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Green Cities & Transportation

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Green Cities and Transportation

GREEN CITIES AND TRANSPORTATION

ARIADNA REYES-SANCHEZ; SOHEIL SHARIFI-ASL; AND LADAN MOZAFFARIAN

Mavs Open Press

Arlington

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This open textbook is part of the ***OERT*ransport** collection of six transportation planning OER textbooks and their respective graduate course implementation at each of the three collaborating universities. The creation of each textbook benefitted from an independent industry advisory board's review and the savvy contributions of each institution's OER librarians. For more information on OERTransport: [OERT Website]

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PREFACE

The OER textbook, "Green Cities and Transportation," seeks to educate planners on sustainable transportation, transportation equity, and climate change mitigation. Although the focus is on sustainable transport for US cities, the book examines North and Global South towns that may serve as a reference because they have implemented illuminating approaches to sustainable and equitable mobility. Case studies include Bus Rapid Transit in Curitiba, Brazil, congestion charging in London, and biking in Amsterdam.

This textbook fosters knowledge, skills, and multidisciplinary conversations on how sustainable mobility and infrastructure may support climate change mitigation and transportation equity for low-income commuters.

The textbook is divided into three sections: 1) Sustainability, Transportation Equity, and Planning, 2) Case Studies and Lessons from the North and South, and 3) Greenhouse Gas Emissions, Cities, and Mobility. The textbook includes eleven chapters with discussion questions, reading materials, and in-class exercises to help students develop a research paper on transportation. Students' learning outcomes include:

- Developing research skills drawn from transportation case study projects,
- Explaining and demonstrating the significance of transportation for climate change mitigation and sustainable development,
- Illustrating sustainable mobility strategies that help reduce greenhouse gas emissions and, at the same time, support transportation equity for low-income commuters.

CHAPTER TITLES

Section I: Sustainability, Transportation, and City Planning.

Chapter 1: Transportation and Sustainable Development.

- Dr. Ariadna Reyes, Ladan Mozaffarian, and Soheil Sharifiasl.

Chapter 2: Transportation Equity and Justice. The Effects of Driving in the Built Environment: Pollution and Global Warming.

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Chapter 5: Case Study III: Car Bans in Mexico City.

- Dr. Ariadna Reyes and Ladan Mozaffarian.

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Chapter 7: Case Study V: California High-Speed Rail.

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Chapter 8: Case Study VI: Sustainable Transportation in Latin America: Bus Rapid Transit Systems in Curitiba, Brazil and Transmilenio in Bogota, Colombia.

- Dr. Ariadna Reyes and Ladan Mozaffarian.

Chapter 9: Case Study VII: Non-Motorized Transportation in Europe and the United States.

- Dr. Ariadna Reyes, Soheil Sharifiasl, Anna Laura Harmjanz, and Jenifer Reiner.

Section III: Greenhouse Gas Emissions, Cities, and Mobility.

Chapter 10: Transportation and Climate Change Mitigation: A Life Cycle Assessment Perspective.

- Dr. Ariadna Reyes.

Chapter 11: Environmental Impact Assessment: Data, Methodological Approaches, and Examples.

- Dr. Ariadna Reyes.

ABOUT THE AUTHORS

DR. ARIADNA REYES

Assistant Professor, Department of Public Affairs and Planning. College of Architecture, Planning, and Public Affairs. The University of Texas at Arlington.

Dr. Ariadna Reyes is an Assistant Professor in Planning at the College of Architecture, Planning, and Public Affairs. She teaches planning, sustainable communities, green cities, and transportation courses. Before this, she was a research associate at the Cooperative Mobility for Competitive Megaregions (CM2) and a lecturer at the University of Pennsylvania Weitzman School of Design. She was a postdoctoral fellow in the Global Shifts Program at Penn's Perry World House. She earned a Ph.D. in Community and Regional Planning from the University of Texas at Austin School of Architecture in 2018. She received the Fulbright-Garcia Robles and Mexico's National Council for Science and Technology (CONACYT) grants as a doctoral researcher. Her research provides a comprehensive approach to housing, transportation, and sustainability. Her study on the transportation burdens of low-income communities in Mexico City has been published in the Journal of Planning Education and Research, Urban Studies, and Transportation Research Part D. Her current research will reveal the transportation and climate injustices that low-income residents of color face in North Texas.

CONTRIBUTING AUTHORS

SOHEIL SHARIFI-ASL

Ph.D. Student, Urban Planning & Public Policy, UTA

Soheil is a Ph.D. student and graduate research assistant at the College of Architecture, Planning, and Public Affairs. Holding a master's and bachelor's degree in urban planning from the University of Tehran and completing his dissertations in transportation, Soheil is interested in urban transport, transportation equity, transportation infrastructure planning, public transit planning and modeling, transportation big data, and statistical models.

LADAN MOZAFFARIAN

Ph.D. Student, Urban Planning & Public Policy, UTA

Ladan Mozaffarian is a Ph.D. student of Urban Planning and Public Policy (UPPP) at The University of Texas at Arlington. Ladan completed her Master of Landscape Architecture and Bachelor of Architecture from SBU in Tehran, Iran. As a graduate research assistant (GRA), Ladan has worked on different research projects at the Center for Transportation Equity, Decisions, and Dollars (CTEDD).

ABOUT THE INSTITUTION

Founded in 1895, the University of Texas at Arlington, a Carnegie Research-1 Institution (Very High Research Activity), is a comprehensive teaching, research, and public service institution dedicated to the advancement of knowledge through scholarship and creative work. UT Arlington is committed to providing access and ensuring student success, and to a culture of innovation, entrepreneurship, and commercialization of discoveries by our community of scholars. The University promotes lifelong learning though its academic, continuing education, and experiential learning programs. The faculty, staff, and student community share diverse cultural values that foster inclusivity and cultivate mutual respect.

UT Arlington is one of the most ethnically diverse campuses in the United States, according to rankings of national universities published by *U.S. News & World Report* in 2020. In fall 2022, the student population was 32% Hispanic, 13% African American, and 12% Asian. UT Arlington has been designated a Hispanic-Serving Institution and an Asian American Native American Pacific Islander-Serving Institution by the U.S. Department of Education.

In response to societal needs, UT Arlington has evolved into a renowned university within the state and one of emerging position nationally and internationally. The University's history of achievement can be attributed to its outstanding faculty, a strong student body, a record of success by graduates in their respective fields, and the growth of the Dallas/Fort Worth area as a nationally and internationally significant metropolis.

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- David Weinreich, Ph.D., Postdoctoral Fellow in Urban Governance and Sustainable Transformation, University of Bergen, Norway.
- James Wood, Ph.D., Project Manager at the Dallas-Fort Worth International Airport.

PROJECT DIRECTION

- Ivonne Audirac, Ph.D., Professor, City and Regional Planning Program and Associate Director for Education, Center for Transportation, Equity Decisions, and Dollars CTEDD, University of Texas at Arlington (UTA), OERTransport Project PI.
- Jay M. Rosenberger, Ph.D., Professor, Industrial Engineering, University of Texas at Arlington (UTA), OERTransport Project Co-PI.
- Amber Raley, M.A., Urban Planning and Public Policy Ph.D. Student, University of Texas at Arlington (UTA), OERTransport Project Co-PI.

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ABOUT THE COVER

- Mexico City's "Muevete en Bici" program has closed down Paseo de la Reforma, a major car corridor, and opened it to cyclists, every Sunday since 2017. Image by Dr. Ariadna Reyes, cover layout by Elvira Shirgir.

PART I.

SECTION 1 SUSTAINABILITY, TRANSPORTATION, AND CITY PLANNING

CHAPTER 1.

TRANSPORTATION AND SUSTAINABLE DEVELOPMENT

CHAPTER OVERVIEW

In this chapter, we introduce some of the challenges associated with transportation planning, particularly in the context of environmental issues such as **climate change**, and **sustainable development** strategies. We review the current state of environmental pollution and the transportation sector's contribution to these problems. Additionally, we evaluate policies aimed at various goals, including reducing greenhouse gas (GHG) emissions, mitigating climate change and warming, and promoting environmental justice and equity. Finally, we conclude the chapter by discussing the challenges associated with these practices and how environmental justice, equity, and sustainable development are interconnected from a policy perspective.

Learning Objectives

- Explain the significance of the transportation sector's role in global climate change.
- Summarize and compare how different factors with regard to transportation access and density will affect energy use in cities of the North and the **Global South**.
- Recognize sustainable mobility's significance in reducing greenhouse gas (GHG) emissions in the transportation sector and support justice for low-income commuters.
- Explain how sustainable mobility policies and projects may foster the United Nations' 17 Sustainable Development Goals (SDGs)

THE CHALLENGES OF TRANSPORTATION IN THE US

This section examines some of the most relevant US transportation challenges from climate change and sustainable development perspectives.

- **Problem 1**: Transportation (driving) is the largest contributor to GHG emissions.

Energy used in land for residential activities accounts for 30-40% of the world's energy consumption. Land-use planning can directly or indirectly affect the energy used by transportation. Research shows that when combined, transportation and housing energy use are responsible for about 62% of the world's energy use and 55% of global greenhouse gas (GHG) emissions (Anderson et al., 2015). Several planning-related factors, such as population density, the spatial layout of the city, and access to transit, significantly affect the amount of energy consumed by residential and transportation needs. Accordingly, higher urban densities allow a larger population to reside in an urban area, providing commuters greater access to public transportation options. For instance, results from a 2016 study in Toronto, Canada, show that a higher population density reduces commuters' miles traveled and therefore reduces the consumption of fossil fuels. This study reveals that commuter contribution to GHG emissions of a low-density suburban development is higher (by a factor of 2–2.5 partly) than in a high-density urban core development (Norman et al., 2006). Transportation scholars agree that in developed-world cities, suburban commuters use more fossil fuels and contribute more to GHG emissions than urban residents (Bastos et al., 2016; Marique & Reiter, 2012)

- **Problem 2**: U.S. cities are among the largest GHG emission producers in the world because of built environment-related factors such as lower density, fewer public transportation facilities, and poor access to public transit.

Figure 1.1 also shows the relationship between density and energy consumption for many cities in the world. What is evident from this graph is that U.S. cities are typically less dense and consume more energy for transportation. This may be attributed to the predominance of commutes single-occupancy private vehicles. Low-density development and a lack of transit systems in most U.S. cities have created car-dependent cities. However, European cities are denser and more compact and provide a variety of transportation modes. The graph depicts how much less energy is consumed for transportation in Europe and Asia. Thus, sustainable mobility is achievable when factors such as density, access to transit, availability of different modes of transportation, and shorter commute distances are realized.

On the other hand, in Latin America, as exemplified by Mexican cities, residents tend to have better access to transit along with denser communities; these cities use less transportation-related energy consumption than most U.S. cities (Figure 1.1). In Mexican cities, people use public transit and walk more than their US counterparts (Guerra et al., 2020). Therefore, cities in this part of the world have a lower impact on increasing GHG emissions and energy consumption than some low-density and car-dependent cities in America

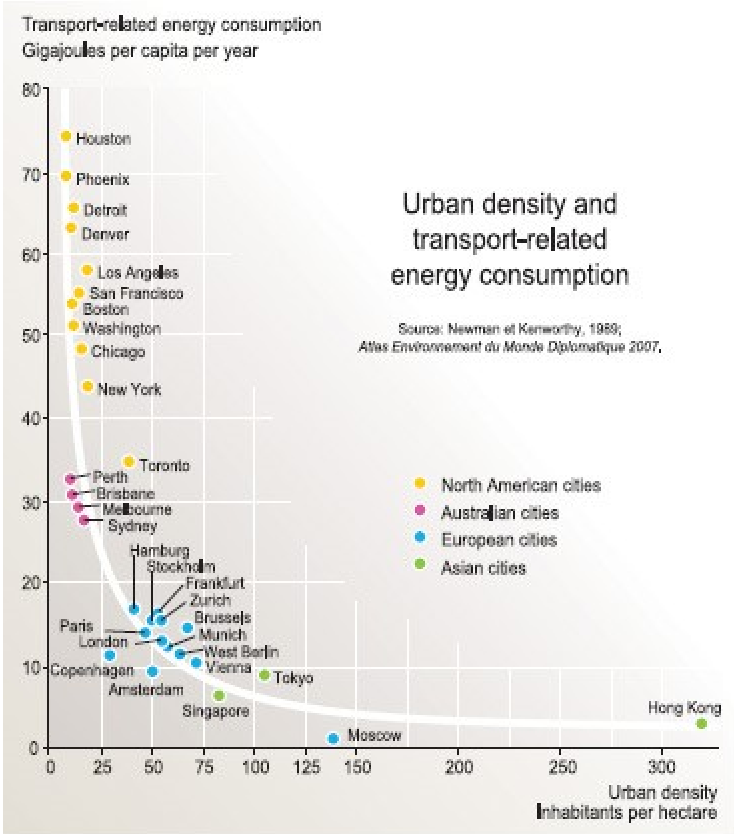

Figure 1.1 Influences of urban densities on transport-related energy consumption for 32 cities. From "Urban Transport Energy Consumption: Determinants and Strategies for its Reduction" by B. Lefèvre & G. Mainguy, 2009, Cities and Climate Change, p.3, CC-BY

SUSTAINABLE DEVELOPMENT POLICY SOLUTIONS FOR US CITIES

- **Sustainable Development**: What is sustainable development, and what are the 17 Sustainable Development Goals?
- **Sustainable Mobility**: How may sustainable mobility serve to enable the United Nations' 17 Sustainable Development Goals?

