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## Urban Transportation

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## Transport as Climate Challenge and Solution

Urban transport systems are major emitters of greenhouse gases (GHGs) and are essential to developing resilience to climate impacts. At the same time, cities need to move forward quickly to adopt a new paradigm that ensures access to clean, safe, and affordable mobility for all.

In middle-income countries, rising incomes are spurring demand for low-cost vehicles, and, together with rapid and sprawling urbanization and segregated land use, this is posing unprecedented challenges to sustainable development while contributing to climate change.

Expanded climate-related financing mechanisms are being developed at national and international levels, such as the Green Climate Fund. Local policy-makers should prepare the institutional capacity and policy frameworks needed to access financing for low-carbon and resilient transport.

- Low-carbon transport systems yield co-benefits that can reduce implementation costs, yet policy-makers often need more than a good economic case to capture potential savings.
- Integrated low-carbon transport strategies – Avoid-Shift-Improve – involve avoiding travel through improved mixed land-use planning and other measures; shifting passengers to more efficient modes through provision of high-quality, high-capacity mass transit systems; and improving vehicle design and propulsion technologies to reduce fuel use.
- Designing and implementing risk-reduction solutions and mitigation strategies require supportive policy and public-private investments. Key ingredients include employing market-based mechanisms; promoting information and communication technologies; building synergies across land-use and transport planning; and refining regulations to encourage mass transit and non-motorized modes.

### Major Findings

- Cities account for approximately 70% of CO<sub>2</sub> emissions (depending on measurement protocols), with a significant proportion due to urban transport choices. The transport sector directly accounted for nearly 30% of total end-use energy-related CO<sub>2</sub> emissions. Of these, direct emissions from urban transport account for 40%.
- Urban transport emissions are growing at 2–3% annually. The majority of emissions from urban transport are from higher-income countries. In contrast, 90% of the growth in emissions is from transport systems in lower-income countries.
- Climate-related shocks to urban transportation have economy-wide impacts, beyond disruptions to the movement of people and goods. The interdependencies between transportation and other economic, social, and environmental sectors can lead to citywide impacts.
- Integrating climate risk reduction into transport planning and management is necessary in spatial planning and land-use regulations. Accounting for these vulnerabilities in transport decisions can ensure that residential and economic activities are concentrated in low-risk zones.

### Key Messages

Co-benefits such as improved public health, better air quality, reduced congestion, mass transit development, and sustainable infrastructure can make low-carbon transport more affordable and can yield significant urban development advantages. For many transport policy-makers, co-benefits are primary entry points for reducing GHG emissions. Moreover, policy-makers should find innovative ways to price the externalities – the unattributed costs – of carbon-based fuels.

The interdependencies between transport and other urban sectors mean that disruptions to transport can have citywide impacts. To minimize disruptions due to such interdependencies, policy-makers should take a systems approach to risk management that explicitly addresses the interconnectedness of climate, transport, and other relevant urban sectors.

Low-carbon transport should also be socially inclusive because social equity can improve a city's resilience to climate change impacts. Automobile-focused urban transport systems fail to provide mobility for significant segments of urban populations. Women, the elderly, the poor, non-drivers, and disadvantaged people need urban transport systems that go beyond enabling mobility to fostering social mobility as well.

## 13.1 Introduction

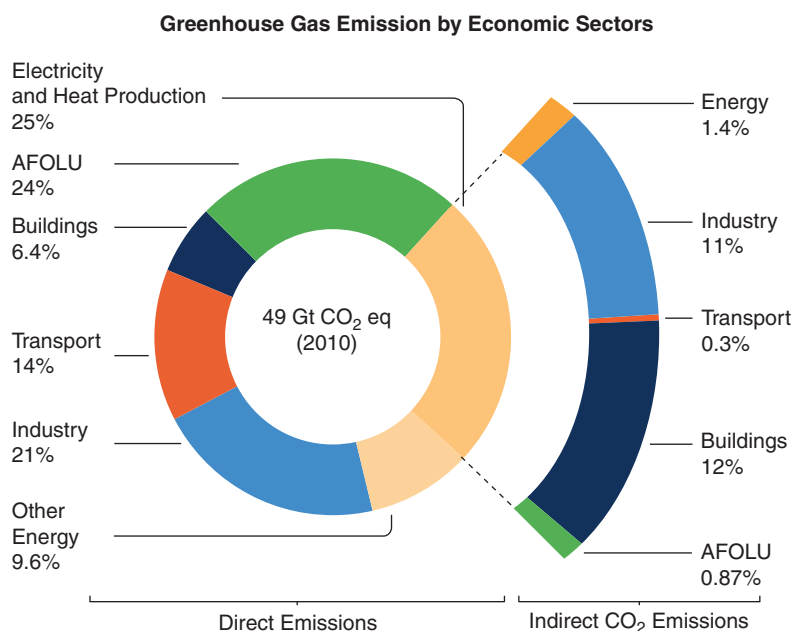
Over US\$2 trillion dollars are spent on infrastructure – transport, energy, and water – globally each year, half in developing countries (International Monetary Fund [IMF], 2014). Cities account for approximately 70% of CO<sub>2</sub> emissions (depending on measurement protocols) with a significant proportion due to urban transport choices (Seto et al., 2014). The transport sector directly accounted for 28% of total end-use energy-related carbon dioxide (CO<sub>2</sub>) emissions (Sims et al., 2014). Direct urban transport emissions accounts for 40% of these emissions (see Figure 13.1). The share of urban transport emissions becomes even greater with the inclusion of indirect transport emissions. For example, emissions resulting from the production of fuels and building of transit systems, energy consumed in non-travel functions of urban transportation departments such as offices and maintenance yards, and, counterintuitively, adaptation measures such as construction of transit-oriented development.

Urban transport emissions are growing at 2–3% annually (International Energy Agency [IEA], 2014). The majority of the stock of GHG emissions is from developed-country urban transport services. In contrast, 90% of the flow – growth in emissions – is expected to come from developing-country transit services (IEA, 2014). In developing countries, rising incomes that spur demand for low-cost vehicles accompanied by rapid and sprawling urbanization and segregated land use pose an unprecedented challenge to sustainable development. They are also a fast-growing cause of climate change. In response, billions of dollars are being invested in developing low-carbon transit systems – from metro rail systems and light rail networks

in Latin America to bus rapid transit (BRTs) systems in Asia. However, there is a knowledge gap when it comes to understanding the sustainability of these interventions, particularly as they pertain to urban climate change impacts; technological, institutional, and commercial viability; and benefits to the poor.

Urban transportation systems consist of passenger and freight subsectors. By modal choice, transportation services are classified into land-, water-, and air-based systems. Ownership and management of transit systems are split between public and private sectors and combinations of the two. More than 70% of transport emissions are from road-based systems (Sims et al., 2014), therefore, in this chapter we focus on climate change risks, mitigation, adaptation, and policy mechanisms for intra-urban road and rail systems for passengers and freight.

Our objective is to assess the state-of-the-knowledge on urban transport and climate change. The assessment is structured around four subcomponents: urban transport and climate change risks, adaptation solutions, mitigation choices, and policy mechanisms nested within enabling environments that can operationalize action. The assessment has engaged leading transport scholars and practitioners to evaluate existing research as well as to identify tacit knowledge. Case Studies of New York, Lagos, Johannesburg, and Delhi are integrated into the chapter to contextualize solutions. The chapter also builds on and extends themes in the first urban transport assessment (Mehrotra et al., 2011) and has iteratively informed and benefited from the endeavors of the chapter authors' engagement and leadership role in the United Nations Sustainable Development Goals process on issues of urbanization and transport as well as the 21<sup>st</sup> United Nations Framework Convention on Climate Change (UNFCCC) Climate Summit in Paris (COP21).



**Figure 13.1** Share of urban transport's greenhouse gas emissions among economic sectors.

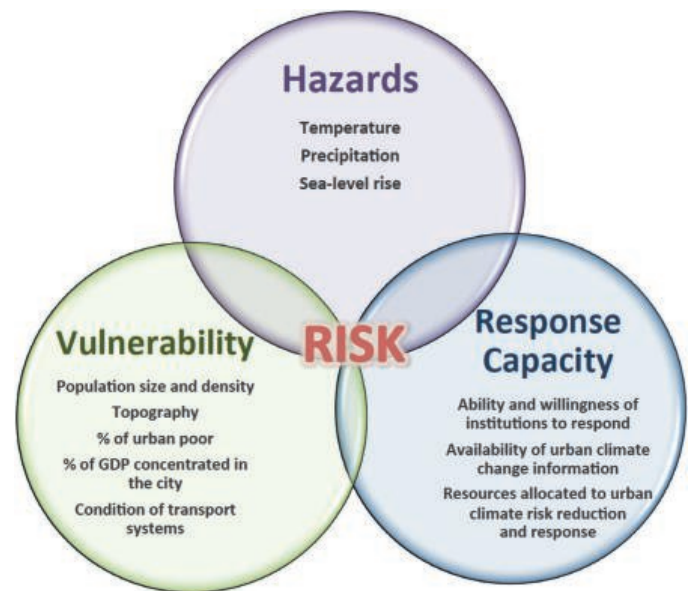
Source: Adapted from IPCC, 2014

## 13.2 Climate Risk for Urban Transport

To comprehensively assess climate risk to urban transport, we utilize the urban climate change risk assessment framework (Mehrotra et al., 2009) that combines three vectors: hazards, vulnerabilities, and response capacity (see Figure 13.2). Global climate risk is accumulated in urban areas and increases as people, private and public assets, and economic activities become more concentrated in cities (Mehrotra et al., 2009, 2011; Revi et al., 2014). Urban transport systems that enable movement of people, goods, and services within and between cities are at risk, particularly during extreme events such as heat waves, hurricanes, floods. These events can disrupt transport systems and interdependent urban services during extreme weather conditions with impacts lasting through the relief and recovery phase. Transport systems utilized for emergency response to rescue vulnerable populations (e.g., hospitalized patients) can be temporarily impaired due to system disruptions ranging from lack of fuel supply to inundated roads and tunnels (New York [NYC], 2013).

The first vector in the urban climate risk framework is climate hazards, which captures external forcings due to observed and projected change in mean and extreme precipitation, temperature, and sea levels. Hazards impacting urban transport systems include intense precipitation, increasing temperature, rising sea levels, and growing frequency and intensity of coastal storms.

More frequent and intense precipitation increases the probability and extent of threats to underground systems such as tunnels for rail and road. The structural strength of bridge footings may be compromised due to corrosion from saltwater intrusion and soil erosion. Storms with high-velocity winds impact static and mobile transport systems differently. Static systems such as roads, bridges, and railway networks may be inundated due to



**Figure 13.2** Urban climate risk framework.

Source: Adapted from Mehrotra et al., 2009

storm surges or create additional stress on critical infrastructure and cause structural damage. Mobile assets and vehicles, such as cars and buses or train coaches, may be damaged due to flying debris. Heat waves can compromise the design strength of roads and rail structures due to damage to physical infrastructure. For example, roads can experience cracking, rutting, and peeling of asphalt or buckling of concrete and steel structures. Furthermore, road, rail, and water-based system connections can compound the impacts of climate hazards felt in one transport system and carry over to another. For a summary of climate change impacts on urban transport, see Table 13.1. Hazards are context-related, varying for land-based systems at local and national scales, and

**Table 13.1** Climate hazards and urban transportation impacts. Source: Adapted from Hodges, 2011

Climate Hazard	Likely impacts (Impacts differ by vulnerabilities and response capacities)
<b>Precipitation:</b> Intense rainfall and sudden snowstorms	Damage and incapacitation of transit networks due to flooding of tracks, roadways, tunnels, maintenance facilities Blockage of roadways and drainage systems Landslides as a consequence of precipitation Scour on bridge as a result of precipitation
<b>Temperature:</b> Heat waves	Buckling of railroad tracks Damage to paved surfaces Passenger and worker health and safety
<b>Sea level rise and land subsidence</b>	Flooding of roadways, tracks, maintenance facilities, and tunnels Corrosion resulting from exposure to seawater
<b>Coastal storms:</b> Typhoons, cyclones, and hurricanes	Coastal inundation from storm surge Rainfall of sudden or intense nature Damage from debris and high winds Demand for evacuation services

therefore require context-appropriate assessments (PlaNYC, 2013; Transport Research Board [TRB], 2014).

