes of transportation available to humanity. Walking and bicycling provide "first/last-mile" connections that increase transit ridership, and they are also important modes on their own.

Techniques for promoting walking and cycling	Successful implementations
High-quality footpaths, guided by a non-motorized transport strategy and following streetscape design guides like the Global Street Design Guide.	Chennai, India
Dedicated, physically protected, connected citywide bicycle networks.	Bogotá, Colombia Seville, Spain
Public bikeshare systems, including e-bikes, closely integrated with public transit.	Hangzhou, China Mexico City, Mexico

PUBLIC TRANSIT

More than any other mode, public transit makes the High Shift scenario possible. A massive increase in public transit compensates for more than half the decrease in car travel, with the vast majority provided by large buses.

Techniques for promoting public transit	Successful implementations
Informal transportation modernized around multimodal public transport rather than directly competing with it.	Jakarta, Indonesia
Expansion of frequent bus networks so all city residents live near bus lines with a frequency of 10 minutes or less.	Seattle, USA
Rapid transit network construction and expansion (including metro, light rail transit, and bus rapid transit).	Tehran, Iran Jakarta, Indonesia

CAR CONTROL

Sustainable land use, effective walking and bicycling infrastructure, and comprehensive high-frequency public transit can make it easy for people to move around a city without a car. But to achieve the *High Shift* scenario, cities and countries will also have to take steps to bring the convenience and cost of driving in line with its negative effects.

Techniques for car control	Successful implementations
Pricing parking: reducing or eliminating free on-street parking and other subsidies; disincentivizing off-street parking.	São Paulo, Brazil Mexico City, Mexico
Pricing emissions: charging a fee each time a vehicle enters a zone based on the vehicle's emissions level. This also incentivizes electrification.	Milan, Italy
Pricing congestion: requiring vehicles to pay a fee to enter or drive within an area.	London, England Singapore

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