Sustainable development

In terms of sustainable development, the United Nations (UN) has proposed 17 goals for achieving sustainable development, which are listed as follows (United Nations, 2015):

1. Ending all forms of poverty globally.
2. Promoting food security and nutrition through sustainable agriculture.
3. Promoting healthy life for all age groups.
4. Promoting equitable and inclusive education with lifelong opportunities.
5. Ensuring gender equality and promoting women's rights.
6. Ensuring safe and sustainable water resources with the possibility of sanitation for all.
7. Providing affordable and sustainable energy for all.
8. Promoting economic growth that is sustainable and equitable and provides decent, full, and productive employment for all

9. Developing sustainable and resilient infrastructure along with innovative industrialization.
10. Reducing the gap of inequality globally.
11. Promoting livability of cities through inclusive design and development, safe and sustainable settlements.
12. Ensuring sustainable consumption and production patterns.
13. Developing feasible plans for fighting climate change.
14. Cautiously using resources such as oceans, seas, and all other marine resources in a sustainable manner.
15. Promoting sustainable use of ecosystems such as forests while reducing **Biodiversity** loss.
16. Ensuring equal access to justice within societies for everyone.
17. Promoting the means for establishing a global partnership for sustainable development across all countries and building an international coalition for realizing sustainable development (United Nations, 2015).

These Sustainable Development Goals recognize that sustainable development relies heavily on environmental sustainability policies that encourage green cities, **sustainable transportation** infrastructure, and effective actions to combat climate change. However, sustainable development cannot be achieved only by these environmental planning policies and solutions. Thus, ideals associated with more equitable and just societies, such as no poverty, quality education, and gender equality, are also significant and critical to truly achieving sustainable development goals. Incorporation of the UN SDGs into government plans and policies to eliminate poverty, reduce inequalities, and tackle climate change while creating partnerships with communities, NGOs (non-governmental organizations), and industry will further **Sustainable development**. Figure 1.2 thematically depicts the United Nations' Sustainable Development Goals.

Figure 1.2 United Nations (UN) Sustainable Development Goals (2015-2030). From "UN adopts new Global Goals, charting sustainable development for people and planet by 2030," by United Nations, 2015 (https://news.un.org/en/story/2015/09/509732). Copyrighted.

Sustainable development is not a simple concept and has a complex meaning that includes references to many different global and local problems. This concept and policy approach has evolved over the last four decades. In the 1980s, global leaders and policymakers defined it as "A development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Keeble, B. R, 1987. p.20). Sustainable development was defined in relation to nature, economy, and society. However, when equity and justice issues are disregarded in sustainable development, the balance between economic, environmental, and social dimensions of sustainability is undermined (Agyeman, 2005; Agyeman et al., 2002).

Because extreme climate events, such as floods and droughts, are expected to exacerbate the current vulnerabilities and spatial inequities currently experienced by low-income families across the globe (Adger, 2006; Boone & Fragkias, 2012), scholars and planners have urged policymakers to raise justice and equity as the core principles of sustainable development (Agyeman, 2005). Recently, sustainability has been coupled with environmental justice to empower grassroots social movements of low-income communities to face the spatial injustices that disproportionately threaten them (Agyeman, 2005; Boone & Fragkias, 2012).

Also, because the urban poor tend to contribute little to greenhouse gas emissions but are disproportionately exposed to extreme climate events, climate justice emerges as another central component of the concept of sustainability (Adger, 2006; Steele et al., 2012). Finally, sustainability in transportation is linked with the concept of compact urban development (Davoudi, 2014). Urban density and transportation access determine how commuters get to places, use transportation energy, and contribute to greenhouse gas emissions (Davoudi, 2009; Norman et al., 2006; Stephan et al., 2011). Compact cities with resilient, robust, and multi-modal transportation systems may allow residents to commute efficiently to use the city's services and opportunities (Gudmundsson & Höjer, 1996).

SUSTAINABLE TRANSPORTATION/MOBILITY

Sustainable mobility, also known as sustainable transportation, is defined as different solutions and policies that 1) help to reduce GHG emissions, 2) decrease air pollution, and 3) provide an equitable transportation system (e.g., for low-income residents, disabled populations, and women). One way to achieve sustainable development goals is to have sustainable transportation that is environmentally friendly, affordable, accessible, and equitable for all. In the UN Sustainable Development Goals (SDGs), sustainable transportation is either directly mentioned or implied within several SDGs and targets. Sustainable transportation is also directly related to sustainable food security, energy consumption and conservation, health-related issues like pollution, economic growth and development, enhancing urban areas and population settlements, and promotion of infrastructure. The following graph provides a comprehensive explanation of the impacts of sustainable transportation on achieving the SDGs (Figure 1.3) (United Nations, 2023). To summarize, a transportation system is sustainable when it is safe, affordable, accessible, efficient, and resilient and minimizes carbon and other emissions.

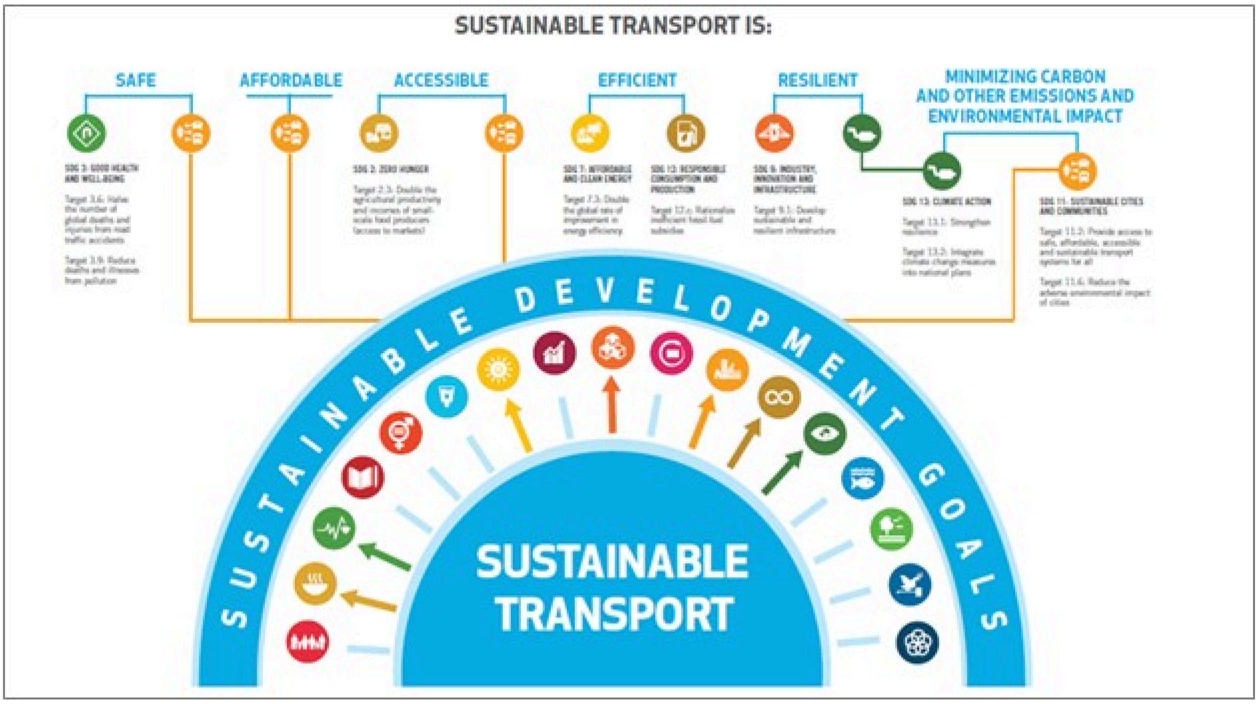

Figure 1.3 Sustainable transport impacts on achieving the Sustainable Development Goals (SDGs). From "SustainableTransport impacts the achievement of the sustainable development goals," by United Nations ESCAP , 2016 (https://x.com/UNESCAP/status/802013948706816000). Copyrighted.

SUSTAINABLE TRANSPORTATION POLICIES

Much can be learned from the outcomes of transportation policies implemented in other cities worldwide. Effective transportation policies result in equitable access, climate mitigation, and reduction of GHGs.

Policies that Promote Access

Transportation-related policies that help to provide access to public transit for low-income residents lead to achieving sustainable development goals. An example is the city of Medellin, Colombia, where implemented policies have achieved SDGs through the transportation system. This example shows how the access of slum dwellers to different opportunities, such as education, jobs, and public services, is improved by transportation policies and infrastructure improvements

(Galvin & Maassen, 2019). Another example of the implementation of sustainable transportation policies is the "Integrated BRT System" in Curitiba, Brazil. As a result of this policy, currently, "80% of travelers use the BRT system, and it carries around 2 million passengers per day. The BRT has 30 hybrid buses, reducing overall fuel needs by 35% and limiting pollutant emissions" (C40 Cities.org, 2016, p. 40).

Policies that Reduce GHGs

Policymakers in the United States have also introduced strategies such as fuel-efficient vehicles and electric cars to support sustainable transportation (Lutsey & Sperling, 2009; Tong & Azevedo, 2020). This strategy tends to reduce GHG emissions; however, these vehicles and the associated infrastructure (including ports and stations) are not accessible and affordable for disadvantaged and underserved commuters, such as minorities and low-income residents (Guerra et al., 2020). On the other hand, the difference between the use of public transport in Global South and American cities shows that this difference is related to the different ways that cities are formed. While in the U.S., suburbs provide housing for higher-income populations, in Mexico City and other Latin American cities, the low-income populations are usually pushed away to the edge of the cities (Monkkonen et al., 2018). Therefore, they usually cannot afford a car and must use formal or informal public transportation to access jobs and other opportunities (Cervero & Golub, 2007; Oviedo Hernandez & Titheridge, 2016).

Policies that Address Global Climate Change

The Paris Agreement on climate change is also related to sustainable transportation. Studies show that the U.S. is the second largest country after China contributing to GHG emissions (Figure 1.4). Therefore, countries like the United States must provide policies to control and mitigate GHG emissions. Also, by comparing the per-capita contribution of residents in the United States and China, we can conclude that the contribution of GHG emissions is significantly more critical in the U.S. The impact of different countries and cities on **Global Warming** is different. While only 2% of the land is occupied by cities globally, they contribute to over 60% of global energy consumption, about 70% of GHG emissions, and about 70% of global waste (Habitat3.org, 2016). As shown in Figure 1.4, transportation contributes to the most GHG emission in the United States, which is the second largest GHG emitter in the world, after electricity and heat. Therefore, transportation plays a significant role in producing GHG in the U.S.

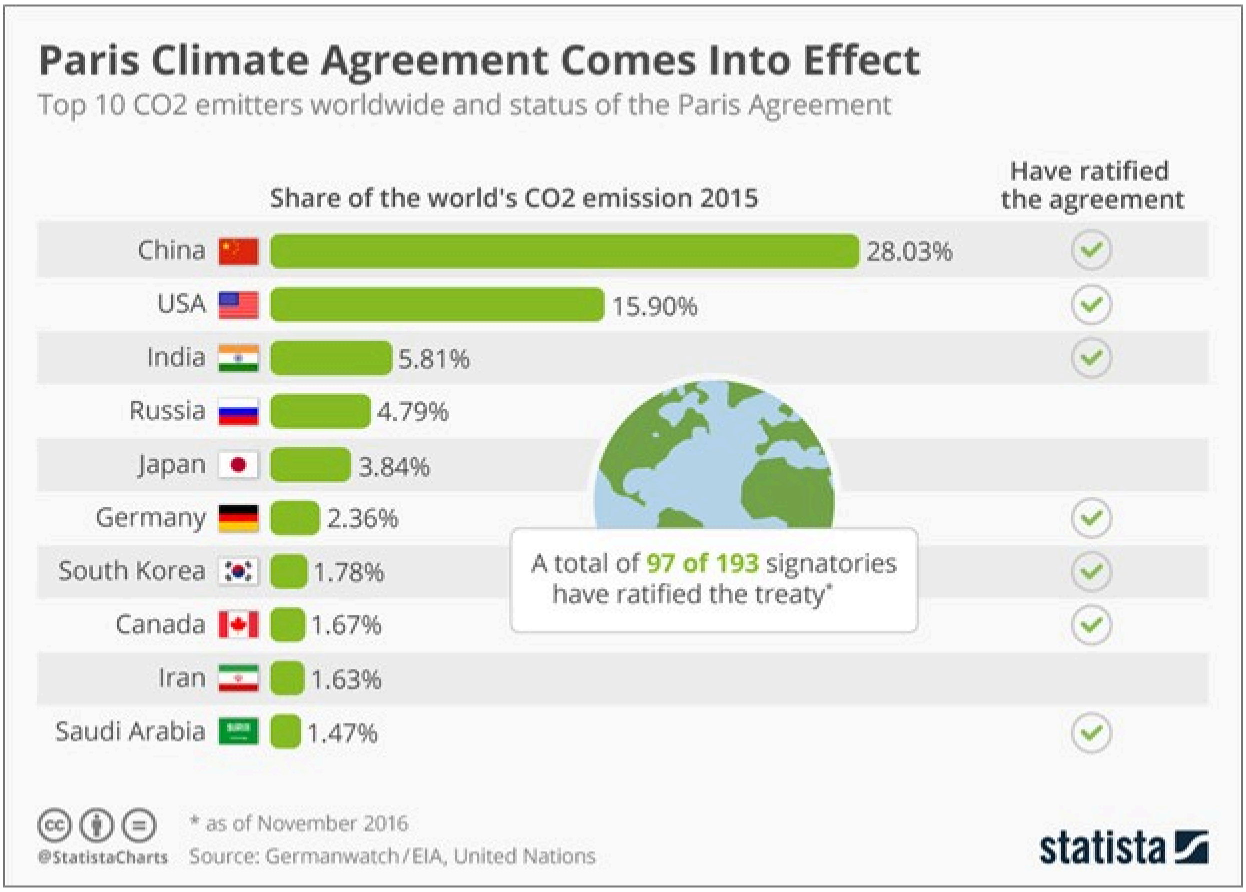

Figure 1.4 Top 10 CO2 emitters worldwide and status of the Paris Agreement. From "Paris Climate Agreement Comes Into Effect," by D. Loesche, 2016 (https://www.statista.com/chart/6572/paris-climate-agreement-comes-into-effect/). CC-BY-SA

The impact of different countries and cities on global warming is different. On the other hand, while only 2% of the land is occupied by cities today, they contribute to over 60% of global energy consumption, about 70% of GHG emissions, and about 70% of global waste (Habitat3.org, 2016). As shown in Figure 1.7, transportation contributes to the most GHG emission in the United States, which is the second largest GHG emitter in the world, after electricity and heat. Therefore, transportation plays a significant role in producing GHG in the U.S.