Gradual change in climate-induced hazards receives less attention than more immediate changes in relevant research. Long-term gradual changes in temperature and precipitation patterns stress and test the design strength of urban transit systems. Climate hazards have indirect or secondary impacts as well. Heat waves may impose health hazards on passengers or damage freight. Likewise, extreme heat and precipitation events limit the time of day and duration of safe work hours for experts to restore transit system disruptions (Hodges, 2011; U.S. Global Change Research Program, 2014).

The second set of vectors are internal vulnerabilities due to the physical, social, and economic conditions of the city and its transportation system. These can be measured through the size and density of the population, topography, proportion of poor population, concentration of economic activity in cities, and the condition of transportation systems. Aging and obsolete transportation assets such as bridges, roads, and railways make urban transport infrastructure in the developed world vulnerable (American Society of Civil Engineers [ASCE], 2013). The absence of adequate and reliable urban transport systems and the widespread reliance of poor populations on walking and use of bicycles in developing-country cities increase the vulnerabilities of the poor during heat waves or floods (Mehrotra, 2012a; UN-Habitat, 2013; Revi et al., 2014). Each city's modal mix is different and combines the preferences of travelers, land-use-induced trip origins and destinations, and supply of transportation alternatives, ranging from individual modes such as cars and bicycles to mass transit systems of trains and buses. The particular combination of these urban mobility choices along with existing socioeconomic, topographical, and other urban conditions in a city shape the vulnerability of the urban transit systems and its users (European Commission, 2013).

The third set of vectors is response capacity. Response capacity measures refer to a city's urban transport-related institutional attributes and its actors. These capacities determine the

degree of its capability to respond to potential climate change impacts. Variables that can determine the extent of a city's ability to adapt its transport systems include the structure and capacity of institutions, presence of adaptation and mitigation programs, and motivation of change agents. The greater the ability (institutional structure, caliber, resources, information, analysis) and willingness of actors to proactively respond to climate change, the higher the capacity to act, and *ceteris paribus*, the lower the impact. New York's transit system offers an example of reducing risk through preventive measures (NYC, 2013). Key actors for such response include city governments, their urban transport-related constituent departments, the private sector, civil society, nongovernmental organizations (NGOs), and academics (Mehrotra, 2009).

In sum, urban transport risks are shaped by the hazard exposure, existing system vulnerabilities, and response capacity, both ex-ante and ex-post. Extreme events convert risks to costs to the urban transport infrastructure. Hurricane Sandy demonstrated that even a well-managed city like New York was vulnerable to climate risks despite a robust early warning system (Kaufman et al., 2012). In resource-constrained cities in the developing world, impacts of severe climate events are more disruptive. Road networks of major cities like Mumbai frequently flood during monsoons and lack adequate access for emergency and evacuation efforts, while settlements of the urban poor are placed at greater risk by a lack of access to public transit or emergency planning (Revi et al., 2014). A storm of the magnitude of Hurricane Sandy, which brought storm surges of more than 9 feet to New York (Blake et al., 2013), pose many-fold higher risks for cities that lack preparedness.

While there is limited research estimating costs of climate change on urban transport infrastructure (Koetse and Rietveld, 2009), extreme weather events offer some insights. Hurricanes Katrina and Sandy (Jacob et al., 2011) in the United States or typhoon Haiyan in the Philippines (Kostro et al., 2013) cost billions of dollars in direct and indirect transit system damages and disruption to the economy (Hodges, 2011; Koetse, 2009). In New York, the Metropolitan Transportation Authority reported US\$5.8 billion

**Table 13.2** Transportation sector interdependencies. Adapted from URS, 2010

<p><b>Transportation Depends on Energy</b></p> <p>Transport sector is reliant on electricity for signage and lighting</p> <p>Electrified rail network</p> <p>Flooding of oil refineries and depots disrupt supply</p> <p>Electric cars reliant on recharging stations</p>	<p><b>Energy Dependence on Transport</b></p> <p>Operator access to power stations during severe weather</p> <p>Access to local distribution facilities</p> <p>Raw material supply depends</p> <p>Road, rail, and ports disruption curtails fuel supply</p>
<p><b>Transportation Depends on Water</b></p> <p>Drain design and maintenance impact road and rail flooding</p> <p>Water supply for rail and road vehicle cleaning and refill provisions</p>	<p><b>Water Dependence on Transport</b></p> <p>Wastewater sludge requires transport to off-site disposal</p> <p>Road access to treatment works, pumping stations</p> <p>Overland transport of potable water during floods or service disruption</p>
<p><b>Transportation Depends on ICT</b></p> <p>ICT enabled transport road signage or rail signaling</p> <p>Disruption of telecommunication and Internet services curtail communication for transport</p>	<p><b>Intermodal Dependencies</b></p> <p>Road failure impact on rail</p> <p>Airports and seaports dependent on road and rail</p> <p>Rail failure leads to diversion of traffic onto roads</p>



in recovery projects after landfall by Hurricane Sandy, while damage to additional transportation infrastructure stock in New York totaled US\$2.5 billion (Blake et al., 2013). Hurricanes Katrina and Rita in 2005 cost approximately US\$1.1 billion in infrastructure damages in New Orleans (Grenzeback and Lukmann, 2007). Flooding affects noncoastal urban transport systems as well (U.S. DOT, 2014). In Chicago, the damage to flooded transport systems and associated delays amounted to US\$48 million in 1996 (Changnon, 1999). In developing-country cities, the cost of damages to land-based transport systems, including buses, cars, and rail, underrepresent the total cost to firms and households because poor households and small firms rely on several alternate modes like bicycles, carts, walking, and other non-motorized modes.

The preceding sets of risks are significant by themselves, but urban transport systems are interconnected. Thus, failure in one system produces failures in transport and other systems. Road and rail networks are increasingly dependent on the energy, water, and information and communications technology sectors and are interlinked to other modes of transportation (URS, 2010). Transportation infrastructure risks compound risks to households and firms (Revi et al., 2014). Table 13.2 illustrates interdependencies between transport and other sectors.

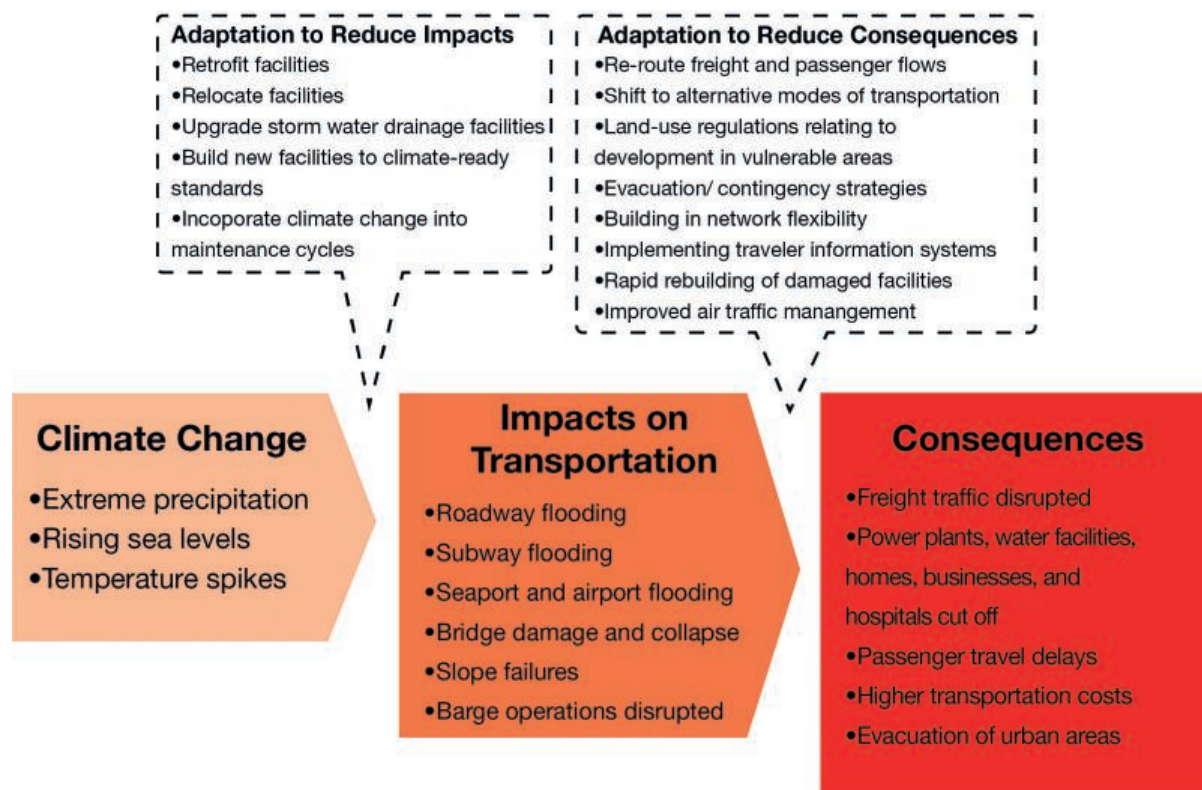
Cascading failures of transportation systems impede disaster response. City transportation planners increasingly need to prepare transportation networks for pre- and post-disaster response (e.g., the evacuation of residents prior to storms, floods, and

landslides, and the delivery of food, water, medical supplies). Not all cities are adequately prepared for extreme climate events (Revi et al., 2014). To illustrate, the impacts of Typhoon Haiyan were made worse because the storm destroyed roads that link secondary cities to better equipped primary urban centers (Kostro et al., 2013). Power failure in parts of New York during Hurricane Sandy disrupted traffic control systems and pump operations, making it difficult to remove water from subway facilities and to fuel cars at gas stations (PlanNYC, 2013).

### 13.3 Adaptation Options and Strategies for Climate-Resilient Transport

#### 13.3.1 Types of Adaptation

Adaptation solutions can offer the twin benefits of reducing impacts of climate change on urban transport as well as downstream consequences (see Figure 13.3). Adaptation measures to reduce impacts of extreme climate events as well as gradual change in climate trends can be unpacked by scales and scopes of impact into short, medium, and long-term *tactics* (quick-fix), *projects* (tasks), *programs* (systems), and *policies* (institutional arrangements and processes). Some recommended measures include tactics such as relocating facilities and vehicles to avoid damage during storms; projects such as retrofitting facilities to protect existing infrastructure, altering train speeds and schedules, and upgrading stormwater drainage systems; programs such



**Figure 13.3** Adaptation to reduce impacts and consequences: policies, program, projects, and tactics.

Source: Adapted from Melillo et al., 2014

as building new facilities to climate-resilient standards; and policies that incorporate climate projections into maintenance cycles (Mehrotra et al., 2011; Zimmerman, 2012; Melillo et al., 2014).

Adaptation measures to reduce the consequences of climate change impacts on urban transport in the short-term range from the tactics of rerouting passenger flows and substituting modes of transport, to projects such as building in network flexibility and rebuilding damaged facilities. In the medium term, programs such as creating traveler information systems and policies for regulating land use in vulnerable areas and developing evacuation contingency strategies should be considered (Mehrotra et al., 2011; Melillo et al., 2014). Long-term adaptation measures for risk reduction include recalibrating design standards that incorporate climate change projections and considering the service life of transportation systems. In some cases, short- and medium-term policies are more effective for addressing flooding and sea level rise over a 30- to 40-year period. Long-term policies may focus on projected temperature variations over a 40- to 100-year period (Meyer, 2008). Table 13.3 summarizes the climate change hazards, impacts, and associated adaptation solutions. Temporal parsing of policies is desirable, as is constant monitoring and recalibration of policies (Mehrotra, 2012a) that respond to changing climate risk information.

### 13.3.2 Urban Planning, Transport Engineering, and Design Solutions

To mainstream adaptation measures in the planning, design, and implementation of transport projects, cities need new policies, standards, and codes that address transport system vulnerabilities. With long-term change in environmental factors that are likely to expose urban transport infrastructure to intense

and frequent floods, strong winds, and rising temperature, cities should consider reducing risks through the integration of high-probability scenarios in the design of transport systems and associated citywide interdependent systems (Meyer, 2008). These practices and procedures are equally relevant for new capital-intensive investments as well as for routine retrofits for rail systems, roadways, bridges, vehicles, and other interdependent urban systems that have life expectancies of 50–100 years.

For many cities, urban transport adaptation requires a comprehensive reassessment of design practices and procedures. These include climate change risk assessment and the identification and selection of the appropriate mix of policies, programs, projects, and tactical responses parsed over the short and long term that incorporate new research, recalibrate maintenance and operations procedures, and asset management (Hodges, 2011; Filosa, 2015).