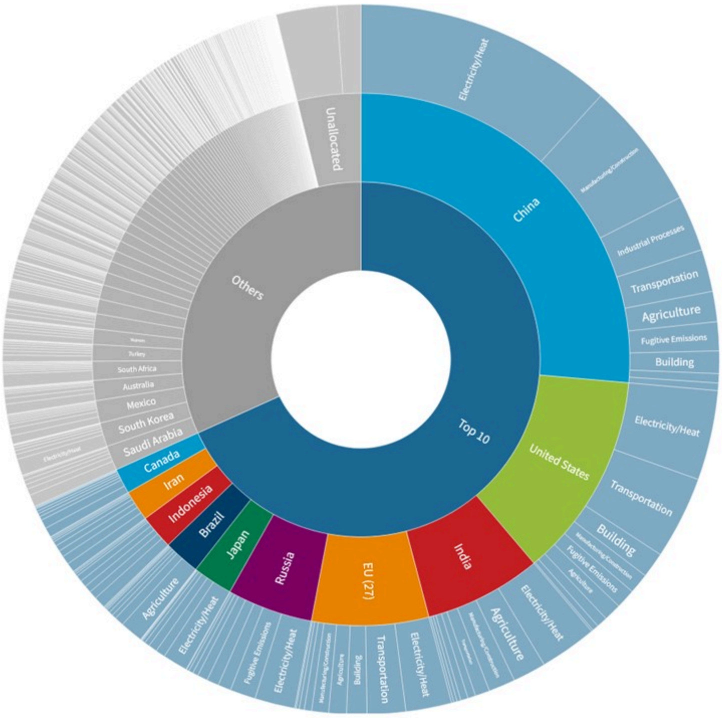

Figure 1.5 Top 10 GHG emitters by country and sector. From "This Interactive Chart Shows Changes in the World's Top 10 Emitters," by D. Loesche, 2016 (https://www.statista.com/chart/6572/paris-climate-agreement-comes-into-effect/). CC-BY-SA

Where Sustainable Development Policies Are Most Needed

Figure 1.5 shows that the three large contributors (China, the U.S., and the European Union countries) are responsible for around 40% of global emissions. The ten largest countries emit two-thirds of global GHG emissions. On the other hand, the other 100 countries produce only 4% of global emissions (Friedrich et al., 2020). This assessment reveals the inequities in the contribution of GHG emissions between developed and developing countries in the Global North and the Global South, respectively. Therefore, to combat climate change and mitigate GHG emissions, the role of the top 10 countries that produce the largest amount of GHG is more significant than others. While electricity and heat consumption in buildings are the most significant contributors to global GHG emissions, in China, the manufacturing sector is the most significant contributor, given the large industrial sector. On the other hand, transportation is the largest contributor to global warming in the United States due to the high car dependency in most American cities. From the beginning of recording and reporting of emissions in 1990, electricity, transportation, manufacturing, construction, and fossil fuel consumption were the biggest GHG emitters (around 73% of the total) in 2017 (Friedrich et al., 2020). Accordingly, since transportation plays a significant role in GHG emissions, there is a strong relationship between sustainable development and sustainable transportation. The following table summarizes different definitions, the effects/externalities of sustainable development, and the solutions to achieve sustainable development.

Table 1.1 Sustainable development definitions, effects, and solutions. Adapted From "Sustainable development principles and their implications for transport " by H. Gudmundsson & M. Höjer, *Ecological Economics* 19 (1996) 269-282. Copyright 1996 by Elsevier.

Sustainable Development	Effects/Externalities	Solutions	
1	Preserving natural resources for future generations	Air emissions and GHG, biodiversity loss, etc.	Biofuels and clean energy
2	Preserving human capital for future generations	Increasing transport system investments	They will become essential to cope with future resource scarcity
3	Improving the quality of life for individuals	More affordable services, commodities	Public and private transportation
4	Ensuring a fair distribution of life-quality	Distribution of mobility and access	To ensure mobility for all

Source: Gudmundsson & Höjer, 1996

The primary role of transportation is to maximize mobility; however, transportation can have both positive and negative effects on people's quality of life. The following table demonstrates the major effects of transportation on the quality of daily life.

Table 1.1 Sustainable development definitions, effects, and solutions. Adapted From "Sustainable development principles and their implications for transport " by H. Gudmundsson & M. Höjer, Ecological Economics 19 (1996) 269-282. Copyright 1996 by Elsevier.

Positive effects	Negative effects
Access	Accidents, insecurity, barriers
Mobility	Noise, vibrations
More diversity in supply	Impaired air quality
Cheaper goods and services	Loss of production value
Visual enjoyment	Visual intrusion and damage

In addition to what is mentioned in the above table, transportation can positively or negatively affect equity. While equal access to public transportation can result in a more equitable society, restricted public transit systems can add to inequalities.

An example of GHG emissions in Australia shows that the transportation sector contributes around 15.3% of GHG emissions in the country, of which road transport is responsible for 86%. Among road transport's different sectors, passenger movement has the most significant share (Philp & Taylor, 2017). Figure 1.6 illustrates the GHG emissions and the contribution of transportation to GHG emissions in the world.

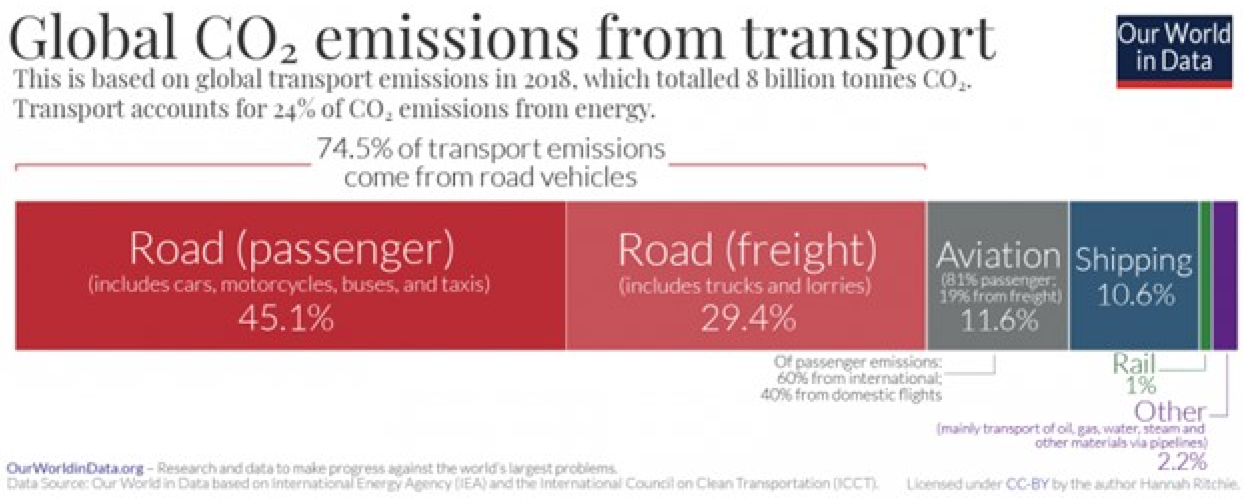

Figure 1.6 Contribution of passenger car usage in urban areas to the world's total GHG emissions (road, aviation, shipping, rail, and other). From "Cars, planes, trains: where do CO_2 emissions from transport come from?," by H. Ritchie, 2020 (https://ourworldindata.org/co2-emissions-from-transport#article-citation). CC-BY

A comparison of the United States and Australia regarding the GHG emission related to transportation shows that while transportation is still one of the most significant contributors to GHG emission, in the U.S., the amount of GHG produced by transportation (Figure 1.7) is much higher than that produced in Australia.

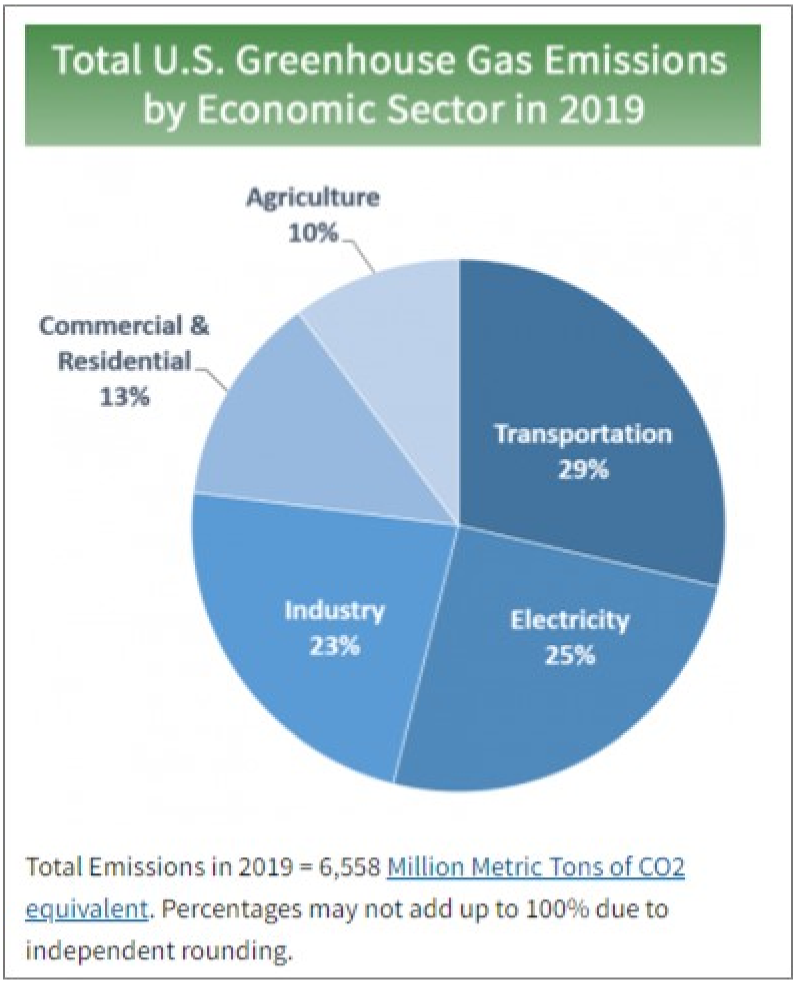

Figure 1.7 Total U.S. GHG emissions by economic sectors in 2019. From "Sources of Greenhouse Gas Emissions" by EPA, 2020 (https://19january2021snapshot.epa.gov/ghgemissions/sources-greenhouse-gas-emissions_.html). In the (Public Domain)

Policies that Promote Low-Carbon Mobility

Therefore, several policies in terms of lowering carbon mobility have been discussed to manage the level of GHG emissions by the transportation sector and to mitigate its negative effect. These policies can be categorized by various aspects, including urban design and planning, Low Carbon Mobility (LCM) policy and behavior change, system and infrastructure, and innovative technology. These strategies need careful modeling, measuring, and monitoring to understand the implications for supporting sustainable urban development. Solutions such as using electric vehicles or congestion charging are among the most common solutions derived from these policies.

Additionally, there are methods to measure the benefits of sustainable transportation policies. Different factors should be considered when measuring the benefits of shifting from using private cars to using public transport (Gudmundsson & Höjer, 1996; Philp & Taylor, 2017). The factors that could support the transition to sustainable mobility in Global North countries are listed below.

- Urban design and transport integrations
- Behavior changes and public perceptions
- Technological development and adoption
- Modeling

Finally, there are also many implementation challenges of sustainable **transportation policy**, such as:

- Data collection and availability
- Integration
- Evaluation
- Urban planning and design
- Technological improvement
- Safety
- Equity for all

CONCLUSION

In summary, sustainable mobility or transportation refers to solutions and policies that reduce **greenhouse gas emissions** and air pollution and provide equitable access to transportation. From the sustainability and social justice perspective, a sustainable transportation system offers safe, affordable, accessible, efficient, and resilient access to mobility to all commuters, especially low-income residents. At the same time, sustainable transportation systems mitigate the contribution to GHG emissions because they use sustainable materials and non fossil fuels.

Glossary

- **Biodiversity** is a top-notch bus-based transportation system that offers metro-level capabilities for quick, pleasant, and economical services (Essay on Biodiversity, n.d.).