Examples of climate change integration into transport design standards and adaptation initiatives can be found predominantly at the national level. Canadian, British, Danish, and New Zealand departments of transport have developed adaptation action plans and set goals for resiliency (Filosa, 2015). Canadian public infrastructure programs have re-engineered construction protocols to reduce system vulnerabilities. The Danish road department has incorporated Intergovernmental Panel on Climate Change (IPCC)-based precipitation projections to recalibrate drainage standards and road regulations. Korean, British, and New Zealand transport agencies have altered design standards, improved drainage structures, and retrofitted bridges in accordance with precipitation projections and recalibrated flood levels (Filosa, 2015). New York's Metropolitan Transportation Authority offers a rare example of urban transport-specific comprehensive adaptation planning and implementation (see Case Study 13.1).

**Table 13.3** *Climate change hazards, impacts, and adaptation solutions*

Hazard (Impact)	Transport module	Adaptation Solution
<b>Temperature</b> (Speed)	Roads, rail, transit vehicles, private vehicles	Milling out ruts (tactic); laying of more heat resistant materials such as asphalt for roads (project) Heat-tolerant metals for rail and rail connections (project)
<b>Floods</b> (Congestion, delays, accidents)	Drainage system; roads, rails, subways; transit vehicles, private vehicles	Deploy early warning systems – remote sensing technology to detect flood levels (program) Dikes and barriers (project) Enhancing the performance of drainage systems and contingency rechanneling of water (program) Enhance use of pumps (project) Elevation of structures (project)
<b>Storms</b> (Lower visibility, delays, accidents, cancelled trips, closure or reduction in capacity of routes)	Roads, bridges, rails, airports, subways, transit and private vehicles	Arrangement to park vehicles in secure garages (tactic) Enhancing emergency evacuation planning (program) Constructing protective barriers (project) Increasing clearance for bridges (project) Anchoring vulnerable structures (tactic) Preparedness of equipment and material for repairs (tactic, management)

Note: Tactics (quick-fix), projects (tasks), programs (systems), and policies (institutions and processes).

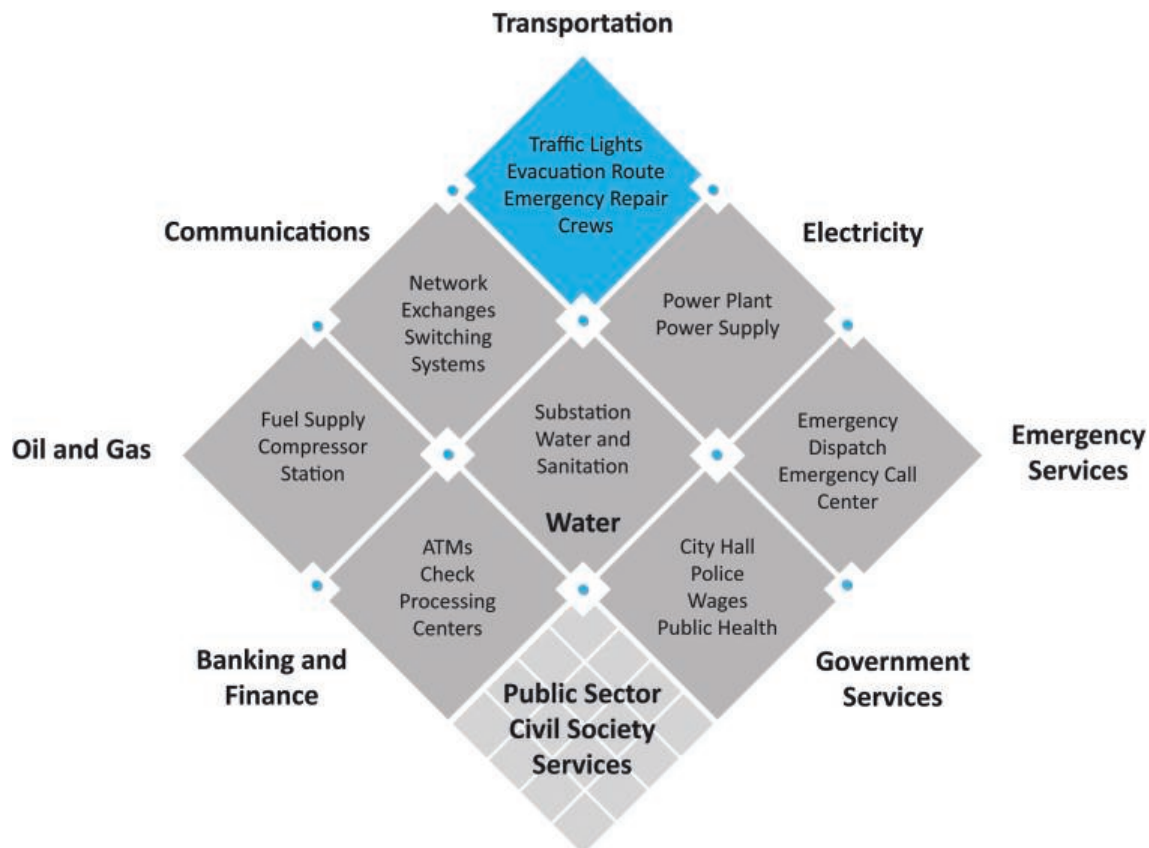
Source: Mehrotra et al. (2011, 2015)

Developing-country cities face constraints when integrating adaptation into urban planning. Dar es Salaam, a city of 4 million, lacks an adaptation plan (Kiunsi, 2013). Symptomatic of many developing-country cities (UN-Habitat, 2013; Revi et al., 2014), a large proportion of Dar es Salaam's population lacks access to basic services: networked water supply and sanitation, storm water drains, and solid waste collection. More than half the population lives in informal settlements located on low-lying flood-prone embankments. Underdevelopment and deprivation is further exacerbated by the lack of fiscal and managerial capacity to address climate impacts. The primary adaptation challenge for cities with large slums and deep development deficits is to prioritize the integration of climate change adaptation into ongoing and planned urban transport and city-wide development processes. Integration is imperative because for many cities the incremental cost of adaptation is negligible, whereas the cost of neglecting adaptation is high. In Malaysia, for example, the cost of landslide prevention in high-risk road segments was one-fifth of post-landslide road repair (URS, 2010). The New Zealand Transport Agency Bridge Manual points to significant economic benefits of ex-ante retrofitting bridges and culverts at the design stage instead of ex-post retrofitting after construction. Likewise, the New Zealand and Korean long-term transport plans integrate climate data into asset management systems to analyze hazards and integrate

adaptation measures into routine asset management procedures (Filosa, 2015).

Most urban transport adaptation literature focuses on supply-side planning, engineering, and design solutions. However, a significant space for adaptation solutions involves land-use planning. In some cases, land-use planning provides benefits for adaptation and mitigation. Mehrotra et al. (2011) discuss the mutually interdependent relationship between land use and transport systems and associated GHG reductions. Land use, zoning, and building codes along with other urban development policies determine the distribution of population density and mix of activities associated with urban land use. These non-transport urban development policies shape travel demand. The existing research and policy literature, however, lack a discussion of adaptation potential of such land- and real estate-derived policy instruments. Likewise, adaptation potential for emerging flexible and information technology-enabled flood response systems that can respond to real-time changes in travel demand or the elevation of structures (Meyer, 2008) should be explored, as should low-cost and low-technology solutions, particularly for resource-constrained cities.

Urban transport adaptation planning and investments should incorporate intermodal and intersectoral interdependencies (see Figure 13.4) to prevent cascading failures (Melillo et al., 2014).



**Figure 13.4** Urban transport's interconnectivity with urban systems.

Source: Adapted from Melillo et al., 2014



## Case Study 13.1 New York Metropolitan Transportation Authority: Climate Adaptation Solutions Leading up to Hurricane Sandy

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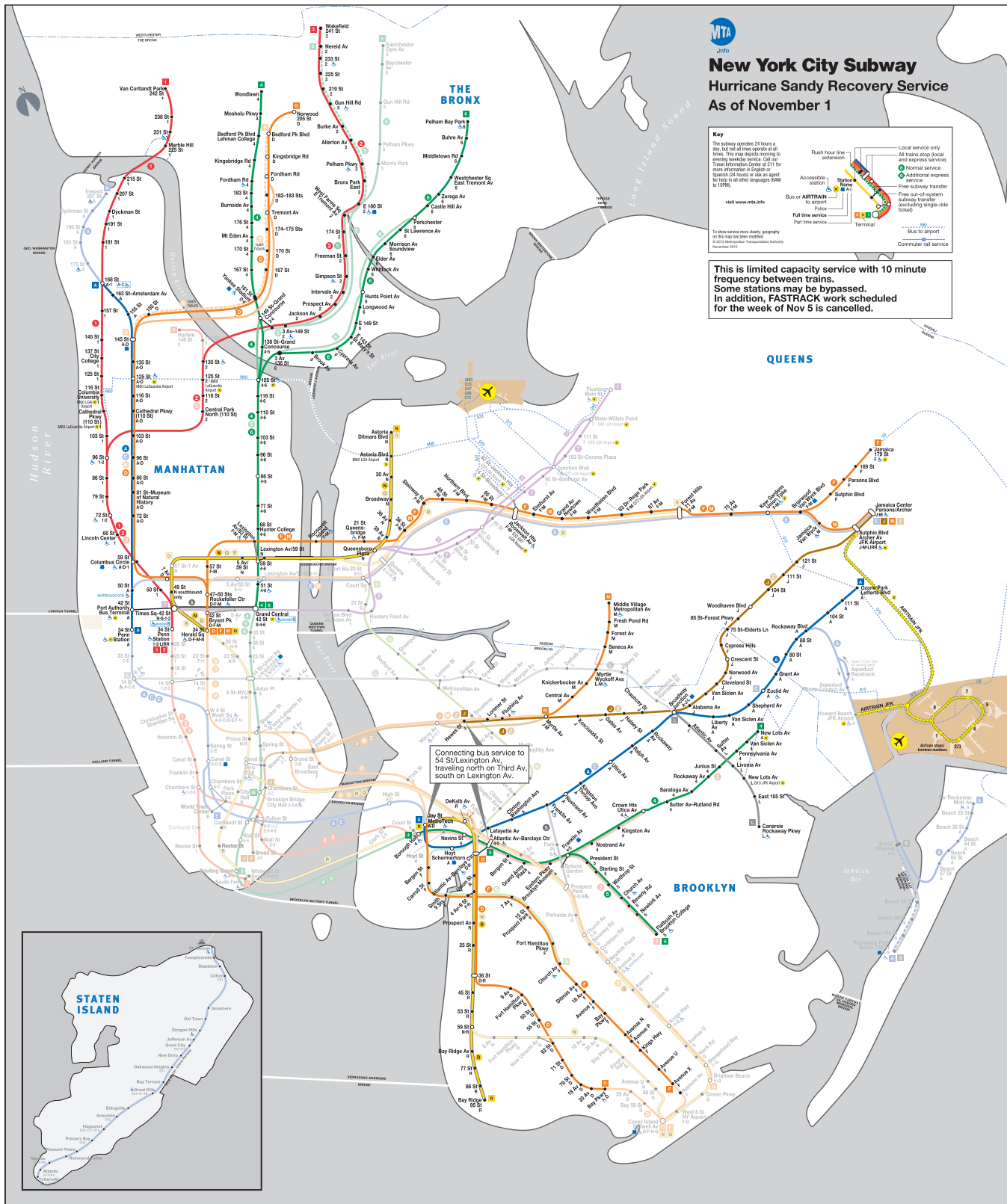
<b>Keywords</b>	Transportation, adaptation, infrastructure, climate risk
<b>Population (Metropolitan Region)</b>	20,153,634 (U.S. Census Bureau, 2016)
<b>Area (Metropolitan Region)</b>	17,319 km <sup>2</sup> (U.S. Census Bureau, 2010)
<b>Income per capita</b>	US\$56,180 (World Bank, 2017)
<b>Climate zone</b>	Dfa – Cold, without dry season, hot summer (Peel et al., 2007)

On October 29, 2012, Hurricane Sandy imposed approximately US\$5 billion of losses on the New York State Metropolitan Transportation Authority's (MTA's) infrastructure (Blake et al., 2013; MTA, 2013) (see Case Study 13.1 Figure 1). These damages occurred despite a well-prepared adaptation planning process. In the decade leading up to Hurricane Sandy, the MTA had undergone a review of its emergency response systems, had upgraded its pumping and sewage infrastructure, and had commissioned storm and climate adaptation committees. In the days leading up to the storm, the MTA implemented its hurricane plan, activated its Incident Command Center and Situation Room, and responded to the immediate impact of the storm via direct response and in collaboration with federal, state, and local agencies.



**Case Study 13.1 Figure 1** Map of Hurricane Sandy inundation area and MTA New York Transit routes.

Source: Spatiality, FEMA Modeling Task Force (MOTF)



**Case Study 13.1 Figure 2** Example of subway service updates posted on November 1, 2012, on the MTA website and distributed to all major news outlets. Subway routes represented in brighter colors remained functional; the lighter colors represent parts of the network that were out of service.

Source: Metropolitan Transportation Authority (used with permission)

The MTA is the largest public transportation provider in the Western Hemisphere, with infrastructure valued at more than US\$1 trillion dollars. The Authority serves a 13,000 square kilometer metropolitan region with an average weekday ridership of 8.7 million (MTA, 2014).

Prior to 2012, the MTA had begun preparing for extreme climate events – prompted by two intense precipitation events in 2004 and 2007. In response to the 2004 storm, which delivered 2 inches of rain per hour and resulted in 1,156 subway train cancellations, the MTA authorized an Inspector General investigation and formed an MTA Board Task Force (MTA, 2006; MTA, 2007; Kaufman, 2012). The 2007 storm, which delivered 3.5 inches of rain in one morning, prompted the MTA to form an official Storm Task Force and issue the August 8, 2007 Storm Report (MTA, 2007). Additionally, in the fall of 2007, the MTA convened the Blue Ribbon Commission on Sustainability with a dedicated Climate Adaptation Working Group tasked with developing near-term strategies as well as long-range climate adaptation recommendations (Jacob et al., 2008; MTA, 2009). Findings from these committees included inadequacies in stormwater drainage systems, shortcomings in internal organizational communication, and the need for increased capacity to provide public service alerts. The findings led to an analysis of flood-prone stations, upgrades to valves for pumping water and preventing sewage backflow, installation of Doppler radar access throughout the network, embankment stabilization, elevation of 30 subway station exits, retrofits of 1,500 ventilation grates, and the recalibration of the MTA's hurricane plan. The experience and lessons from these prior climate events led the MTA to initiate its first-ever transit service suspension prior to Hurricane Irene in 2011 (Kaufman et al., 2012).

In 2012, three days prior to Hurricane Sandy's landfall, the MTA activated its hurricane plan. One day before the storm, the MTA

began suspending service system-wide on subways, buses, and the commuter rail systems for the second time in its history. The Authority implemented hurricane and flood preparedness measures across the network. These actions included the pre-deployment of mobile pumping units, the covering of ventilation grates and subway entrances, the relocation of vehicles and rolling stock to higher ground, and the removal of signal and control systems from tunnels expected to be flooded. Removal of equipment prevented saltwater damage, allowed for a swifter resumption of subway service, and decreased the duration of bridge and tunnel closures. The adaptation response policy and procedures detailed in the hurricane plan outlined specific responsibilities for MTA officials and strategies for deployment of personnel and equipment. The plan also included communication protocols between internal agencies and between MTA officials and local, state, and federal agencies, as well as with news and media agencies (Coyle, 2014; MTA, 2013).

Adaptation policy measures and procedures reduced damage to the urban transit systems, enhanced passenger and personnel safety, and minimized the duration of service disruption, allowing the MTA to reinstate service shortly after the storm. By November 3, 2012, 80% of the 108-year-old subway system was operational (see Case Study 13.1 Figure 2). The rest of the MTA system was fully operational by November 16, 2012 (Kaufman et al., 2012). Despite having these adaptation protocols in place, major portions of the networks, including nine under-river subway tubes, two vehicular tunnels, and critical transit hubs such as South Ferry Station, were inundated with saltwater and suffered severe damage. The Montague Tube, connecting the Boroughs of Manhattan and Brooklyn, did not reopen until September 2014, and the process of restoring the network to its pre-Sandy condition will take years (MTA, n.d.). For additional information on the MTA's recovery, see Zimmerman (2014).

Furthermore, cost-benefit assessments of adaptation alternatives are best incorporating both impacts and consequences. The accounting costs of damage to transportation networks as well as long-term social, environmental, and economic impacts exacerbated by sectoral interdependencies should also be factored into analyses (Koetse, 2009).

Urban transport adaptation efforts in New York illustrate the value of multistakeholder engagement in addressing interdependencies inherent in transport systems. New York's Metropolitan Transportation Authority works across its transport departments and agencies that are responsible for planning, regulation, enforcement, operations, and maintenance to determine interdependencies of regional transport operations and investments. The adoption of a multistakeholder, multilevel engagement process helped strengthen coordination and dialogue between sectors and agencies – for example, between those tasked with environmental assessments and flood and climate forecasting (Jacob et al., 2011). The emphasis on engagement helped to formulate urban development and transit plans and policies, and review and screen investment incorporating climate risk assessments, monitoring climate indicators, evaluating program performance, and developing an effective urban transport adaptation system.

## 13.4 Low-Carbon Transport

Although adaptation can make transport systems resilient to climate change, low-carbon transport can mitigate climate impacts. In 2010, transport accounted for 22% of energy-related CO<sub>2</sub> emissions and 20% of global energy use. Urban transport accounts for approximately 40% of these totals (IEA, 2012). Even with advances in technology and fuel, energy consumption from urban transport is expected to double by 2050 (IEA, 2013). Globally, motor vehicle emissions could increase threefold between 2010 and 2050 (UN-Habitat, 2013). Developing countries will be the fastest-growing source of these emissions. Rising incomes and urbanization has already pushed up travel demand, motorization, and emissions in China and India (Pucher et al., 2007). In China specifically, transport is the fastest-growing emission source (Baumler et al., 2012).

The preceding estimates are based on top-down methods that multiply national fuel use by emission factors to reach emissions estimates. Increasingly, urban transport emissions are estimated from bottom-up models that consider urban transport activity levels and mode structures. Bottom-up modeling shows that Mexico



City has significant emission reduction potential from new technologies and public transport (Chavez-Baeza and Sheinbaum-Pardo, 2014). Models in the four cities of Barcelona, Spain; Malmö, Sweden; Sofia, Bulgaria; and Freiburg, Germany, demonstrate reductions of up to 80% from 2010 to 2040 as well as cleaner air, reduced noise pollution, and other co-benefits (Creutzig et al., 2012). Meanwhile, models of CO<sub>2</sub> emissions in Osaka highlight the interactions between built environments and lifecycle stages (Waygood et al., 2014).

### 13.4.1 Emissions Drivers

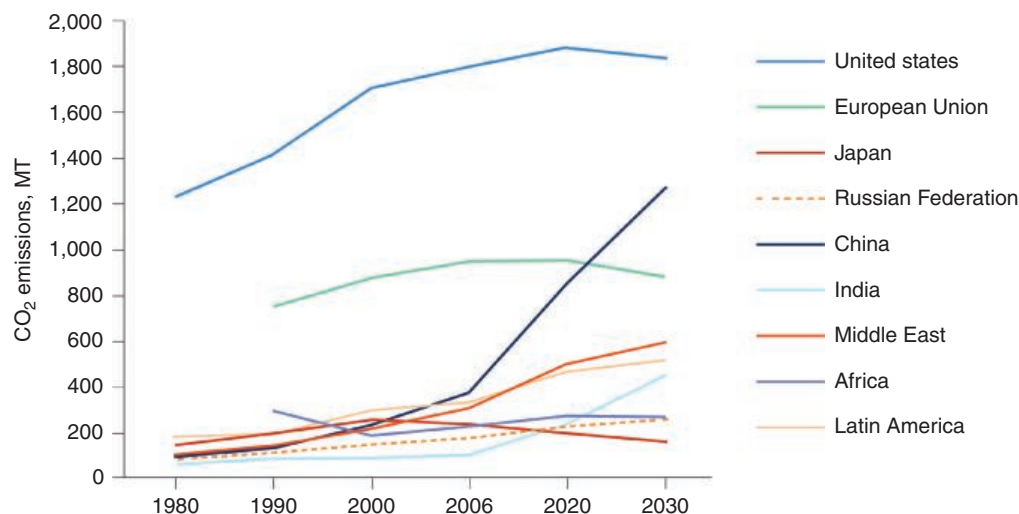
Several interconnected drivers contribute to emission increases. Drivers can be classified as operating on the supply and demand sides. These categories parallel the top-down and bottom-up estimation techniques. The supply side concentrates on the fuel quality and emissions intensities. The demand side focuses on vehicle activity and modal structure (Schipper et al., 2000). Four drivers that work chiefly on the demand side are particularly relevant to urban transport and are thus emphasized here.

The first driver is urbanization. Approximately 54% of the global population lives in urban areas and will grow to 66% by 2050 (United Nations Department of Economic and Social Affairs [UN DESA], 2014). Globally, 2.5 billion people will be added to cities by 2050, with nearly 90% of that growth concentrated in developing areas of Asia and Africa (UN DESA, 2014). While Africa's population is predominantly rural, its urban population is greater than the United States' population and rapidly growing. Asia is home to the fastest-growing cities. Asia's urban population has grown sevenfold, from 232 million to 2.13 billion people between 1950 and 2015 (UN-Habitat/ESCAP, 2015). In Latin America,

three-quarters of the population lives in cities (UN DESA, 2014). Urbanization characteristics – land use mix, population density, and income levels – and associated transportation modal choices will determine urban transit emissions (see Figure 13.5) and its mitigation opportunities. Much of the urban growth will be in cities with populations below 1 million (UN DESA, 2014). This could cause a further spike in emissions as research shows that smaller cities tend to use energy less efficiently (Seto et al., 2014).

The second core driver of emissions is motorization. Motorized modes accounted for about 47% of urban trips globally in 2005; this figure could grow to 54% without significant policy changes (Pourbaix, 2012). Private vehicle ownership in China is projected to rise from 40 to 310 per 1,000 people between 2010 and 2035. Similar trends are anticipated for India. Other rapidly emerging economies are witnessing growth of 20% annually in vehicles (IEA, 2012). Figure 13.6 illustrates motorization in the developing world over the next three to four decades.

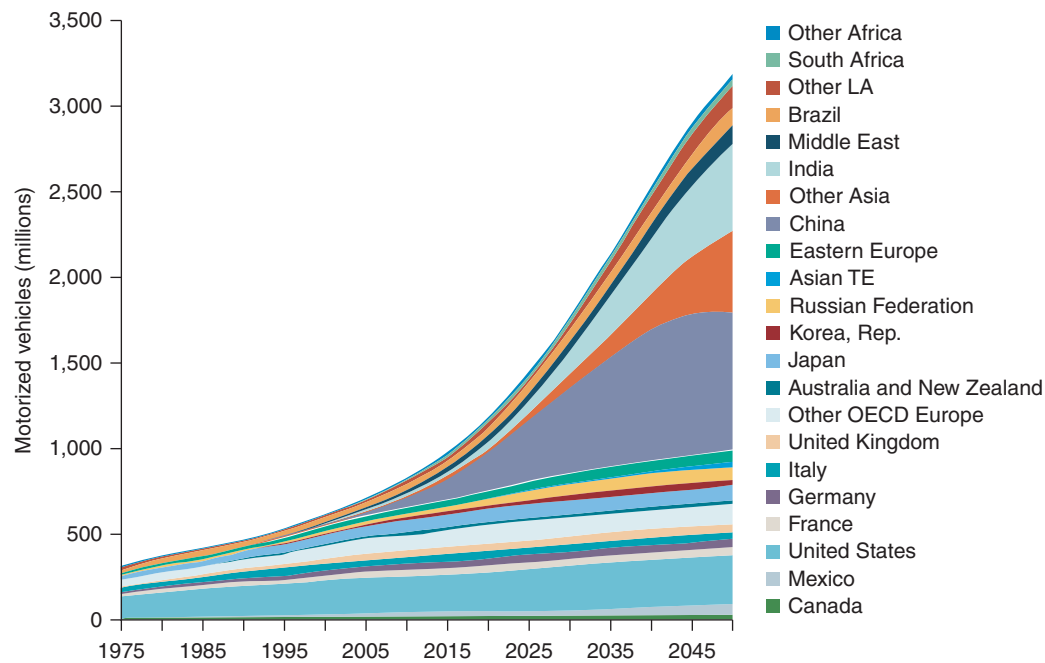
The third emissions driver is infrastructure investment. China's urban roads have doubled between 1990 and 2003, while Kenya invested more than US\$530 million in 143 kilometers of urban road construction and repair between 2008 and 2012 (UN-Habitat, 2013). Increased connectivity will be essential for development, but short-sighted infrastructure planning can create path dependencies that lock in energy-intensive development patterns for decades (Sims et al., 2014). Path dependencies not only apply to roads and bridges but also to institutional and individual behaviors; to exemplify the connection to behavior, research illustrates that investments in infrastructure to ease traffic and mobility can boost vehicle kilometers traveled (VKT). For instance, studies show a 10–20%



**Figure 13.5** Actual and projected global CO<sub>2</sub> emissions from the transport sector, 1980–2030.

Source: Fulton and Cazzola, 2008; in Suzuki et al., 2013





**Figure 13.6** Current and projected growth rates in private vehicle ownership in select countries and regions, 1975–2050.