- **Climate change** is a change in regional or worldwide climate patterns since the middle to late 20th century. It is primarily attributable to the increasing atmospheric carbon dioxide caused by burning fossil fuels (Society of Exploration Geophysicists, n.d.).
- **Global North** encompasses rich and powerful regions such as North America, Europe, and Australia.
- **Global South** is the regions of Latin America, Asia, Africa, and Oceania.
- **Global warming** is a slow-moving rise in the planet's average temperature typically linked to the greenhouse effect of higher amounts of carbon dioxide, chlorofluorocarbons, and other pollutants.
- **Sustainable development** refers to economic development that does not deplete natural resources.
- **Sustainable transportation** refers to low- and zero-emission, energy-efficient, affordable modes of transport, including electric and alternative-fuel vehicles and domestic fuels. The benefits of sustainable transportation in the United States include Cost savings on energy and cars (U.S. Department of Energy, n.d.).

Prep/Quiz Questions

- What is the contribution of the transportation sector (driving) to global greenhouse gas (GHG) emissions?
- What is the transportation sector's contribution to GHG emissions in the U.S.?
- How does the transportation sector's contribution to GHG emissions in U.S. cities compare to that in the European Union?
- Why do low-density cities with poor access to public transportation increase transportation energy use?
- What is sustainable mobility?
- How does sustainable mobility help address the United Nation's 17 Sustainable Development Goals (SDGs)?

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CHAPTER 2.

TRANSPORTATION EQUITY AND JUSTICE. THE EFFECTS OF DRIVING IN THE BUILT ENVIRONMENT: POLLUTION AND GLOBAL WARMING

CHAPTER OVERVIEW

This chapter is divided into two sections.

- **Section 1** critically examines the social and environmental implications of the relationship between the built environment and car dependency. It highlights how transportation policies and projects in U.S. cities have led to environmental injustices, introducing the concept of transportation justice and equity in planning.
- **Section 2** explores the opportunities offered by the U. S. National Blueprint for Transportation Decarbonization

Learning Objectives

- Explain and interpret the equity and justice challenges in U.S. transportation, particularly the disproportionate exposure of low-income families and minorities to air pollution.
- Analyze the public health implications of car dependency on local air quality.
- Assess the impact of extensive car use in low-density cities on greenhouse gas emissions and global warming.
- Identify key pathways for transportation decarbonization based on the work of the U. S. Departments of Energy, Transportation, Housing and Urban Development, and the Environmental Protection Agency.

THE ENVIRONMENTAL AND EQUITY IMPLICATIONS OF DRIVING FOR CITIES

Equity in Transportation

Our understanding of justice issues in transportation, where low-income and racial minorities are marginalized in terms of access to transportation benefits, has roots in the Civil Rights Movement, which emerged in the 1950s in the U. S. (Coolsaet et al., 2020). However, the earliest form of transportation inequity in the U. S. can be traced back to the 18th century, when enslaved people who had escaped to freedom were legislated to be brought back to their owners, which is equivalent to restricted travel. Although the Civil Rights Act of 1875, 18 Stat. 335 (1875) required equal accommodation for blacks and whites in public facilities, it was voided by supreme court and later in 1878, the supreme court banned states from prohibiting segregation on public transportation. Between 1865 and 1967, more than four hundred state laws, ordinances, and amendments were passed to constitutionalize segregation. During this time, several racial conflicts, directly or indirectly, related to transportation injustice, such as the Montgomery Bus

Boycott, the Freedom Rides (Arsenault, 2006), or the takeover of lands from Native Americans to enable railroad owners to expand rail transportation (Brenman, 2007).

Another practice of injustice occurred through the Federal Aid Highway Act of 1956 and the intentional routing of the interstate highway system through Black and brown communities, dividing and destroying once vibrant communities, as well as the subsequent migration of wealthier Whites ("white flight," 2024) to the suburban ring or exurban periphery. Despite the emergence of the Civil Rights Acts of 1964, which aimed to end segregation and discrimination based on race, color, religion, sex, or national origin, planning practices such as the aforementioned interstate highway system as well as redlining, mortgage discrimination, and racially restrictive covenants gave rise to polarized urban form, where access to opportunities are disproportionately distributed between different populations groups. Urban decentralization and suburbanization were detrimental to disinvested neighborhoods and minoritized groups and contributed to **environmental racism**.

Challenges with transportation inequities in the United States continue today as low-income communities and minorities receive fewer benefits and take on more potential harms from transportation projects (Bullard & Johnson, 1997). For instance, the highway system in the United States has heavily impacted low-income communities of color over the past sixty years (Weingroff, 1966). Highways were planned and constructed to connect suburbs to central cities. Historically, due to suburbanization, many employment centers have relocated to suburbs. At the same time, many vulnerable communities live near highways and congested roads, exacerbating their exposure to air pollution (Sanchez et al., 2004), or experiencing disconnection to their matched job types. This spatial mismatch hypothesis posits that greater distance to work centers, lower car ownership, and reliance on public transportation for workers dependent on low-level entry jobs (which have mostly relocated to the suburbs) all serve to amplify the economic issues for lower-income inner-city residents (Ihlanfeldt & Sjoquist, 1998; "Spatial mismatch," 2024).

Equity in transportation is relevant because transportation is the second-highest expenditure for American families. Lower-income families in the U. S. spend around 30% of their budget on transportation, whereas the share carried by middle-income families is about 16% (ITDP, 2024). This disparity imposes additional inequities in urban living for low-income families. Many studies reveal that income, residential location, race, and ethnicity determine access to mobility resources, especially private vehicles. Therefore, access to transportation is a crucial concern in transportation mobility and economic mobility (Chetty et al., 2019). For instance, those lacking private cars depend heavily on public transit and non-motorized transportation. The time spent commuting is greater, and the distances traveled are longer than those who drive cars (Miller, 2018). Thus, transportation equity is a complex issue that requires coordinated efforts from local, state, and national governments to improve the distribution of benefits of transportation projects among all residents.

Moreover, beyond access, other factors affect low-income communities. Often, there is a lack of safe infrastructure for walking and biking, and these communities are exposed to higher levels of pollution associated with transportation projects, such as transit and roads. Finally, meaningful involvement of low-income communities is essential for improving transportation justice (Burgos-Rodríguez, et al., 2023).

Previous research in travel behavior and built environment shows that the type of urban form (compact cities or sprawling) has a higher impact on commuter travel behavior (transportation mode choice) than income (Leck, 2006). This fact sheds light on the importance of the design and density of the urban form. Compact and walkable urban environments enable alternative modes of transportation, providing various modal choices and opportunities for low-income commuters. However, in the U.S., the urban form has a lesser effect on commuter behavior than in other global cities. This is partly because of low-density and suburban developments. For instance, low-income families spend approximately 30% of their income on car-related expenses in the largest U.S. cities, while their counterparts in Mexico spend only around 3% (Guerra et al., 2020). This metric highlights the importance of supporting affordable public transit in U.S. cities to support the household economies of low-income commuters.

Current Status of equity in US transportation planning

According to the Federal Transit Administration (FTA, initially the Urban Mass Transportation Administration, UMTA), agencies operating 50 or more fixed route vehicles serving populations over 200,000 are required to conduct equity analyses such as disparate impacts and disproportionate burden analysis, service monitoring, demographic and service maps and surveys related to demographics and travel behavior (Karner, et al, 2023). The goal for such efforts is primarily to expand the access of all population groups with a particular focus on marginalized populations, as stated in the U.S. Department of Transportation's Equity Action Plan (USDOT, 2023). USDOT's intention under equity programs is to empower marginalized populations and help them have a more respected voice in the transportation planning process. USDOT requires state Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) to regularly perform quantitative equity analyses including an equity screening tool and public involvement in Statewide Transportation Improvement Program (STIP) and Transportation Improvement Program (TIP) projects. These recently developed actions are products of legislative movements in recent decades, including Title VI of the Civil Rights Act of 1964 (Title VI); Executive Order 12898, Federal Actions to Address **Environmental Justice** (EJ) in Minority Populations and Low-Income Populations; and the National Environmental Policy Act (NEPA) as well as Executive Order (EO) 13985, "Advancing Racial Equity and Support for Underserved Communities Through the Federal Government." When assessing the equity of transportation services, quantitative equity analysis suggests data-driven processes that assess the ability of the proposed programs and efforts in addressing marginalized groups' needs. Demographic data on race, income, disability, living arrangement, vehicle ownership and English's language proficiency are usually collected from American Community Surveys and compared with the distribution of impacts from proposed projects.

The outcome of such efforts has been the development of several equity analysis or screening tools for evaluating plans, which serve to increase the opportunities for a more inclusive approach in transportation planning. Similarly, the birth of University Transportation Centers in 1988 after enactment of Surface Transportation and Uniform Relocation Assistance Act of 1987 is another research-based effort to bring equity in the context of transportation planning research. The Transportation Equity Act for the 21st Century (TEA-21) in 1988 and the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) in 2005 expanded the number of centers nationwide. The Surface Transportation Extension Act of 2010, sec. 411(e)(3), gave the authority to USDOT to allocate funds among centers. Several new acts and policies have been passed since then to bolster equity, environmental justice and inclusiveness in transportation. Under the Infrastructure Investment and Jobs Act (IIJA) enacted in 2021, UTCs are assigned to sustain and establish new and vital efforts in research, education, and technology transfer that benefit the movement and safety of Americans and freight. Concerned with environmental impacts, this act requires the UTCs to conduct research in: 1. Improving Mobility of People and Goods; 2. Reducing Congestion; 3. Promoting Safety; 4. Improving the Durability and Extending the Life of Transportation Infrastructure; 5. Preserving the Environment; 6. Preserving the Existing Transportation System; and 7. Reducing Transportation Cybersecurity Risks (USDOT, 2023b).

Although promoted significantly throughout the nation, these equity assessments have their limitations. In fact, most of the existing methods suffer from aggregation bias, meaning that usually, a geographic unit of analysis (such as census tract or traffic analysis zone) is chosen while assuming homogeneity within each unit of analysis is unrealistic. For this, the development of activity-based models with households or individuals as the unit of analysis may be more accurate. Furthermore, in equity studies, the impacts are assumed to have the same effect on marginalized population, while different people (such as African-Americans vs disabled people) may have completely different needs and desires. Absence of sensitivity analysis (scenario analysis) as well as using catchment (proximity measures) rather than actual usage data (such as ridership for public transit) are some other shortcomings of current equity analyses (Frost & Boutros, 2023).

Environmental Justice in Transportation

Similar to transportation equity, the conceptualization of environmental justice in US is rooted in the Civil Rights Acts of 1964 and can refer to disproportionately impacted by governmental decisions through an environmental context. In the US, environmental justice issues and analysis frequently look at the impacts on people of color, other minoritized populations, and, more recently, low-income groups. Related to transportation issues, environmental justice is mostly concerned with the effects of transportation infrastructure on population. For instance, for a household living close to a main corridor, implementing a light rail service may mean overexposure to noise or environmental pollution. Similarly, a huge highway passing through a town may act as a physical barrier for disabled persons who work on the other side of town and commute by walking. The dominant car-based transportation planning can translate to no access to jobs for individuals without a private vehicle (Kennedy, 2004).

As mentioned, the concept of environmental justice has been a part of planning practice since the enactment of the Civil Rights Act of 1964, "Nondiscrimination in federally assisted programs." This act ensures that no person is denied benefits or subjected to discrimination resulting from programs or activities receiving federal financial assistance. Section 602 of the act requires federal agencies to administer program orders or rules that will align with the act's objectives (Kennedy, 2004). Poverty, disability, race, English-speaking proficiency and other marginalized identities can all be the subjects of transportation equity practices and studies. Since the Civil Rights Movement, several programs have been developed by federal and local authorities to better connect minority populations or welfare recipients to job opportunities and other activities. Temporary Assistance for Needy Families (TANF) program and the Job Access and Reverse Commute (JARC) grant program are some of the programs aimed at providing job opportunities that are accessible for these populations.

The uneven distribution of environmental advantages and impediments associated with transportation has urged planners to consider allocating costs and benefits of transportation networks (Karner, 2016; Schweitzer & Valenzuela Jr, 2004). From a transportation equity lens, transportation infrastructure improvements and operations (and impacts) should not disproportionately affect low-income households and minority populations (Litman, 2017).

Instead, transportation should focus on equitable access and provision. Although transportation systems provide economic and social benefits and opportunities, they may also generate adverse environmental impacts. Environmental conditions and extreme climate events may also affect transportation facilities' construction, operation, and maintenance. The environmental impacts can be categorized as:

- **Direct impacts**, such as noise and carbon monoxide emissions
- **Indirect impacts**, such as particulates resulting from incomplete combustion in an internal combustion engine
- **Cumulative** impacts, including greenhouse gas emissions (Rodriguez, 2020).

The significance of these impact analyses can be immediate or long-term, especially when cumulative and producing a wide range of impacts overtime if neglected. Recent studies show that a major portion of these impacts are usually produced and experienced in proximity of marginalized populations (Chen et al., 1998; Delbosc & Currie, 2011; Sharifiasl et al., 2023).

The transportation sector is the largest direct source of air pollution and greenhouse gas (GHGs) emissions in metropolitan areas across the globe (EPA, 2024). Idling trucks and cars in **traffic congestion** increase exposure to carbon monoxide emissions and sulfur dioxide and reduces oxygen intake, which can aggravate respiratory issues such as asthma. Nitrogen monoxide, hydrocarbons, and peroxyacetyl nitrates are associated with respiratory and eye irritations and lung cancer. More research is needed to understand the environmental impacts, such as air pollution and noise levels, on low-income and minority groups that live immediately adjacent to transportation networks.