Source: Fulton and Cazzola, 2008; in Suzuki et al., 2013

jump in VKT is associated with a doubling of infrastructure capacity (Seto et al., 2014).

The fourth emissions driver is land-use change. Many cities have grown out rather than up. Reports show that between 1995 and 2005 the vast majority of the developed world's seventy-eight largest cities experienced faster growth in suburbs than in urban cores (UN-Habitat, 2013). Outward expansion causes increased trip lengths, motor vehicle dependencies, and emission increases (Kennedy et al., 2009; Rickwood et al., 2011; Seto et al., 2014). Projections showing that between 2005 and 2025 private motorized transport will increase by 80% reinforce the need for farsighted land use and infrastructure planning to curb emissions (UN-Habitat, 2013).

### 13.4.2 Mitigation Options: Avoid-Shift-Improve (ASI)

Civil society, industry, and governments are increasingly cooperating in promoting an approach known as *Avoid-Shift-Improve (ASI)* to mitigate emissions (Dalkmann and Brannigan, 2007). ASI organizes mitigation options into actions that (1) avoid unnecessary travel through smart urban planning, compact cities, and transit-oriented development (TOD); (2) shift travel to non-motorized or high-occupancy modes; and (3) improve efficiencies with cleaner vehicles and fuels (Dalkmann and Brannigan, 2007).

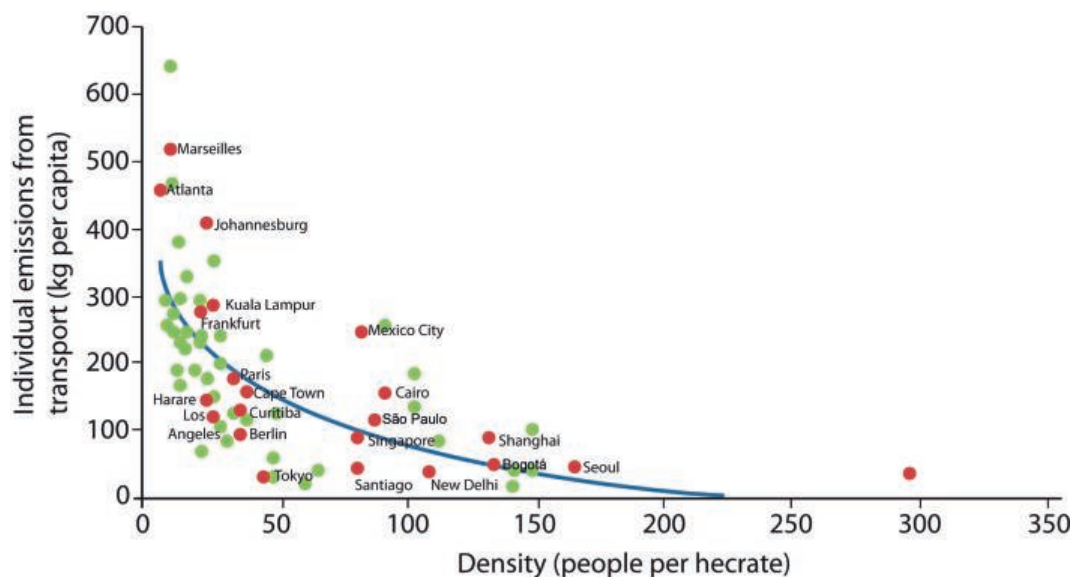
Arguably the greatest reductions in cities involve urban and spatial planning that avoid unnecessary travel. The scatterplot in Figure 13.7 illustrates the advantage of “avoid” by showing that greater density is often associated with lower emissions.

The benefits of density are also suggested in studies that show urban density above 35 person per hectare reduces automobile dependency (Newman and Kenworthy, 2006). Findings from the United States underscore that when mixed land-use is combined with transit-oriented development policies, residential densities can double and VKT can fall by 25% in the long run (EPA, 2014).

Some cities have attempted to increase densities, lower emissions, and achieve other development goals. To make an aging population more mobile, Toyama, Japan, successfully introduced a compact city design with dense networks of residences and businesses linked by monorail (Takami and Hatoyama, 2008). Others cities have emphasized not just density but *articulated density*, referring to pockets strategically concentrated across metropolitan areas (Suzuki et al., 2013). Yet other cities have found urban connectivity – determined by block size, number of intersections in road systems, and space for pedestrians – to lower VKT and emissions (Seto et al., 2014).

The “shift” options involve increasing mode shares of higher occupancy and more efficient vehicles. This often involves different forms of mass transit trips that can cut VKT per person (see Figure 13.8a). This frequently means improving “public transport that has been the backbone of development” (Wright, 2004).

BRTs are an increasingly common “shift” option (see Figure 13.8b). BRTs are bus systems that run on a segregated lane. They currently operate or are being built in more than 300



**Figure 13.7** Urban densities and per capita emissions from transport are much lower in denser cities.

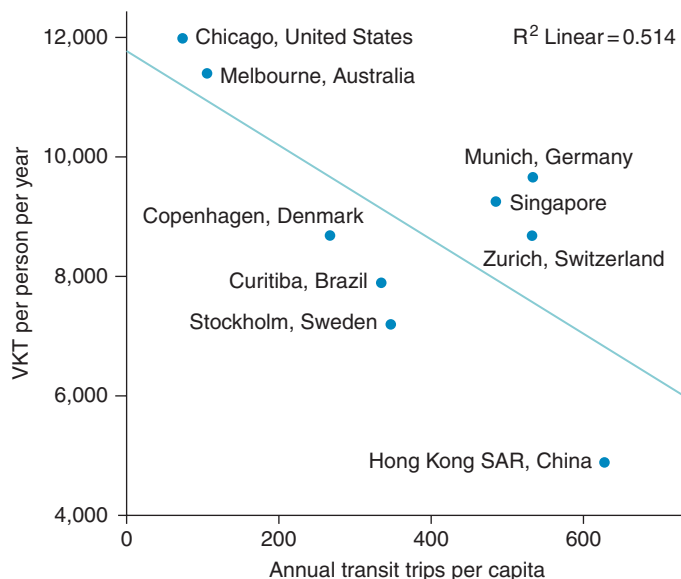
Source: World Bank, 2009. Based on 1995 data

cities (UN-Habitat, 2013; Carrigan et al., 2013). Most BRTs are located in Latin America (64%) and Asia (27%), but some are being built in Africa (UN-Habitat, 2013; Carrigan et al., 2013; see Case Study 13.2). The spread of BRTs is attributable to costs that are one-third to one-fifth of light rail and one-tenth of metro or subway systems. The BRTs also bring a range of benefits. Cities with established systems, such as Curitiba and Bogotá, have seen reduced automobile trips, fuel use, and emissions (UN-Habitat, 2013; Suzuki et al., 2013; Turner et al., 2012).

In larger megacities, subways that can move higher occupancies (up to 30,000 passengers per hour) are becoming a more common “shift” option (De Jong et al., 2010). (UN-Habitat, 2013). Currently, 187 cities have metro systems – up from 40 in 1970 (Metrobits, 2012). China is investing heavily in subways; eighteen cities are currently constructing metros and light rail and another twenty-two are at various points in planning stages (UN-Habitat, 2013).

Non-motorized transport (NMT), the lowest emission “shift” option, accounts for half of all trips in many cities (SLoCat, 2014a). Among NMT options, cycling has considerable promise to improve mobility and keep emissions lower than private vehicles (European Cyclists’ Federation, 2011). Despite these benefits, many urban areas have seen the prevalence of bicycles decline. India witnessed bicycle use fall from a 30% to an 11% mode share between 1994 and 2008 (UN-Habitat, 2013). Walking is another important NMT “shift” option. Walking currently accounts for between 40% and 60% of trips in several Asian cities (Institute for Transportation and Development Policy [ITDP], 2014). Retaining these percentages requires pedestrian-friendly infrastructure (UN-Habitat, 2013).

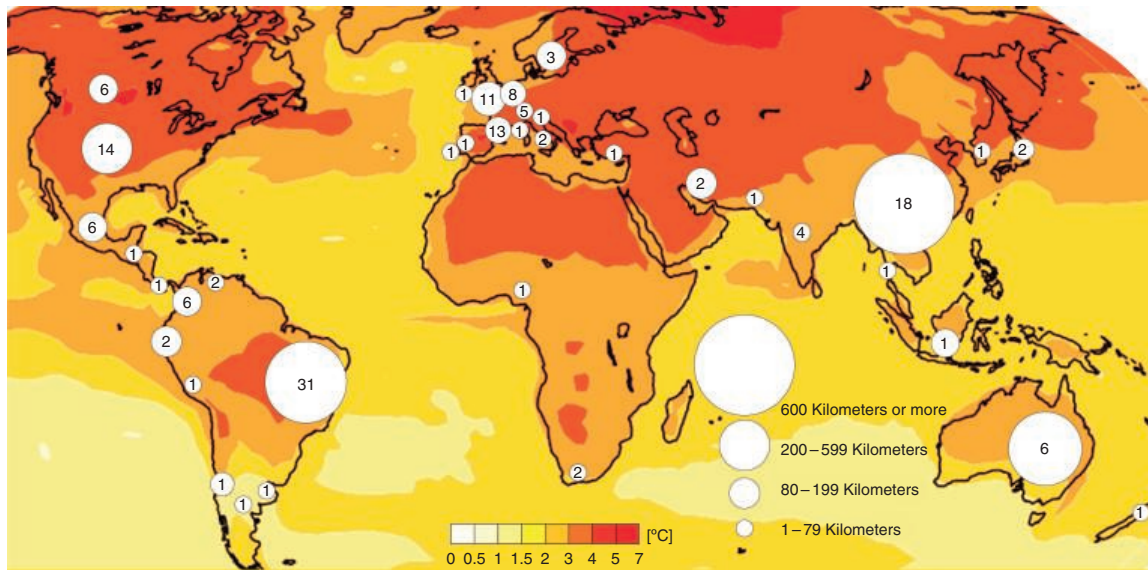
The third set of *ASI* options involves improving vehicle technologies and fuels. These improvements often involve leapfrogging or skipping stages of technological development. Leapfrogging through continuing fuel efficiency improvements could reduce 50% of fuel use per kilometer in new conventional vehicles by 2030 (Fulton, 2013). Improved technologies in larger trucks and buses could consume 20–30% less fuel using



Note: VKT = vehicle kilometers traveled.

**Figure 13.8a** Annual vehicle kilometers traveled and transit trips for selected global cities.

Source: Suzuki et al., 2013 Based on data from UITP, 2006



**Figure 13.8b** Global temperature projections and distribution of bus rapid transit systems.

Source: Sustainable Development Solutions Center analysis with data from IPCC, 2014; UN-Habitat, 2013; brtdata.org, and Hidalgo, 2012

hybrid electric or hydraulic hybrid drive trains (Chandler et al., 2006; AEA Consulting, 2011).

Electric vehicles reduce emissions by converting fuel to energy more efficiently and cutting tailpipe emissions. Studies show electric motors convert 59–62% of electricity drawn from the grid into energy at the wheel, whereas gasoline engines convert 17–21% (U.S. Department of Energy [DOE], n.d.). A global launch of electric vehicles could cost US\$500 billion but save US\$2 trillion through 2025. The UN set a goal for electric vehicles to make up 30% of urban motorized travel by 2030 to capture these savings (UN, 2014). Improvement in battery performance and reductions in battery prices make this goal feasible (U.S. DOE, n.d.). The impacts of electric vehicles nevertheless require changes to the overall energy system, or emissions will shift from vehicles to power plants.

Clean fuels, another “improve” option, reduce GHG emissions. Brazil’s flex-fuel and biodiesel programs are two notable initiatives promoting these clean fuel alternatives (Ribeiro and de Abreu, 2008). However, clearing carbon-rich lands for biofuel production can create CO<sub>2</sub> emissions (Fargione et al., 2008). Reductions in energy prices from biofuels can increase energy usage and emissions (Fargione et al., 2008). Additional research is needed on emissions across the lifecycle of biofuels.