Environmental justice studies use examine the relationship between income, race, ethnicity, and other socioeconomic factors and pollution rates across different communities (Schweitzer & Valenzuela Jr, 2004). These studies of indirect impacts reveal a higher concentration of airborne particulates in low-income and minority neighborhoods. The disparity is further aggravated because studies indicate that low-income commuters contribute significantly less to air pollution (Bullard & Johnson, 1997). Lower-income households are less likely to own and drive private cars than their higher-income counterparts (Bullard & Johnson, 1997).

In addition, hospital admission rates show that low-income commuters and households suffer health impacts from greater exposure to higher ozone, aerosol acidity, and sulfate concentrations (Rivas et al., 2017). Other findings indicate a high correlation between traffic congestion and pollutants, including benzene, 1,3-butadiene, and diesel particulate matter. There is approximately a three times higher probability that the lowest income groups reside in neighborhoods with a higher concentration of noise and air pollution due to traffic congestion. Yet another study finds a negative correlation between traffic density and household income for all races except for white communities (Houston et al., 2004). Finally, studies that examined different U.S. contexts acknowledge the relationship between public health issues, diseases, and residents in low-income neighborhoods or areas adjacent to major roadways and highways (Schweitzer & Valenzuela Jr, 2004).

Numerous acts and executive orders have sought to mitigate the adverse effects of transportation projects on vulnerable communities (Rowangould et al., 2016). For instance, in 1992, President Clinton issued an executive order (EO 12805) that required all federal agencies, such as the U.S. Department of Transportation (USDOT), to evaluate the impact of transportation projects on low-income communities. In addition, planning agencies at all levels conduct impact assessments and seek to address environmental justice issues. Moreover, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) promotes public involvement in regional transport plans and requires a commitment to continuous public transit funding. Finally, the Transportation Equity Act for the 21st Century (TEA21), which became effective in 1998, formally and explicitly declared equity a priority for U.S. transportation practices. These orders and acts protect low-income groups and minorities from bearing transportation costs and call for action that allows these communities to enjoy equal benefits (Schweitzer & Valenzuela Jr, 2004).

In addition, the Intermodal Surface Transportation Efficiency Act (ISTEA) broadened the required factors that transportation planning agencies must consider. ISTEA also promotes multimodal transportation and air quality monitoring. This act also empowered Metropolitan Planning Organizations (MPOs) and regional planning agencies in the U.S. to advocate and plan for equity in transportation. This practice is relevant because studies underscore that equity is a serious issue at both regional and metropolitan scales. ISTEA was a turning point in U.S. transportation planning as it relegated several transportation decisions (such as multimodal transport system) to local government and called for the end of highway-oriented development (Abbot & Lowry, 2010).

Local groups, like community-based, faith-based, or other non-governmental organizations, are partners in disseminating information among vulnerable communities. These organizations may assist government agencies in developing more equitable projects under the newest federal transportation reauthorization bill, SAFTEA—Safe, Accountable, Flexible and Efficient Transportation Equity Act (Schweitzer & Valenzuela Jr, 2004). Other examples of recent transportation equity acts include the Fixing America's Surface Transportation Act or "FAST Act" ("Intermodal Surface Transportation Efficiency Act," 2024)

1. **U.S. National Blueprint for Transportation Decarbonization**

The U. S. National Blueprint for Transportation Decarbonization (The Blueprint) of 2023 has at its foundation the Infrastructure Investment and Jobs Act, which is also called the Bipartisan Infrastructure Law (BIL) from November of 2021 and the Inflation Reduction Act (IRA) from August 2022. By combining these three laws, the United States addresses the environmental impacts of climate change, maintaining a thriving economy, and improving human health, safety, and well-being, especially for those in historically disinvested communities (Office of Energy Efficiency & Renewable Energy, 2023). As the brief video summarizes, the strategies are for a whole-government effort to eliminate greenhouse gas emissions from the transportation sector by 2050 through the collaboration of the Departments of Energy, Transportation, Housing and Urban Development, and the Environmental Protection Agency (USDOE, 2023).

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://uta.pressbooks.pub/oertgreentransport/?p=84#oembed-1

United States Department of Energy (USDOE). (2023, January 13). *U. S. National Blueprint for Transportation Decarbonization* [Video]. YouTube. https://www.youtube.com/watch?v=RKplZwqFwVk

The Blueprint employs three interconnected strategies to reduce transportation sector GHG emissions. First, it addresses the design and layout of both the transportation system and adjacent land uses to promote greater accessibility to jobs, housing, and services through efficient transportation modes. This strategy enhances the convenience of sustainable transportation options, such as walking and biking, while improving connectivity to opportunities and overall quality of life. Second, the Blueprint focuses on increasing vehicle and engine efficiency to advance decarbonization goals. This includes improving the reliability, affordability, and safety of public transit and other modes of transportation. Finally, the plan promotes reducing reliance on petroleum and other high-GHG fuels. This strategy further strengthens the first two approaches as cleaner fuel options become available for vehicles across the transportation sector—including aviation, commercial trucking, transit, and private vehicles. Successfully implementing these strategies will require a coordinated approach, significant investment, and time. Additionally, the departments and agencies involved are committed to addressing the historical inequities in distributing transportation benefits and burdens, focusing on promoting environmental justice and equity (Office of Energy Efficiency & Renewable Energy, 2023).

CONCLUSION

This chapter examines the equity and environmental justice implications of car driving for the built environment and people in cities. It reviews the origins and state-of-the-art practices of equity in transportation. This chapter reviews the unfair distribution of transportation burdens across the city, especially for marginalized groups. Finally, this chapter discusses the efforts of the U. S. National Blueprint for Transportation Decarbonization to transform the transportation sector toward more sustainable and equitable operations.

Glossary

- **Environmental justice** is the equitable treatment and meaningful participation of all people in creating, implementing, and enforcing environmental laws, rules, and policies, regardless of race, color, country of origin, or income level. ("Ethical Management," n.d.)
- **Environmental racism,** sometimes also known as ecological racism or apartheid, is a form of racism that can be observed through the adverse environmental outcomes disproportionately impacting communities of color ("Environmental racism," 2024).
- **Equity** refers to fairness and justice and is distinguished from equality: Whereas equality means providing the same to all, equity means recognizing that we do not all start from the same place and must acknowledge and adjust to imbalances.
- **Traffic congestion** is a condition on road networks that occurs as use increases and is characterized by slower speeds, longer trip times, and increased vehicular queuing. Congestion begins when traffic demand is great enough for vehicle interaction to slow the traffic rate. (Jung and Vu, 2016)
- **Mandatory trips** are required for performing activities with limitations in terms of time, such as work trips.

Quiz/Prep Questions

- What are some of the equity and justice challenges of transportation in the United States?
- How do equity and environmental challenges of transportation affect low-income communities and minorities in the United States?
- What is the significance of private transport (cars) for air pollution and greenhouse gas emissions in U.S. cities?
- What factors contribute to the transportation sector's GHG emissions and local air pollution?

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PART II.

SECTION 2 CASE STUDIES, STRATEGIES, AND LESSONS FROM THE NORTH AND SOUTH

CHAPTER 3.

CASE STUDY I: THE MOBILITY CHALLENGES IN THE CITIES OF THE GLOBAL SOUTH

CHAPTER OVERVIEW

This chapter is divided into three sections. The first part critically examines the mobility challenges experienced in large cities of the **Global South**. These challenges include congestion in central towns and limited access to transportation by low-income communities and informal settlements on the urban edge. The second part examines paratransit and conversational transportation forms, such as low-capacity buses and minivans, which provide mobility to impoverished communities. The deficiencies that exacerbate safety concerns are also presented. The third section examines sustainable mobility approaches emerging in cities of the Global South, such as cable cars in Medellin. Informal transport improvements that enable more equitable transportation are also considered.

Learning Objectives

- Identify the mobility challenges that considerable city experience in the Global South.
- Identify how different forms of informal transportation emerge across Global South cities.
- Recognize the benefits and drawbacks of informal transit, including safety and efficiency concerns.
- Apply sustainable and equitable mobility approaches to improve the access of low-income commuters to transportation systems by drawing from the experience of cable cars in Medellin, Colombia.

THE TRANSPORTATION CHALLENGES IN LARGE CITIES OF THE GLOBAL SOUTH

This section examines the mobility challenges experienced by low-income commuters in large cities of the Global South. These challenges include limited access to public transportation, especially on the city fringe, where the poorest families tend to live (Suárez et al., 2016). In addition, they are more likely to work at times and in locations where public transport is unavailable. However, as discussed in Chapter 1, and supported by the United Nation's Habitat (2016), some local and national governments in Latin America, as exemplified by Curitiba in Brazil and Medellin in Colombia, have increased transportation access for low-income commuters and implemented policies and constructed infrastructure, such as the Bus Rapid Transit and the cable car, to mitigate the regressive and unjust consequences of insufficient transportation.

Comparison of Global North and South

To illustrate the characteristics of low-income commuters in Global South cities, we draw on the research conducted by Guerra et al. (2020). They compared how poor commuters get to places in U.S. and Mexican cities. The U.S. and Mexico share one of the longest borders between North and South. **Low-income commuters** in Mexico earn only one-sixth of what their American counterparts do. Although low-income commuters in the U.S. are more likely to live in high-density urban centers with convenient public transportation, their Mexican counterparts live in cities nearly four times denser. In addition, Mexican cities have significantly better access to transit, including mass transit, such as subways and bus rapid transit, and low-capacity buses. The latter are informal forms of transportation because private organizations, not the government or the transportation authority, manage and operate low-capacity buses and minivans (Guerra et al., 2020).

Mexico City, Mexico

Poor workers in Mexico are more likely to commute by public transit or non-motorized modes, such as biking or walking to work. While poor commuters in Mexico are unlikely to drive private cars in dense metropolitan areas. Instead, they primarily drive old vehicles within the city's peripheral areas. On the other hand, wealthier commuters are more likely to go to work and less likely to utilize non-motorized transportation (Guerra et al., 2020). Thus, car congestion is associated with wealthy solo drivers that overcrowd roads and highways. However, as poor workers improve their economic situation, they are more likely to switch to driving cars. Over the past two decades, car ownership has increased significantly in Mexican cities, exacerbating congestion and air pollution (Guerra, 2015).

Mexican cities are not unique. Instead, it exemplifies the typical large city in the Global South, which often have better access to transit than U.S. cities (Guerra et al., 2020). However, transit is scarce, inefficient, and unsafe as the periphery rapidly expands. As a result, low-income commuters in periurban municipalities endure more considerable commute burdens than those residing in central cities with better transit access (Reyes, 2020).

The Traffic and Congestion Challenges in Jakarta

Typical of large cities in the Global South, most commuters travel to central locations where jobs and education services are concentrated. Drivers of private cars, especially solo drivers, cause congestion and traffic in the central city areas. Global South cities have implemented solutions to address congestion and traffic, including 1) investments to expand the road network and 2) managing the existing road network by implementing car restrictions. However, expanding the space of roads, highways, and private transportation infrastructure does not alleviate congestion. Instead, it incentivizes car driving and thus increases traffic congestion (Pojani & Stead, 2015).

To examine the congestion challenges of Global South cities, we can refer to Jakarta, Indonesia. Three and a half million people travel in this congested city which is typically hot and humid weather. Car congestion is particularly intense, especially during morning and evening rush hours. In 2015, the Index developed by the oil company Castrol found Jakarta the city with the worst traffic in the world. The typical motorist is stuck in stop-and-go traffic more than 33,000 times yearly. In addition, private vehicles contribute to 70% of the city's air pollution. Traffic congestion has increased partly because of rapid population growth on the periphery and the drivers who travel from the city to the fringe (Mead, 2016).

Commuters in Bogor, a sizeable peripheral city in the metropolitan area around Jakarta, spend an average of two hours one-way commuting from downtown locations. A complicated trip may take up to three hours one way. This means it is not uncommon that commuters may spend five to six hours on their daily commutes. In addition, while private cars in Bogor occupy most of the road right-of-way, they only move a small number of passengers because wealthy drivers tend to travel alone. Ironically, there may be more passengers on bikes than in cars. And congestion has forced some commuters to switch to scooters, unsafely weaving through traffic. In Jakarta, motorcycles travel twice as fast as cars, taking up significantly less space. They also consume less gasoline and cost approximately one-tenth the cost of a vehicle. Yet, drivers of motorcycles are disproportionately exposed to accidents and fatalities (Mead, 2016).

Commuter trains travel from Bogor to the city center in Jakarta in approximately 55 minutes, twice as quickly as driving. However, public transportation is overcrowded, especially during rush hours. After a recent crackdown, passengers may no longer ride on the roof or hang on the sides of the vehicle. For decades, Jakarta has implemented simplistic solutions to address congestion, such as expanding roads and private car infrastructure. Unfortunately, the broader streets incentivized drivers of private cars and informal buses to drive more, and thus, congestion and traffic remained unchanged or increased over time (Mead, 2016). More recently, to address the transportation challenges, the city is constructing a new hub at Dukuh Atas that will eventually house a subway system, light rail, airport link, and a projected bullet train from Bandung. In addition, Jakarta, and many cities in the Global South, have implemented Bus Rapid Transit to address congestion and, at the same time, promote sustainable transportation systems. As a result, Jakarta became the first city in Southeast Asia to operate a Bus Rapid Transit 12 years ago. Also, the town promotes non-motorized transportation and has constructed three bike lanes in downtown areas. Unfortunately, drivers disregard bike lanes partly because they are only painted on the roads and thus lack protective infrastructure. Mead (2016) found that one potential solution to encourage commuters to bike in the city and improve their safety perceptions is to provide protected bike infrastructure that enhances their sense of safety (Mead, 2016).