### 13.4.3 Co-Benefits of Low-Carbon Transport

Reducing transport emissions can yield additional benefits beyond mitigating GHGs or co-benefits (see Table 13.4).

Capturing co-benefits can make low-carbon transport more affordable and sustainable. The highest value co-benefits tend to be those that improve public health from reduced air pollution (see Chapter 10, Urban Health). To illustrate, bringing emissions levels within World Health Organization (WHO) guidelines in twenty-five European cities could add 6 months of life expectancy (for 30-year-olds) in half the cities and save €31 billion (Pascal et al., 2012). In Asia, such savings project to be even greater due to poorer air quality (Chen and Whalley, 2010). In Taipei, Taiwan, a 9–14% reduction in carbon monoxide (CO) and particulate matter (PM) from public rail could deliver welfare gains of US\$264 million annually. Importantly, the air quality benefits often accrue to poor residents who are more exposed to pollution because they live closer to highways and traffic. Co-benefits therefore can also address inequities.

Another co-benefit is reducing congestion and travel times. Time lost in traffic costs an estimated 2% of gross domestic product (GDP) in Europe’s cities and 2–5% in Asia’s cities (UN-Habitat, 2013). In Dakar, Senegal, and Abidjan, Cote d’Ivoire, the costs of traffic congestion amount to 5% of GDP (UN-Habitat, 2013). In American cities, congestion created 5.5 billion extra hours of travel, required the purchase of an extra 2.9 billion gallons of fuel, and cost drivers US\$121 billion dollars in 2011 (Schrang et al., 2012). In Western Europe, reduced noise pollution could save 1 million lost life years from sleep deprivation, cognitive impairments in children, and other defects (WHO, 2011). Yet another co-benefit of some avoid-and-shift options is improved traffic safety (UN-Habitat, 2013).

## Case Study 13.2 Bus Rapid Transit in Lagos and Johannesburg: Establishing Formal Public Transit in Sub-Saharan Africa

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<b>Keywords</b>	BRT, Africa, mobility, emissions reductions
<b>Population (Metropolitan Region)</b>	Lagos: 21 million (Lagos State, 2013) Johannesburg: 7.2 million (Statssa, 2015)
<b>Area (Metropolitan Region)</b>	Lagos: 3,569 km <sup>2</sup> (Lagos State, 2013) Johannesburg: 6,009 km <sup>2</sup> (Statssa, 2015)
<b>Income per capita</b>	Nigeria: US\$2,450 South Africa: US\$5,480 (World Bank, 2017)
<b>Climate zone</b>	Lagos: Aw – Tropical savannah Johannesburg: BSk – Arid, steppe, cold (Peel et al., 2007)

Formal public transit remains virtually nonexistent in Sub-Saharan Africa (UN-Habitat, 2013), although this is beginning to change with recent and planned implementation of Bus Rapid Transit (BRT) systems in the region. The pioneers of this movement toward formal mass transit are the cities of Lagos and Johannesburg, the latter of which is credited with launching the first BRT system in the region only because the (slightly) older system in Lagos is described as BRT “lite.” This distinction exists because the Lagos system was designed to capture most of the desirable traits of BRT while requiring less capital investment, making the project feasible for the city. The result is a high-quality system at US\$2.75 million per kilometer, or half the cost of the usual BRT system (UN-Habitat, 2013). This increase in affordability is balanced by slightly slower transit times and lower capacities due to the lack of separated busways and other capital-intensive infrastructure changes, but the net gains for passengers remain substantial. In both Lagos and Johannesburg, informal taxis and minibuses dominated the public transport sector, usually exacting high fares and lacking in efficiency. BRT has improved economic, environmental, safety, and other outcomes for residents in both cities.

In Lagos, the BRT “lite” corridor opened in 2008 with a planned capacity of 60,000 passengers per day, a number that had reached 220,000 per day in 2010 (UN-Habitat, 2013). The World Bank provided technical advice and US\$100 million in financing, with Lagos state providing US\$35 million (World Bank, n.d.). To complete the financing and operation of the system a public–private partnership was established where the Lagos transit authority (LAMATA) provided facilities and terminals while private operators bought and operated the buses (World Bank, n.d.) The result for passengers was a 30% decrease in average fares, a 40% decrease in travel time, and a 35% decrease in waiting times (UN-Habitat, 2013). The buses are responsible for 25% of all trips along the BRT corridor

while representing just 4% of total vehicle traffic (World Bank, 2015b). As a result, CO<sub>2</sub> emissions have been cut by 13% and overall GHG emissions by 20% according to LAMATA (World Bank, n.d.). The BRT corridor has also created direct employment opportunities for 1,000 people and indirect employment for 500,000 (UN-Habitat, 2013).

Launched in 2009, the Rea Vaya BRT in Johannesburg was the first full BRT system in Africa (Allen, 2011), and cost US\$5.5 million per kilometer to construct (UN-Habitat, 2013). Rea Vaya was born of a transit plan by the city of Johannesburg with a goal of having 85% of residents within 1 kilometer of a BRT trunk corridor or a feeder route (City of Johannesburg, 2013). The awarding of the FIFA World Cup to South Africa in 2010 also provided motivation to get formal public transit systems up and running in host cities (Carrigan et al., 2013; UN-Habitat, 2013). Funding was achieved chiefly through fiscal transfers from national to city government in the form of a transport infrastructure grant. In 2011, the first phase of Rea Vaya was completed at a length of 122 kilometers and carried 434,000 passengers per day (UN-Habitat, 2013). Rea Vaya passengers reduced their travel times by 10–20% based on surveys, and a study by EMBARQ (Carrigan et al., 2013) shows that travel time savings and avoided road fatalities were the chief benefits of the BRT system, accounting for 30% and 28% of total benefits, respectively. Johannesburg launched the second phase of Rea Vaya (Phase 1b) in 2013, and it has registered both phases with the Voluntary Carbon Standard. The expected emissions reductions from the two phases are 400,000 metric tons of CO<sub>2</sub> over a 10-year period (Swiss Association for Quality and Management Systems, 2011).

Both cities are currently expanding their BRT systems, with Lagos planning on adding 13.5 kilometers to the existing corridor and Johannesburg constructing a third phase to service the northern parts of the city (C40 Cities Climate Leadership Group, 2013; Carrigan et al., 2013). Stakeholder engagement was key for both cities – in Johannesburg, the emphasis was on including existing taxi operators in the development and ownership of Rea Vaya to lower resistance and to lessen the impact on livelihoods of those in the transit sector (Allen, 2011). To make up lost revenues as taxis were taken off the road, taxi operators were offered ownership stakes in the Rea Vaya Company as compensation, and taxi drivers were retrained and absorbed into Rea Vaya as bus drivers (Allen, 2011).

In Lagos, community engagement was a key factor in building demand for BRT because there was a history of poor transport system delivery in the city and an overall lack of experience with formal public transit (UN-Habitat, 2013). LAMATA also worked to build a partnership with the National Union of Road Transport Workers, forming a cooperative to manage the BRT and building knowledge on the benefits of formal mass transit (World Bank, n.d.). The success of Lagos and Johannesburg in providing clean, efficient, and affordable public transit while working with the community and the dominant informal sector demonstrates a path forward to the rest of the continent to enhance mobility for urban residents while also improving the economic, environmental, and safety outcomes of transit.



**Table 13.4** Potential co-benefits from the transport sector beyond GHG mitigation. Source: Wright, 2009

Economic co-benefits	Environmental co-benefits	Social co-benefits
Congestion reduction	Reduction of air pollutants (particulate matter, sulfur oxides, nitrogen oxides, carbon monoxide, volatile organic compounds)	Health improvements
Consumer spending savings	Noise reduction	Crime reduction/security enhancement
Employment creation	Solid waste reduction	Gender equity promotion
Small and medium sized enterprise development	Water contaminant reduction	Universal access for physically disabled
Traffic accident reduction		Convenience and comfort
Technology transfer		Community sociability
Reduced dependence on imports/energy security		Reduction in community severance
Economic productivity/efficiency improvements		

### 13.5 Policy Frameworks and Enabling Environments

A well-designed low-carbon transport strategy will typically involve combining the *Avoid* and *Shift* demand-side with *Improve* supply-side options. Combining demand- and supply-side solutions is important to ensure net benefits and avoid unintended increase in emissions from a single intervention. Studies show a 2% increase in driving can offset 10% fuel consumption reductions from efficiency improvements (Greene et al., 1999). Potential synergies between and within the avoid-shift-improve categories is another reason for combining options (Schipper et al., 2000). The greatest benefits come from synergies between reductions in unnecessary travel and travel powered by advanced technologies and clean fuels. For example, this could involve equipping new buses with more efficient engines (Zusman et al., 2012).

Combining options requires support from multiple government and nongovernmental actors at different decision-making levels. It also necessitates well-trained staff and institutions capable of aligning stakeholder interests. Studies on applying multilevel, multistakeholder governance to transport suggest that significant improvements in institutional design are often needed to implement low-carbon strategies in the United Kingdom (Marsden and Rye, 2010) and Indonesia (Jaeger et al., 2015). In response to local conditions, mitigation policies and measures have varied across cities, and cities such as Delhi have shown that the actors and change agents that drive policy changes vary as well.

In 1995, a World Bank study found that poor air quality posed health hazards for households, causing an estimated 1 death every 70 minutes in Delhi, and branded Delhi as one of the most polluted cities in the world (Brandon and Hommann, 1995). The report generated public outrage in the city, and the Centre

for Science and Environment (CSE, 1998) started a campaign demanding clean air. The pollution emitted from poorly managed public transport was identified as one of the main causes of poor air quality.

The campaign galvanized citizen support through involvement of professional associations, media, academics, and other stakeholders and involved bringing the message directly to the attention of the national political leadership. In response, the Supreme Court issued a judgment in 1998 requiring the government of Delhi to stem air pollution by introducing compressed natural gas (CNG)-operated public transport and to augment the supply of mass transit within a prescribed time-frame of 3 years, as well as requiring adoption of stringent emission standards within 5 years. Additionally, to address resistance from automobile firms, the Supreme Court issued stringent directives including appointing a CNG czar to ensure compliance of new regulations; instituted large penalties for defaulters, including state and federal agencies; and increased funding of research and development. Both supply and demand for CNG and safety regulations were addressed through institutional mechanisms.

In about five years (1998–2002), all public transport in Delhi was converted to CNG-operated retrofitted buses. Furthermore, this effort triggered several projects to increase the supply of efficient and clean public transport systems like the Delhi metro, thus contributing to broader climate change mitigation efforts within the city. However, the key lesson from this case was that change agents are diverse – researchers, civil society, and the supreme court – and require creative and persistent efforts as well as the willingness to learn by doing (Mehrotra et al., 2009; with data from Centre for Science and Environment and C40 Cities). Building off past efforts, for the first 15 days of January, in 2016, the Government of Delhi introduced restrictions on car users based on car license plates to curb air pollution. Cars with even-numbered

license plates were allowed to operate on even dates while those with odd license plates were able to operate on odd dates.

Financing is also a key element of an effective enabling environment (see Chapter 7, Economics, Finance, and the Private Sector). Geography, age, and types of infrastructure influence the cost of building, upgrading, and operating a transport system. Policy-makers will need to tailor financing arrangements to different contexts. For most cities, however, public financing from various taxes and fees, government

borrowing, bond financing, and public-private partnerships will constitute the majority of funding. Multilateral and regional development banks may play the role of intermediaries, providing grants and low-interest financing for projects in developing countries.

At the same time, cities can adopt reform synergies and unlock financing as part of an enabling environment, on the one hand, and redirect ongoing and planned investments toward mitigation (see Case Study 13.3) and adaptation (see Case Study 13.1), on the other (Mahendra et al., 2013). The next section profiles four

### Case Study 13.3 London's Crossrail: Integrating Climate Change Mitigation in Construction and Operations

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<b>Keywords</b>	Infrastructure, transportation, mass transit, mitigation
<b>Population (Metropolitan Region)</b>	14,031,830 (Eurostat, 2015a)
<b>Area (Metropolitan Region)</b>	12,091 km <sup>2</sup> (Eurostat, 2015b)
<b>Income per capita</b>	US\$42,390 (World Bank, 2017)
<b>Climate zone</b>	Cfb – Temperate, without dry season, warm summer (Peel et al., 2007)

Large-scale mass transit projects, while consuming energy in both construction and operations, can still achieve net emission savings over time. By taking a proactive, holistic approach that seeks to minimize GHG emissions during all phases of construction and operation, contributions to climate change can be reduced and even prevented (Omega Centre, 2012). Since being approved by the UK

Parliament in 2008, Crossrail Ltd. (CRL) has worked to realize savings by institutionalizing mitigation strategies, accountability mechanisms, and an overall sustainable governance structure. According to the UK Department of Transport (2007), “rail’s biggest contribution to tackling global warming comes from increasing its capacity, so that it can accommodate demand growth.” Crossrail is a product of this strategy.