INFORMAL TRANSPORTATION IN THE GLOBAL SOUTH

This section examines how paratransit and informal transportation, such as low-capacity buses and minivans, provide mobility to impoverished communities but with deficiencies that exacerbate safety concerns. Because of the lack of affordable housing in central locations, low-income families are forced to live on the fringes of the cities, where land and housing are cheap and accessible. However, these peripheral communities often lack access to essential services, including transportation systems, especially high-capacity transportation systems. Poor transit access forces residents to endure long commutes from the outskirts to central city locations where employment and education opportunities are historically/typically concentrated (Reyes, 2020). A primary mobility challenge is insufficient access to affordable, safe, and reliable transportation systems in the communities where the poorest residents live.

Informal transportation systems partially address the mobility needs of many commuters throughout metropolitan areas, especially in the cities of the Global South. Informal transit refers to the transportation services, such as low-capacity buses and minivans, which are privately operated with little oversight by the transportation authority. As Robert Cervero (2007) argued, the most significant contribution of informal transportation is that it exists throughout locations within Global South cities. Entire districts of Latin American cities, such as Lima or Mexico City, would become isolated or inaccessible without informal transportation (Cervero, 2007).

In Latin America, informal transit serves isolated neighborhoods with challenging topographies, such as informal settlements on the slopes of the foothills. Moto taxis, rickshaws, or minivans provide transportation access in poor communities characterized by narrow dirt roads that wind along a hillside. The informal sector provides paratransit services, either door-to-door or flexible enough to stray from fixed routes. Formal transit could not easily replace everyday transportation, especially in urban fringe areas. Therefore, simple transportation is a necessary service. As Robert Cervero states, simple transportation is "a significant gap-filler." A just transit future for Global South should include policies supporting and improving everyday transportation qualities. Informal settlements or poor communities in Global South cities depend on public transit. Informal transit could be an effective complement to connect residents in isolated locations to formal, high-capacity transit.

While informal transportation does fill a gap in trips to and from central business districts, there are challenges associated with this segment of the transportation industry. Some of these challenges include road congestion and safety. Unlike mass transit, informal transit vehicles carry fewer riders, adding many cars to the roads and increasing congestion problems.

Figure 3.1 Informal transportation in the Global South, A: "Tuk-Tuk" by Twicepix is licensed under CC BY-SA 2.0. B: "Traffic in Kolkata" by Arne Hückelheim is licensed under CC BY-SA 3.0. C: "File:2013 07 AMISOM Kismayo 002 (9342716778).jpg" by AMISOM Public Information is marked with CC0 1.0. D: "Tuk-tuks" by Christopher Crouzet is licensed under CC BY 2.0.

Additionally, misguided informal transit increases the number of buses on the road, exacerbating traffic. Congestion from everyday transportation increases air pollution because fleets tend to be older and, thus, inefficient in terms of fuel consumption and emissions. Every day buses increase the exposure of residents in low-income communities to air pollution and are associated with deteriorated health. Sustainable mobility policies should reduce the excessive number of informal transit buses to mitigate air pollution and traffic while maintaining the transit option, catering to low-income residents on the fringe (Jauregui-Fung et al., 2019).

The transportation authority poorly regulates informal services. Operators often lack driving licenses, permits, and insurance to operate public collective-ride services safely. Owners of regular buses do not provide safe and decent work conditions for drivers, who tend to be impoverished workers. Drivers work long hours and thus develop harmful and unsafe driving behavior. In many low-income communities of the Global South, informal transportation is the only source of employment. Owners of regular buses often require operators who rely on thin or low-profit margins to compete vigorously and sometimes dangerously for consumers—stopping anywhere to board passengers, driving overloaded cars, and other hazardous driving behaviors. Informal operators are frequently politically weak and underrepresented. The industry is labor-intensive, low-tech, and horizontally structured, with many individual operators (Cervero & Golub, 2007).

The affordability of informal transportation highly varies in Global South cities because the cost depends on how much cities subsidize public transportation. For example, Mexico City highly funds mass transit. Thus the price of subway systems and BRT (Bus Rapid Transit) is significantly lower than that of informal minivans on the periphery. Yet, informal transit may be more affordable than mass transit in other Latin American cities and, therefore, more accessible for low-income commuters. The following subsection delineates solutions to improve the quality of informal transportation to support the commutes of low-income commuters in Global South cities.

Envisioning solutions to improve informal transit

Whether formal or informal, paratransit supports transportation justice in low-income communities. City governments across the globe struggle to keep up with the demand for public transportation. For example, many cities in Africa and Southeast Asia have limited budgets to support transportation institutions that help with oversight and improve the quality of informal transportation. Informal transportation is flexible, more responsive to passenger needs, and more accessible to isolated homes in metropolitan areas. Thus, everyday transportation is often the most reliable mode of transportation.

Informal transportation is often the most reliable and sometimes the only available mode of transportation. However, as discussed earlier, informal transit raises safety concerns for riders. These include unsafe driving behavior partly due to poorly compensated work conditions for drivers, which require them to work extensively. These factors contribute to the poor and unsafe quality of informal transit. One potential solution to improving drivers' working conditions is the creation of associations and cooperatives. These organized informal transit groups could enhance drivers' training and working conditions. Also, local government should develop policies to invest in the coverage of transit to isolated communities and improve the quality of existing informal transit.

Therefore, policy solutions from local governments include investment in subsidies for transportation coverage in isolated communities. The investment could also be used to increase the number of routes and the frequency of buses. In these situations, regulators must balance investment with quality and safety. Investment issues are managed through competitive bidding in cities with sophisticated management capacities and subsidy sources. Operators compete for specified routes with a predefined remuneration (gross or net cost, depending on different demand variables). Drivers' organizations can be the means for the city government to assist informal transportation agencies by allowing operators to "self-regulate." Operators may join transportation route associations to unite the efforts of dozens of small businesses, ensuring better profit distribution, better access to financing, insurance, and other services, as well as a better level of service and competitive position against competing routes or modes (Cervero & Golub, 2007).

The solution to traffic, safety, health, and pollution problems is not to eliminate informal transit but to improve it. A transitional and just integration of the informal transportation sector with the formal transit segment may result in systemic transportation improvements and enhance the quality of informal transit. One way to strategically bridge the two is by implementing a "single-fare system." This system reduces the cost of multi-linked trips while providing more flexible travel schedules. This would be especially beneficial to the lower-income population living in the urban periphery. Additionally, physical connections between formal and informal transit that provide space outside of train stations or the bus-rapid transit system can facilitate safe travel transfers to passengers.

Another effective policy that some Latin American governments implemented to decrease opposition to formal transportation is to bridge equitable and supportive agreements between informal operators and the city governments. These agreements enable a more regulated cooperative system. For example, some casual transportation drivers constructed and operated the Bus Rapid Transit system (Heinrichs, Dirk et al., 2017). Such an agreement would facilitate switching drivers from commission-based payments to salaried drivers. It would also set vehicle and driver frequencies to improve the mental and physical health of drivers while also mitigating congestion and, thus, air pollution and **greenhouse gas emissions** (GHGEs).

SOLUTIONS FOR A JUST AND SUSTAINABLE TRANSPORTATION SYSTEM IN THE GLOBAL SOUTH

This section examines sustainable mobility approaches emerging in cities of the Global South. According to Pojani (2015), cities in the Global South have implemented various solutions to address their transportation challenges. These solutions range from simplistic solutions to increase the road supply to complicated implementation of rail-based public transit and bus rapid transit. We offer a discussion on the benefits and limitations of the ten transportation solutions discussed by Pojani (2015), as follows:

1. Road infrastructure: Governments increase the road supply to lower traffic congestion. However, increasing road supply induces drivers to drive a lot. As a result, traffic congestion levels quickly return to pre-expansion levels, with no travel time savings. Road investments also exacerbate long-term traffic congestion. They generate new journeys due to the increased land-use development (and sprawl) that greater vehicle access brings.
2. Road construction in densely populated metropolitan areas can be highly disruptive, often requiring the demolition of buildings and the loss of open space. This can lead to economic hardship and poor investment choices, such as legislators cutting road maintenance budgets in favor of new roads in new development financed by donors. Institutional failures, such as the division of responsibility between road providers and users, further exacerbate the problem. In emerging cities, poorly maintained roads and inadequate transportation options (both public and private) can severely hinder economic recovery and development. Current research indicates that while maintenance spending supports economic growth in these cities, large-scale new road infrastructure projects can have negative effects. Simply increasing road supply is also problematic, as it disproportionately benefits wealthier commuters who rely on private transportation, leaving those who depend on public transit overlooked.

3. Rail-based public transportation: Population density impacts how commuters use and benefit from rail-based public transit. Thus, rail or road-based public transportation may be economically viable when it is close and accessible to low-income communities with high densities. In addition, because new rail systems are exceedingly expensive to build and operate, rail should have a clear benefit over road-based systems to justify installation in smaller and distant cities. There are two types of rail-based public transportation: 1) Light Rail Transit (LRT) systems, which span from Eastern Europe's medieval tramways, trolleys, and streetcars, which operate alongside ordinary traffic in city streets, to Singapore's modern elevated and entirely separated systems; and 2) Metro (suburban or heavy rail) systems, which are typically the most expensive type of public transportation to build and operate, but they have the highest performance since they are entirely separated from roads.
4. Metro (suburban or heavy rail): Large cities in the Global South have implemented interconnected metro systems that allow commuters to get to places. These mass transit systems are particularly effective in high-density areas and regions with a high concentration of jobs. Additionally, ropeways, or aerial gondolas, are another form of public transportation that complement these systems by providing an alternative mode of travel in challenging or congested environments. Ropeways have evolved into a reasonable and attractive proposition for mainstream urban public transport in several medium-sized developing cities, including Algiers and Oran (Algeria), Medellin (Colombia), and Caracas (Venezuela), with capacities comparable to small or medium-sized tramways on rail tracks and moderate costs (Venezuela). They may offer adequate urban transportation on steep terrains, along with over rivers, ports, and highways, can accommodate densely populated areas and historic structures, and can supplement other public transportation choices. For example, in Medellin, Colombia, cable cars help connect residents of informal settlements in the foothills to the city. This form of transportation supports transportation justice because it serves low-income commuters and, at the same time, reduces air pollution.
5. Road-based public transportation: In recent decades, creating bus lanes on existing roads (painting a street a distinct color from the rest of the asphalt) has become a popular low-cost technique for increasing the quality of bus services worldwide. Also, BRT is a newly created bus-based mass transport system that mimics the performance and facilities of rail transit. An interconnected system of BRT lines in large cities is the most cost-effective transportation system because it can serve up to 45,000 passengers (about twice the seating capacity of Madison Square Garden) per hour in each direction, which exceeds the capacity of many rail systems. BRT systems have successfully improved residents' commutes in Global South cities, including Bogotá, Curitiba, and Guangzhou. Another advantage is the affordability of BRT systems compared to metro systems. BRT systems are Latin American cities' most sustainable and cost-effective transportation systems. Existing conventional bus and paratransit networks can supplement mainline services by providing feeder connections and serving rural locations. BRT vehicles can run on natural gas, electricity, or biofuels to reduce dependency on fossil fuels. If finance becomes available, a developing community can upgrade to light rail after securing the right of way for a BRT system. Despite its benefits, BRT systems in developing countries may face several challenges. These challenges include excessive occupancy levels, early depreciation of infrastructure, fare-collecting systems needing close supervision, and insufficient user education for initial deployment and system modifications (Pojani & Stead, 2015).
6. Non-motorized travel mode support walking and cycling, as well as pedicabs and other

human-operated vehicles, which are the most common modes of non-motorized transportation in many developing cities, particularly in Asia and Africa. The higher the percentage of non-motorized transportation use, the smaller the town. Bicycles are often more prevalent in developing cities than in developed cities. Because of their lower incomes, the urban poor often walk or bike to work, school, food shopping, and other services. Young and disadvantaged male residents find work as pedicab drivers and other non-motorized taxi services. While non-motorized trips may take longer than automotive travel, many citizens in emerging cities endure longer commutes to avoid transportation costs. Walking and biking help reduce air pollution and greenhouse gas emissions and, at the same time, improve the health and well-being of commuters. Many Global South countries have implemented policies to enable bike lanes in downtown locations where most jobs are concentrated. Latin American cities, such as Mexico City and Bogota, have implemented bicycle pathways with physical separation that are more successful than bike lanes. In addition, a rising number of emerging cities have implemented bicycle-sharing programs. Despite the progress of non-motorized transportation, past studies suggest that bicycle-sharing increases bike utilization but does not decrease automobile use (Pojani & Stead, 2015).

7. Fuel-efficiency: Alternative fuel-based, urban transportation-related technical solutions are some examples of technological innovations in transportation. Fuel-efficient cars use fewer fossil fuels and thus contribute less to air pollution and greenhouse gas emissions. Also, governments are supporting clean technologies to reduce the use of gasoline and diesel. These alternatives include biomass, solar and wind energy, nuclear energy, and decarbonized fossil fuels. Biodiesel can be used in any diesel engine without modification; unlike ethanol, hydrogen, and electricity can only be utilized in specially manufactured or adapted vehicles. Natural gas resources and existing pipelines and delivery infrastructures are incentives in some nations, particularly South American countries, to boost natural gas use for transportation (compressed natural gas and liquefied petroleum gas). Electric vehicles (fuel cell, battery, or plug-in) have a short range (between 100 to 300 miles on a full charge), making them ideal for usage in small and medium-sized cities. Biofuels (primarily ethanol, biodiesel, and mixes) can potentially reduce greenhouse gas emissions, particulate matter, and volatile organic compounds in cities.
8. Awareness-raising campaign: With varying degrees of success, countries in the North and the Global South have supported education, persuasion, and awareness-raising efforts to promote more sustainable urban transportation. These campaigns seek to educate residents on the implications of car use for air pollution and global warming. However, awareness-raising campaigns face opposition from the automotive industry. Private cars symbolize comfort, speed, convenience, power, protection, superiority, individualism, hedonism, and independence. As a result, car ownership is rapidly increasing in the Global South cities, although most commuters still use public transit. Environmental education campaigns aim to motivate drivers to drive less, carpool, and even switch from cars to public transportation. In addition, these campaigns encourage commuters to think about the impacts of private transport on air pollution and greenhouse gas emissions for present and future generations.
9. Pricing methods: Transportation policies use pricing methods to reduce car driving and traffic. Pricing methods include gasoline taxes, vehicles, emission quotas, direct road tolls, area cordon pricing (charges apply for the right to access or circulate within limited geographical areas), and parking charges.

10. Vehicle restrictions: Previous studies found that pricing methods are more successful than regulatory ones because they provide automobile owners with more options, increase revenues to support public transportation, and are flexible to adapt to changing circumstances. There are other mechanisms to control the automobile fleet. These include restrictions on vehicle-used based on fuel efficiency and emissions, occupancy to promote carpooling practices, plate-based restrictions, and quotas for distance traveled or the number of trips. Parking restrictions and speed limits are two more regulatory measures. Also, in recent years, companies and universities have been supporting telecommuting to reduce miles traveled and mitigate greenhouse gas emissions associated with job commutes.
11. Land-use management: Sustainable transportation policy needs land-use planning initiatives that help change the urban form to make transportation systems efficient. Commuters benefit from public transit in job-rich areas or communities with high population densities. This, in turn, ensures that commuters, especially low-income commuters, use public transit. A high occupancy increases the economic feasibility of public transportation. Shorter distances and less usage of motorized transport are connected with compact urban development. As a result, land-use restrictions have significant ramifications for travel patterns. Modifying urban forms in terms of density and land use, housing types, and green and open spaces improves the quality of mobility. Previous research found that land-use policies can increase population densities and land-use diversity. Densification and intensification of land use can enhance transportation occupancy around transport nodes and corridors. For example, the TOD (Transit Oriented Development) model at a regional scale helps increase access for more significant portions of the population if overall dense and compact development is not possible or desirable in each context, e.g., already hyper-dense inner-city areas (Cervero & Kockelman, 1997). Table 3.1 summarizes a cost-benefit analysis of typical approaches to addressing transportation challenges in the Global South.

Table 3.1. Comparing cost-benefit analysis of modes of transportation

Road infrastructure	Poor roads and insufficient road-based (public and private) transportation can constitute an insurmountable barrier to growing cities' economic recovery and progress. Thus, maintaining the existing road infrastructure favors economic production, especially in low-income communities. Still, installing new road infrastructures, such as highways and roads, often hurts economic growth as it incentivizes driving and has the opposite effect of triggering congestion.
Rail-Based Public Transport	Ropeways, often known as air gondolas, are train transportation. As exemplified by cable cars in Medellin, Colombia, ropeways have grown into a feasible and attractive concept for mainstream urban public transport in several medium-sized emerging cities, with a capacity equivalent to small or medium-sized tramways on rail tracks and with moderate costs. On the other hand, high-capacity rail systems, such as subway systems, are significantly more expensive and time-consuming in their construction than other forms of transportation, such as bus rapid transit. Moreover, subways may only be cost-effective when they serve highly dense areas with low-to-moderate commuters who rely on public transit.
Road-Based Public Transport	BRT may be built at a fraction of the cost of rail transit (subway systems). BRT systems are cost-effective, and they may be self-funded by city governments. Their viability has motivated several Global South cities to install interconnected BRT systems, as exemplified by Transmilenio in Bogota, Colombia.
Non-Motorized Modes of transportation	Safe and well-located bicycle-sharing systems and lanes may increase bike utilization but do not decrease automobile use. Commuters in the Global South cities bike and walk more often than in developed-world cities. Low-income commuters usually bike, partly because they cannot afford motorized transportation. Low-income residents bike, walk, or ride a pedicab to get to their job, education, and food shopping locations. Young and underprivileged urban males can find work in pedicabs and other non-motorized taxi services. While non-motorized excursions may take longer than automotive travels, many citizens in emerging cities prefer the higher time expense to the higher financial cost of transportation.

Source: Adapted from Pojani & Stead (2015).

SUSTAINABLE TRANSPORTATION IN MEDIUM-SIZED CITIES

While much of transportation research has been conducted in large cities (megacities) in the Global South, such as Sao Paulo or Beijing, sustainable transportation systems may work particularly well in emerging medium-sized towns, such as Medellin, Colombia, and Curitiba, Brazil. These cities tend to have high-population densities and compact urban forms, enabling sustainable and just transportation systems. In addition, these two cities demonstrate how low-cost improvements and small taxes on road users can reduce car driving and improve air quality, ultimately improving residents' health. However, sustainable transportation requires not one solution but a comprehensive approach. More importantly, transportation planners must understand how workers at all income levels commute to provide sustainable alternatives that benefit the transportation system. Furthermore, smaller and medium-sized emerging cities require different approaches to sustainable transportation than those applied in megacities (e.g., fuel taxes rather than congestion charges). Emerging cities are in a suitable position to implement strategies and solutions learned from larger cities.

Medium-sized cities may proactively implement policies and construct infrastructure to promote walkability and accessibility. These strategies include pedestrian-only zones in areas with heavy traffic and exclusive bus and bike lanes. Cities can also improve the quality of the street network by implementing low-cost interventions, such as sidewalk maintenance and speed limits. Also, cities could prioritize the deteriorated road infrastructure in low-income communities through maintenance projects rather than focusing only on new infrastructure.

A comprehensive **transportation policy** combines strategies and monitors implementation progress over time. Sustainable urban transportation requires packages of policies that maximize synergies to enable multimodal transportation systems. A careful assessment of transportation policy's cost, benefits, and obstacles is essential for successful implementation. Finally, transportation planners should carefully understand the suitability and efficacy of policy solutions in the specific urban context of smaller and medium-sized cities in developing countries instead of replicating ineffective policies from the Global North (Pojani & Stead, 2015).

CONCLUSION

This chapter discusses the challenges faced by low-income commuters in large cities of the Global South, who have limited access to public transportation and often rely on informal transit services such as low-capacity buses and minivans. While these services provide mobility to impoverished communities, they also have deficiencies that exacerbate safety concerns. Also, here we examine sustainable mobility approaches emerging in cities of the Global South and highlight the need for policies that support and improve the quality of informal transportation, which is a necessary service for many communities. The challenges of everyday vehicles include road congestion, air pollution, and safety concerns due to a lack of regulation. Here we suggest reducing the excessive number of daily transit buses to mitigate air pollution and traffic while maintaining the transit option for low-income residents. The affordability of simple transportation varies across cities and depends on how much cities subsidize public transit.

Glossary

- **Global South:** "Global North and Global South, framework for understanding and analyzing the relative prosperity and international power of countries around the world, which became increasingly popular following criticism of other taxonomic systems, such as the three-world system and the developed and developing countries system. The Global North–Global South system is frequently used interchangeably with the system of more- and less-developed countries by the United Nations and other such groups. Most commentators typically include in the Global North the United States, Canada, the countries of Europe, Japan, South Korea, Taiwan, Australia, New Zealand, and Israel. The Global South usually includes the countries of Latin America, Africa, the Middle East excluding Israel, and Asia and Oceania excluding the aforementioned countries. The Global South usually includes the countries of Latin America, Africa, the Middle East excluding Israel, and Asia and Oceania excluding the aforementioned countries. That said, by some measures there are other countries in the Global South that are more similar to those in the Global North and vice versa" (Kenny, 2024).
- **Greenhouse Gas Emissions (GHGEs)** are the different gases released into the planet's atmosphere, particularly carbon dioxide, which contribute to the greenhouse effect.
- **Low-Income Commuters** are those who work irregular schedules with no safe or affordable way to get to work.
- **Transportation policy** focuses on creating a collection of ideas and theories to attain certain goals in relation to the social, economic, and environmental situations as well as the operation and effectiveness of the transportation system. (Transport Geography, n.d.)

Prep/Quiz Questions

- What are some of the mobility challenges in the Global South?
- What are the causes of congestion in the cities of the Global South?
- What solutions do governments in the Global South use to reduce travel demand? More specifically, reflect on policies that 1) increase road supply and 2) manage the existing supply.
- Drawing from Cervero and Golub (2007), please describe informal transport in the Global South. What challenges and opportunities are associated with policies that "formalize" transport in these cities?
- Drawing on Pojani and Stead (2015), what policy approaches can governments in the Global South implement to enable sustainable transport? Please provide specific examples and discuss the main takeaways from them.

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CHAPTER 4.

CASE STUDY II: CONGESTION CHARGING IN LONDON: THE WESTERN EXPANSION

CHAPTER OVERVIEW

This chapter introduces and elaborates on **congestion charging** as a policy response to the ever-growing mobility problems of cities, specifically in the Global North. This chapter is divided into three sections. The first section introduces the reader to the congestion pricing concept and the transportation and land use planning policies needed for effective implementation. Drawing on the experiences of London and Stockholm, the second part elaborates on the benefits of congestion charging in terms of air pollution and traffic congestion reduction. The third part presents some of the expected benefits and challenges of congestion pricing in U.S. cities, reflecting on the case of New York City. The chapter concludes with an examination of equity implications associated with congestion pricing.

Learning Objectives

- Identify and explain the benefits of the **congestion charging** scheme in London and Stockholm for congestion reduction.
- Describe how the tax revenues of congestion pricing may serve to foster a more efficient and equitable transportation system.
- Identify the potential challenges and benefits of congestion pricing for U.S. cities, reflecting on the New York City case.

WHAT IS CONGESTION PRICING?

Economists, including Adam Smith and transportation scholars, have examined the concept of congestion pricing as a strategy for reducing the negative externalities of cars (Lindsey, 2006). Congestion pricing seeks to shift a fraction of car travel, especially during rush hours, to other modes of travel, such as transit and non-motorized transportation. Eliminating a fraction of car travel from the transportation network can reduce congestion and thus create a more efficient flow of vehicles on roads. Transportation economics researchers concur that congestion pricing, combined with other policies that support public transit, is the most viable, progressive, and sustainable pricing approach to curb driving and traffic congestion (Paul et al. 2017). Congestion pricing requires car drivers to pay a fee for driving in urban areas, typically in downtown and central city locations, which are usually the most congested. This fee will induce some drivers to drive less or switch to alternative transportation modes.

Congestion pricing overall affects travel behavior with economic, social, and environmental benefits. In Western cities, congestion pricing has reduced car driving and congestion while increasing the transportation network level of service (LOS) for those who still use the road. Another benefit of congestion pricing is the generation of revenue from drivers. Although there is a debate about how revenue from congestion pricing should be used, scholars concur that the revenues should support the commutes of vulnerable social groups, including low-income commuters, people with disabilities, and those who do not have cars and must rely on public transit. In congestion charging, drivers compensate for the negative externalities by paying a congestion pricing fee (Givoni, 2012; Whitehead et al., 2014). Congestion pricing can be a strategy that promotes equity and transportation justice (Small, 1992). Small (1992) argues that congestion pricing may enable a (1) monetary reimbursement to low-income travelers, (2) substitution for general taxes used to pay for transportation services, and (3) the creation of new transportation services. Congestion pricing may be coupled with other transportation policies and strategies to reduce congestion, including fuel taxes and vehicle registration fees. The congestion pricing revenues may reduce the operating costs of toll collection and traffic management facilities while supporting sustainable transportation infrastructure, especially public and non-motorized transportation (Small, 1992).

Governments implement congestion pricing in two ways: toll-based and non-toll strategies. Toll-based congestion pricing can restrict **High Occupancy Toll (HOT)** lanes or express toll lanes and the entire roadway or create zone-based or regionwide pricing. Examples of non-toll-based methods include parking pricing, priced vehicle sharing, dynamic ridesharing, and pay-as-you-drive. In this chapter, we focus on zone-based pricing and explore the implementation of congestion charging in several case studies.

Singapore was the first city to implement congestion pricing successfully. In 1975, the congestion pricing policy mandated all vehicles entering a 5 square kilometer area in the city center during rush hours to pay a fee (Figure 4.1). Although frequent adjustments were applied to the program, it produced benefits, significantly reducing traffic congestion. Adjustments have included extended times of congestion pricing and enforcement mechanisms (Santos, 2005). In addition, alternative routes divert drivers from the congestion charging zone. After a few years, interest in congestion pricing began to extend to other parts of the world. Several cities in the Global North have implemented the same scheme, such as Bergen, Oslo, Trondheim, Gothenburg, and Stockholm (Norway and Sweden). Paris, London, Hong Kong, and Seoul also use similar schemes to reduce traffic congestion.

Figure 4.1 Initial downtown congestion pricing (DCP) implemented in Singapore in 1975. From "Lessons Learned From International Experience in Congestion Pricing". From " Lessons learned from international experience in congestion pricing (No. FHWA-HOP-08-047)" By Bhatt, K., Higgins, T., Berg, J. T., & Analytics, K. T., 2021. United States. Federal Highway Administration.