## PROJECT SPECIFICATIONS

London's Crossrail is a new east-west rail line that, for the first time, will directly link London's major financial and commercial centers of Heathrow, the West End, the City of London, and Canary Wharf. The line will connect Maidenhead and Redding in the west to Shenfield and Abbey Wood (see Case Study 13.3 Figure 1) to the east with thirty-seven stations and 110 kilometers of track, including 21 kilometers of new twinbore tunnels dug deep under the City. At £14.9 billion (US\$19.4b), Crossrail is the largest infrastructure project under construction in Europe and the largest project in the United Kingdom in more than 50 years. Crossrail is fully funded and set to start operations in 2018.

Deemed essential to London's global competitiveness, Crossrail will increase rail capacity by 10% and east-west capacity by 40%, greatly alleviating severe overcrowding and already at-peak capacity routes (Mayor of London, 2014). Poised to meet growing



**Case Study 13.3 Figure 1** *Crossrail Route Map.*

Source: Crossrail LTD

travel demand,<sup>1</sup> the line is designed to be highly efficient, capable of handling 72,000 passengers per hour and 200 million riders per year (Crossrail, 2014). Crossrail promises to cut travel times, increase access, and improve connectivity throughout Greater London and beyond. The UK economy is expected to benefit by “at least £42 billion (US\$54.7b) over the next 60 years” (deSilva and Paris, 2014) through job creation and higher productivity and property value.<sup>2</sup> The project is expected to generate “added value” of residential and commercial property by as much as £5.5 billion (US\$7.16b) between 2012 and 2022. Development along its corridor is expected to support and accelerate an additional 57,000 new homes and 3.25 million square meters of office floor space all within 1 kilometer of the new stations (GVA, 2012). London’s economy alone could benefit by £1.24 billion (US\$1.61b) annually (Roukouni and Medda, 2012).

CRL will bring an additional 1.5 million people within a 45-minute manageable commute to employment centers, including thousands in some of London’s most deprived areas (HM Treasury, 2007). According to the Crossrail, “97% of Crossrail related contracts are being delivered by UK-based companies ... with about 60% going to small and medium businesses” (Crossrail, 2014).

### OVERSIGHT AND ACCOUNTABILITY

Aligning with national and local climate mitigation policies CRL developed a performance-based sustainability strategy that addresses seven sustainability themes.<sup>3</sup> Fifteen Key Sustainability Initiatives (KSI) translate the themes into actions with senior management assigned to meet objectives. Initiatives associated with the theme

to “Address Climate Change and Energy,” include minimization of resource usage, minimization of energy use, optimization of logistics supply chain, minimization of environmental impacts, and reuse of excavation materials (de Silva and Paris, 2014). Indicators for each initiative are monitored and reviewed by in-house managers, further aiding adjustments and decision-making.

### CONSTRUCTION

**GHG Emissions:** To meet initiatives, CRL first measured its construction carbon footprint and then sought to shrink it by 8%. It is on track to meet this target and reduce emissions by 57,000 tons of carbon.<sup>4</sup> Actions include fitting 73% of machinery with diesel particle filters and utilizing cement-free concrete (Avidan, 2015; Crossrail, 2014). Once construction is complete, the payback period will likely be 9–13 years, after which CRL expects annual net savings of 70,000 to 225,000 tons of CO<sub>2</sub>, largely due to the displacement of car journeys and replacement of diesel trains on the existing network (Crossrail, 2014).

**Landfill Diversion:** About 99% of excavated tunnel spoil will be reused or recycled according to CRL. In Essex, 3 million tons have already been delivered and are being used to build a new, 670-hectare wetland habitat (Smale, 2015). The Wallasea Island Wild Coast Project, developed in partnership with the Royal Society (n.d.) for the Protection of Birds, will not only help to restore coastline, encourage biodiversity, and provide a buffer to rising sea levels, but will also divert waste from landfills, significantly reducing GHG emissions further, particularly methane (see Case Study 13.3 Figures 2 and 3).



**Case Study 13.3 Figures 2 and 3** Wallasea Island Wild Coast Project.

Sources: Royal Society for the Protection of Birds and Geographical Association (UK)

- 1 By 2050, London’s population is expected to grow by 37% and its workforce by 29%. Tourism is expected to grow by 40% by 2022. TfL predicts “public transport trips could increase by 50–60% over the next decades” (Mayor of London, 2014).
- 2 Benefits from transport generally include travel time savings, increased speed of travel, reduced crowding, reduced waiting times, seating availability, improved safety, etc. (Gomez-ibanez, 2008). Estimates of Crossrail’s impact on “wider benefits,” include moves to more productive jobs, higher economic productivity, agglomeration benefits, increased labor force participation, and leveling of imperfect competition (Crossrail, 2011).
- 3 For instance, CRL’s efforts to reduce carbon emissions is in line with recommendations laid out in the UK’s 2013 Infrastructure Carbon Review, which if followed could reduce emissions from infrastructure by 24 million tons by 2050, thus contributing to the UK’s climate change commitments. CRL also aligns with the sustainable strategies put forth by the Department for Transport, Transport for London, and the Mayor of London.
- 4 CRL estimates total CO<sub>2</sub> emissions from construction at 1.7 million tones.



## OPERATIONS

*Rolling stock and procurement requirements:* CRL requires all contractors to meet stringent energy-efficient standards for its new rolling stock and applies sustainable standards throughout its entire supply chain. Bombardier's winning £1 billion (US\$1.3b) bid to supply and maintain CRL's rolling stock promises to deliver lightweight trains of only 350 tons, thereby reducing the typical amount of energy needed to move and stop trains (Crossrail, 2014).

*Station design:* All stations will incorporate energy-efficient materials and products from LED lighting and presence detectors to regenerative braking on trains whereby energy used to slow and stop the train is captured and converted or stored for later use. The stations are also designed to reduce energy use. Utilizing a humpback design, trains arrive to the station on a slight incline and

depart on a slight decline, thus capitalizing on the force of gravity (Smith, 2015).

Large-scale urban transport projects can contribute to climate change through their energy consumption during construction and operations. Nevertheless, sustainable outcomes are possible, particularly when calculating offsets gained through reduced energy use, energy efficiency, and mode shifts away from other higher GHG-emitting forms of transport that mass transit provides. As this case shows, it is even more likely that mega urban transit projects have the potential to provide net environmental benefits when applying and adhering to a holistic focus maintained throughout the life of the project. By combining stringent procurement requirements, sustainable supply-chain management, diverting waste from landfills, and using energy-efficient products and materials, CRL is working to mitigate its impact on climate.

key enabling reforms: managing land use, congestion pricing, taxes and auctions, and land value capture. These reforms are an illustrative example, not an exhaustive list, of the kinds of changes cities can introduce to expand the fiscal space for the transport sector.

### 13.5.1 Managing Land Use

Several enabling reforms can promote mixed land-use and transit-oriented development (TOD). In the United States, state governments provide tax credits to promote a form of mixed-land-use planning known as “smart growth” (Bolen et al., 2002). In Ahmadabad, India, policy-makers impose surcharges on land-owners for the right to increase densities (measured in floor area ratios [FAR]) and reinvest revenues in affordable housing near the BRT (UN-Habitat, 2013). In Curitiba, Brazil, officials offer developers the ability to increase density in exchange for open spaces to promote mixed-use development (Seto et al., 2014). Many cities nonetheless adopt poorly designed zoning and codes and fail to coordinate public transport and land-use rules. In consequence, they underuse urban space, face overcrowding, and confront extraordinarily high land prices in city centers (Bertaud, 2004, 2015).

### 13.5.2 Congestion Pricing

Several cities – Singapore, Stockholm, and London – have adopted congestion pricing to encourage environmentally friendly travel, mode shifts, and compact development (Seik, 1998; Givoni, 2012; Börjesson, 2012). Discontent from drivers, impacts on the poor, infringements on privacy from travel tracking, and a shortage of alternative modes have nonetheless often led to political backlash for congestion pricing. Resistance to the congestion pricing initiative in New York is a high-profile example of such contestation (Schaller, 2010). To avoid similar resistance, many cities have adopted less contentious parking restraints and moderate pricing policies. These alternatives to congestion pricing programs may be less effective as drivers

carpool or change parking rather than forgo driving altogether (Marsden, 2006). In other cases, web-based real-time information on bus routes has helped efficient trip planning, thereby supplementing congestion pricing (MTA, 2014; Chicago Transit Authority [CTA], n.d.).

### 13.5.3 Taxes and Auctions

Taxing the carbon content of fuel can be more efficient than directly charging for vehicle use. A fuel tax can affect fuel and vehicle choice. Norway not only imposes fuel taxes but also an annual tax on vehicle ownership and registration (Naess and Smith, 2009). Other parts of the world employ different methods to capture externalities. Singapore auctions a rationed number of “Certificates of Entitlement” to own a vehicle (Seik, 1998). Cities such as Athens, Seoul, San Paulo, Lagos, and Mexico City limit the use of vehicles on days of the week based on license plate numbers (Mehrotra et al., 2011; World Bank, 2009). Well-designed vehicle restraint schemes discouraged peak driving by 14% in São Paulo (Viegas, 2001). Distance-based charging and pay-as-you-drive (PAYD, an insurance premium per mile based on driving record) have been recommended to affect driving behavior, consolidate loading, and improve efficiencies for the freight industry (Litman, 2012). However, a related challenge is posed by the extraordinarily high global subsidy on carbon-based fuels. The International Monetary Fund (IMF) estimates post-tax energy subsidies to be US\$5.3 trillion dollars or 6.5% of global GDP in 2015 (Coady et al., 2015).

### 13.5.4 Land Value Capture

Value capture can supplement traditional revenue for transit infrastructure in dense and congested cities while promoting mixed-use development and facilitating development of affordable housing (Murakami, 2012; Cervero, 2009; Ardila-Gomez et al., 2016). Value capture can be achieved through a wide variety of techniques, including land sale or lease, joint development



between the government and the private sector, sale of air rights, land readjustment (see Figure 13.9), or urban redevelopment schemes (see Chapter 5, Urban Planning and Design). Tokyo has enjoyed considerable success with its land value capture system. Tokyo finances a third of land redevelopment for new transit, grants land readjustment ability under the Housing Highway Integration Law, and allows for land owners and developers to capture value through the Urban Redevelopment Law (Suzuki et al., 2015) (see Figure 13.10). Cities such as Los Angeles have also employed land value capture to derive funds from neighboring commercial business owners, funding 10% of its Red Line metro-rail.

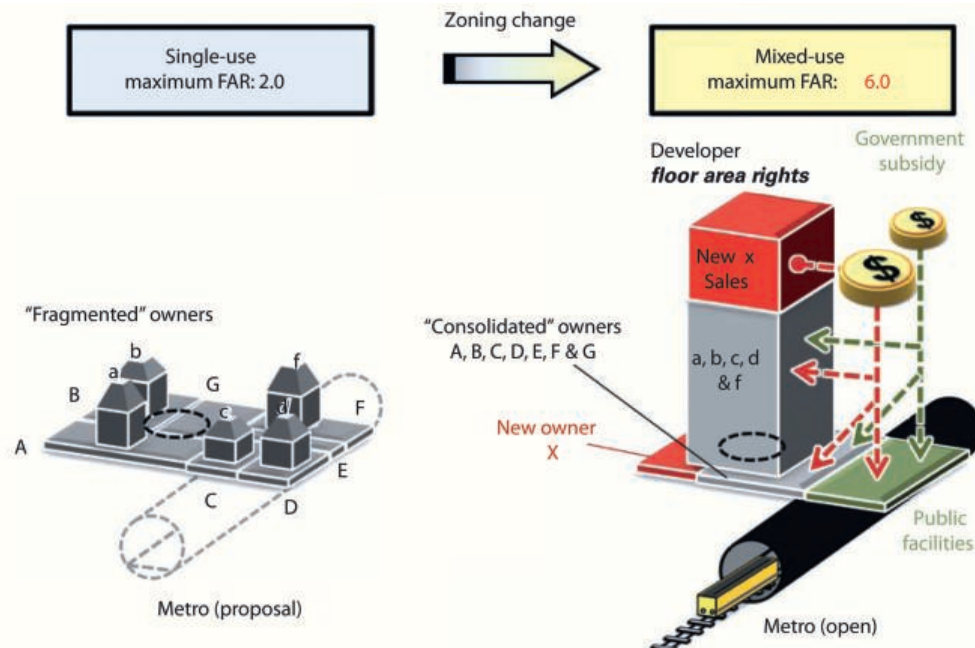
### 13.6 Transport Solutions: Leveraging Sustainable Development Goals, Paris Agreement, and the New Urban Agenda

The discussion on sustainable transport has evolved from defining and discussing the need for sustainable transport to determining the best strategies to implement sustainable transport. With this evolution, the dialogue is less one that is specific to the transport community and more one that needs to be addressed by the wider development community, particularly cities.

The year 2015 marked a critical juncture for sustainable transport. The UN General Assembly finalized and approved

a set of 17 Sustainable Development Goals (SDGs) that are intended to inspire and guide the global development community. SDG 11, “make cities inclusive, safe, resilient and sustainable,” includes a specific target on transportation. The target states that “by 2030, provide access to safe, affordable, accessible, and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons. Additionally, transport-related targets are included in eight of the 17 SDGs. This suggests that it is likely to receive even more attention as an enabler of sustainable low-carbon development between 2015 and 2030 (UN-Habitat, UNEP, SLoCaT, 2015). This chapter’s authors, as members of organizations like the UN Sustainable Development Solutions Network (SDSN), an external advisory group appointed by the UN Secretary General, have continued to advocate for a Post-2015 urban development agenda that offers cities as a space for transformative solutions, including in the New Urban Agenda, as part of the UN General Assembly-mandated Habitat III process – a multiyear engagement that led up to the United Nations Conference on Housing and Sustainable Urban Development, which took place in Quito, Ecuador in October 2016 (Mehrotra, 2012b; Revi et al., 2013).

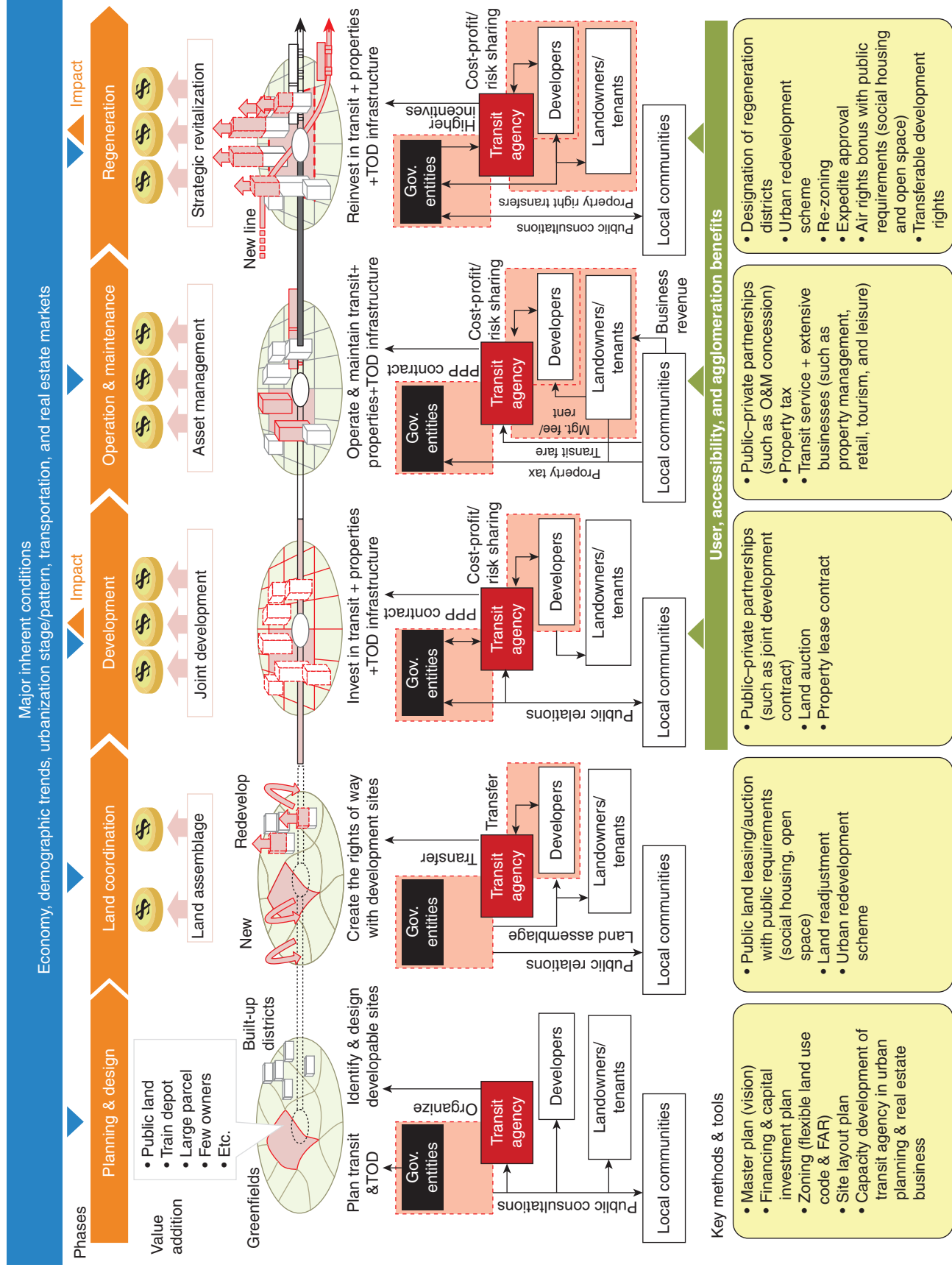
In addition, a global climate change agreement for the post-2020 period was adopted in December 2015 in Paris. The Partnership on Sustainable Low-Carbon Transport (SLoCaT)



Source: Adapted from Ministry of Land, Infrastructure, Transport, and Tourism 2013.  
Note: FAR = floor area ratio.

**Figure 13.9** Financing urban transport through land readjustment.

Source: Suzuki et al., 2015



Note: FAR=floor area ratio; O&M=operation and maintenance; TOD=transit-oriented development.

**Figure 13.10** Land-value capture implementation process.

Source: Suzuki et al., 2015

Results Framework on Sustainable Transport describes the potential contribution of land transport to SDGs by bringing together three targets on improving rural, urban, and national access and connectivity and three targets on reducing road fatalities and serious injuries, air pollution, and GHGs. Sustainable transport has been mainstreamed across seven of the seventeen SDGs adopted by the UN General Assembly. Making sustainable transport an integral part of global policies on sustainable development and climate change needs to go hand-in-hand with the development of effective international funding and financing frameworks for sustainable transport. Although the public sector will have to take the lead in increasing national and local funding and defining long-term strategic planning and investment frameworks, it is now widely acknowledged that greater private-sector involvement is required to provide both financing and technical expertise. Private-sector and international climate finance also have important roles to play in redirecting transport funding from car-centric to more sustainable transport models. Transport systems that utilize low-carbon and mass transit modes, which are designed to reduce the impacts of climate change, cater to urban mobility, and contribute toward creating reasonable densities with mixed land-use development, can transform cities toward sustainability (see Chapter 7, Economics, Finance, and the Private Sector).

These global decisions could make a significant difference in helping national and subnational governments scale up already effective urban transport policy, infrastructure, service development, and mobility management for climate mitigation and adaptation. If sustainable transport is not well-integrated into a global sustainable development and climate policy framework, many cities and companies will continue to press forward with effective actions. But many will not. Delays in helping the world's cities move forward quickly to adopt a new paradigm that ensures access for all to clean, safe, and affordable mobility and climate-resilient communities should be avoided.

## Annex 13.1 Stakeholder Engagement

Urban transport and climate change research and practice are interdisciplinary and necessitate multistakeholder engagement. The combined experience of chapter authors represents over a century and a half of engagement on sustainable urban transport spanning scholarly research and high-level policy-making in developed and developing countries. During the 3-year preparatory process for the chapter, the research, policy engagement, and advocacy work have been shaped by, and have shaped, urban transport and climate change processes and associated state-of-the-knowledge. The community of engagement has spanned young policy-makers, graduate students, leading private-sector executives, high-level policy-makers, multilateral development banks, UN institutions, leading think-tanks and foundations, governments, city leaders, and an even wider spectrum of city stakeholders engaged in the Post 2015 development agenda, Paris COP 21 process, and Habitat III preparatory process.

Michael Replogle led a large-scale consultative process on mainstreaming urban transport into the SDGs, transitioning from a research and advocacy role to leading New York City's Department of Transportation as Deputy Commissioner for Policy. Eric Zusman, based in Japan, led high-level policy dialogues and research at Asia's premier environmental think-tank, the Institute for Global Environmental Studies, exploring co-benefits of climate policies in developing Asia's transport sector. Shagun Mehrotra, building on two decades of his research, policy engagement, and teaching experience, in 2012 was instrumental in the conceptualization and development of the community of practice (urban thematic group) and strategy for the dedicated urban SDG for the UN Secretary General's external advisory group of high-level experts. Through this consultative engagement and the efforts of leading urban city networks and stakeholders, a dedicated Urban SDG was adopted by the UN General Assembly, with a high priority accorded to sustainable and equitable urban transport solutions. Klaus Jacob, leading scholar and reflective practitioner with four decades of experience, has been instrumental during the course of this knowledge assessment in shaping the adaptation plan for one of the world's oldest and largest urban transit authority – New York City's Metropolitan Transportation Authority (MTA). He has been widely sought by the global urban transport and climate change community for consultations. Jitendra N. Bajpai, brought several decades of high-level urban transport policy-making and international development advisory and lending experience to inform the assessment as well as expand the community of stakeholders ranging from graduate students to leading policy forums. Susan Yoon has taken the knowledge assessed in this chapter into her practice of policy-making at New York's MTA. Mathew Woundy has engaged in leadership training of private- and public-sector leaders and education of business executives. Lina Fedirko has engaged with creative private-sector firms, bringing a unique blend of policy and design. All these author engagements, both individually and collectively, have brought a deep and diverse stakeholder perspective, have tested and enriched the knowledge assessment, and have made it relevant to a wide range of intellectual and applied contexts.

## Global Public Engagement on Sustainable Transport

A growing number of local and national governments are adopting an Avoid-Shift-Improve paradigm for transport policy and investment. This emphasizes: (1) avoiding unnecessary or low-value travel through smarter urban planning, transport pricing, sound logistics, and telecommunications; (2) shifting travel to lower polluting modes like public transport, walking, cycling, and rail freight; and (3) improving the remaining transport with cleaner vehicles and fuels and more efficient network operations. Civil society, industry, and governments are increasingly cooperating in promoting this new paradigm and moving away from the failed approach of *predict and provide*, which sought to simply build more roads to accommodate growing traffic demand.

Partnerships between the public and private sector and civil society play a growing role in advancing sustainable transport. The Partnership on Sustainable Low-Carbon Transport (SLoCaT) was formed in 2009 and now brings together more than 90 civil society groups, UN agencies, and multilateral development banks, as well as industry and research organizations (SLoCaT, 2014c; SLoCaT, 2015a). SLoCaT and its members helped pull together an unprecedented Rio+20 voluntary commitment by the eight largest multilateral development banks of US\$175 billion over the coming decade for more sustainable transport (African Development Bank, 2012), with annual reporting on progress (Replogle and Huizenga, 2015). The transport sector responded to the call for bold action on climate change by Secretary General Ban Ki-moon at his Climate Summit in September 2014 by announcing five major transport commitments (SLoCaT, 2015b). These actions on transport will result in scaling up urban public transport and doubling global mode share, greater use of more efficient passenger and freight rail transport, accelerated introduction of urban electric vehicles, more fuel efficient passenger vehicles, and renewed action plans on green freight. Collectively, these actions can reduce the carbon footprint of at least half of all passenger and freight trips made by 2025. The International Energy Agency (2013) has estimated that these actions, if implemented at a global scale, can result in cumulative savings of US\$70 trillion by 2050, due to reduced investment needs for vehicles, fuel, and transport infrastructure.

It is clear that the discussion on sustainable transport has evolved from defining and discussing the need for sustainable transport to determining the best strategies to implement sustainable transport. With this evolution, the discussion is decreasingly one that is specific to the transport community and increasingly one that needs to be addressed by the wider development community. That shift should lead to a more stable climate and sustainable cities.

## Chapter 13 Urban Transportation

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