Some cities in the U.S. have shown interest in using congestion charging. However, the implementation of congestion charging is particularly challenging here because the urban form of most U.S. cities with low-density areas induces car dependence. Nevertheless, Orange County (California), San Diego, and Houston have implemented designated high-occupancy toll (HOT) lanes to discourage driving (Harrington, Krupnick, and Alberini 2001). These schemes differ from congestion charging but seek to prevent driving by collecting fees from those that congest certain roads. Implementing congestion charging in the U.S. seems challenging except for in New York, whose urban form may bear a stronger resemblance to its European counterparts.

THE IMPLICATIONS OF CONGESTION CHARGING IN LONDON

This section examines the implications of congestion charging for the mobility of cities in the Global North, including London and Stockholm. These case studies reveal the implementation challenges and the policy's benefits and drawbacks. Importantly, these cities use the revenues collected from congestion charging to improve the quality of public transit, buses, and non-motorized transportation.

London

The city of London has tried to implement congestion pricing since the 1970s. Between 1991 and 1994, London's Department of Transportation supported studies that examined the implications of congestion pricing through the London Congestion Charging Research Programme (LCCRP). The studies concluded that technological tools at the time did not allow the proper implementation and monitoring of the program. Also, in the 1990s, researchers evaluated the acceptance of congestion charging with a referendum and the political capacity of city governments to implement it. Based on research outcomes, Mayor Livingstone launched congestion charging using Automatic Number Plate Recognition (ANPR) cameras in 2000. The London Congestion Charge (LCC) was enforced as a daily supplementary license policy for car travel within the London Inner Ring Road (Lehe, 2019). The Congestion Charging (CC) program requires drivers to pay £5 weekly from 7:00 AM to 6:30 PM. In addition to this policy, a comprehensive range of supplementary transport-related policies became effective, such as improved bus network service, introducing the "Oyster" smart card, and robust investments in public transportation. Congestion charging faced opposition in its first stages of implementation, especially from business owners in the city core area concerned about their businesses. However, Noland et. al (2008) found that congestion charging does not affect overall retail sales in central London. On the contrary, the policy increases walkability and access to businesses. This comprehensive transportation policy package has worked to alleviate congestion and supports alternative transportation modes.

Evaluating the relationship between congestion charging (CC) and traffic congestion requires carefully understanding the congestion before and after CC implementation. An analysis of casualties in London conducted by (Noland, Quddus, and Ochieng 2008) found a significant reduction of private cars in the congestion charging area. The pre-congestion charging traffic statistics for the central London area showed that private vehicle users accounted for 12% of all trips during morning rush hours. The implementation of congestion pricing resulted in a slowly declining trend of private car traffic in central London. Between 2000 and 2002, traffic levels within the congestion charging zone fell by 7%, while traffic for the unrestricted Greater London area traffic increased by 7% between 1989 and 2001. While it was expected that implementing the CC program would result in fewer vehicles during restricted hours, a 12% reduction of vehicle kilometers traveled after one year was an added benefit. However, these numbers leveled off and increased slightly in 2006, two years after program initiation(Noland, Quddus, and Ochieng 2008).

Figure 4.2 CC Program in London, Road Signs, and Pavements. From "Vertical, horizontal, and road signs at the Tower Hill (A100) entrance of the London Congestion Charge", by Mariordo 2012 (https://commons.wikimedia.org/wiki/File:London_CC_12_2012_5037.JPG). CC-BY-SA 3.0

The evaluation of traffic congestion considers the average excess delay (minute/km), which is an indicator that compares congestion and the free flow of vehicles. Before the implementation of congestion pricing, the ratio between congestion and free flow was 2.3 min/km. This indicator dropped to 1.6 in 2003, then remained unchanged in 2004 but increased to 2.1 afterward (almost the same as pre-congestion pricing). The London case shows changes in congestion over time and the challenges of successfully maintaining reduced driving. Scholars have used other variables, including travel behavior, to comprehensively understand the implications of congestion pricing in London (Givoni, 2012).

Scholars found that congestion charging influences travel behavior and the use of alternative modes of transportation, especially during rush hours. In its first stages, CC significantly reduced the number of car drivers and increased the use of buses and public transportation in London. This change, in turn, suggests a positive effect on the use of public transit. From 2002 to 2003, the number of buses entering the congestion charging zone increased (around 20%), as well as increasing their mileage (about 10%). Also, bus waiting times fell by 24% in the Greater London Area and 30% for the area around and inside the zone. The decrease in excess waiting time was also observed even when congestion remained unchanged. Thus, it is possible that factors other than CC were responsible for the reduced excess waiting time. According to Givoni (2012) states that, while only 6% is associated with the introduction of the CC, increases in bus ridership may also be responsible because of lower fares and a better quality of transportation and service. The Transport for London (TFL) organization 2003 recorded around 70,000 reductions in cars entering the zone, 40% of which switched to buses, 50% to underground, and 10-20% to walking, biking, motorcycle, and taxis (Givoni 2012).

The environmental implications of congestion charging remain mixed. Scholars argue that air pollution mitigation was not the primary concern for congestion charging. Instead the primary concern was congestion and traffic. Nevertheless, some scholars found reduced air pollution associated with congestion charging. While the NOx concentration trends over time for different city zones showed no significant change from 1999 to 2005, the analysis conducted by Beevers and Carslaw (2005) showed a 10% decrease in NOx and PM10 between 2002 and 2003 at the start of the CC program. Another study conducted by Ho and Maddison (2008) also showed a reduction of 10.5% in PM10 due to CC implementation. Yet, Atkinson (2009) found no relationship between CC and air pollution concentration levels (Givoni 2012).

Scholars also examined the implications of the revenues generated by congestion charging. Previous studies found that congestion charging generated £200 million between 2004 and 2006; the net revenue was £110 million (Givoni 2012). Approximately 80% of this revenue served to improve buses in central London (Givoni 2012) as part of the comprehensive package.

To sum up, congestion charging in London is one of the most successful congestion pricing programs worldwide. One of the main lessons from London is the implementation of a comprehensive package of transportation policies that include restricted access to private cars, improved public transit, and increased ridership over time. However, more research is needed to understand the implications of congestion charging alone in traffic, revenue, and air pollution mitigation. Some scholars believe that the perceived reduction in congestion can incentivize some commuters to drive to the congestion zone. This rebound effect may undermine the policy for driving reduction. Research suggests that the early implementation of congestion charging was more successful as it reduced traffic significantly in the early 2000s. However, the effects of congestion pricing leveled off, partly because drivers use strategies to avoid the policy (Givoni

2012). For example, they drive alternative routes to avoid the congestion charging zone. These have led policymakers to expand the congestion pricing zone from central locations to intermediate urban areas in London.

Stockholm

The government of Stockholm enacted restrictions to reduce car driving in the 1980s. Drivers were required to buy and place a transit pass on their windshields (Eliasson, 2009). Later, the Dennis Agreement enacted a toll to collect fees from drivers' use of highways and tunnels. In 2005, the government implemented a trial program of congestion charging in the city (Kottenhoff and Brundell Freij, 2009) to alleviate and further incentivize traffic reduction and improve accessibility and the environment. In addition, the city of Stockholm monitored traffic and collected data to understand the effectiveness of congestion pricing (Gudmundsson et al., 2009). Studies suggest that congestion pricing in Stockholm successfully reduced congestion and improved air quality. Traffic volumes on its busiest roads were reduced by 10–15% and improved **traffic flow** on streets and highways. Environmentally, air pollution and greenhouse gas emissions from transportation were reduced. Finally, the program increased the resources available for public transport enhancements (Gudmundsson et al., 2009). The trial's success motivated 53% of participants to approve a referendum making this scheme a permanent program. Finally, the Stockholm Congestion Tax (SCT) was approved with a 10 billion euro investment in infrastructure for its implementation and monitoring (Lehe, 2019). Figure 4.3 shows the infrastructure of this congestion charging scheme in Stockholm.

Figure 4. 3 Stockholm Congestion Charging Scheme infrastructure. From "Congestion Charging Price List" by Mike, 2007 & M. Halldin, 2006. (CC BY-NC-SA 2.0)

In Stockholm, congestion pricing reduced traffic by 22% and reduced the concentration of air pollutants by 14%. Availability and dissemination of data to the public played an essential part in gaining support from the citizens. However, based on empirical studies, public support for these programs does not necessarily rise or remain constant over time. For instance, in Copenhagen, studies did not observe differences in accepting a toll charge before and after implementing a road pricing experiment (Gehlert & Nielsen, 2007). What seems to be crucial is to develop proper measures and steps for the program and a robust public information program.

Like London, congestion pricing in Stockholm is part of a comprehensive **transportation policy** that supports other interventions. For instance, the government added 1,500 parking spaces on the edge of the zone. In addition, they extended bus services (16 new lines and 14 new express bus lines) as complementary interventions to support sustainable mobility (Schuitema, Steg, & Forward, 2010).

More importantly, the culture and positive perceptions and attitudes toward public transportation increase the support and acceptance of commuters to congestion charging (Schuitema, Steg, & Forward, 2010). Another important component of the success in the implementation of transportation policies is the creation of data that helps examine the factors contributing to or undermining sustainable transportation policy. In Stockholm, residents perceive that congestion and air pollution are two problems that the city needs to address. Thus congestion pricing is seen as a solution that contributes to the improvements in air quality (Schuitema, Steg, & Forward, 2010).

Congestion charging reduced 20-25% of car travel and helped reduce commuting times, with around a one-third reduction for the morning peak and a one-half reduction for the evening peak. Origin destination surveys revealed that around half of the drivers switched to public transit. However, some drivers were incentivized to drive when they perceived a notable reduction in inner-city congestion.

Congestion charging in Stockholm reduced drivers' contribution in central locations by 14% and 2-3% in metropolitan areas. Similarly, congestion charging reduced the concentration of air-borne pollutants by around 10-14%. Likewise, studies found a reduction of around 8.5% in NOx associated with increased bus usage and reduced driving. Residents of Stockholm perceived an improvement in the environmental quality of the urban environment as a result of an increase in the use of non-motorized transit. Notably, congestion charging had an indirect effect of increasing 6% in public transit use in 2006. However, it is possible that drivers switched to transit because of an increase in the cost of fossil fuels. Also, significant investments in public transit helped increase the number of new bus lines in 2006 (Eliasson et al. 2009). More recently, Stockholm's congestion incentivizes the use of fuel-efficient cars, such as electric vehicles, due to exemptions associated with these vehicles. This exemption has increased the number of drivers that use cleaner vehicles by 1.8% (Whitehead, Franklin, and Washington, 2014).

THE U.S. CASE: NEW YORK CITY'S CONGESTION PRICING

Some cities in the U.S. have shown interest in using congestion charging. However, the implementation of congestion charging is particularly challenging in the U.S. because the urban form of most U.S. cities with low-density areas induces car dependence. Nevertheless, Orange County (California), San Diego, and Houston have implemented designated **high-occupancy toll (HOT)** lanes to discourage driving (Harrington, Krupnick, and Alberini, 2001). These schemes could be considered a different form of congestion charging. Implementing congestion charging in the U.S. seems challenging except in New York City, where the urban form is more similar to its European counterparts.

In this section, we examine the potential obstacles and benefits of congestion pricing in the context of U.S. cities by drawing on the case of New York City as an illuminating example. In 2008, New York City tried implementing a daily license program to restrict driving in Lower Manhattan. However, despite the support of the city government and mayor, the New York State Senate and legislators from New York State that do not represent the citizens of NYC suppressed the scheme in the State Assembly (Lehe, 2019). Recently, the city has been reconsidering the implementation of congestion charging. This new program may restrict on-demand car trips, including Uber and Lyft, and taxi trips within a large swath of Lower Manhattan, as well as ordinary traffic, with cars paying $11.52 per day and trucks $25.34. Since then, the daily license has been rejected and postponed, but the taxi/ridesharing surcharge started in 2019. Taxi and ride-sharing restrictions may raise nearly $400 million annually, while the congestion pricing for daily traffic would raise $1 billion (Fix NYC, 2018).

The implementation of congestion pricing will depend on how individuals evaluate the societal benefits and the individual-level impacts on transit riders and motorists (Schaller, 2010). Supporters of congestion pricing argue for the societal benefits, while detractors evaluate the program from an individual perspective. The collective benefits for society associated with the program include the mitigation of congestion and the generation of revenues to support public transit and **non-motorized transportation**. Also, individual commuters may benefit from congestion pricing through improvements in the quality of public transit, a reduction in commuting times, and the reliability of transportation. Opponents argue that congestion pricing may have a minor influence because traffic is mainly exacerbated by trucks and taxis, not ordinary drivers. They also say that congestion pricing and a potential increase in transit riders will exacerbate overcrowding in public transportation. Detractors believe congestion charging may not reduce driving as transit may be overcrowded. In addition, they do not trust that the **Metropolitan Transportation Authority (MTA)** will use the revenues to improve transit. This, in turn, suggests a lower trust of U.S. residents in transportation authorities than in other European cities where the public supports transportation policies and innovations. Contrary to their European counterparts, city governments in the U.S. have little authority to implement transportation policy and thus need state and public approval. Even when the general public supports transportation innovations, a small group of citizens (primarily private car commuters to the zone) can halt the process of transportation policies. A successful approval and implementation of the program requires the active support of low-income commuters and users of non-motorized transportation. These commuters may benefit from implementing congestion pricing in New York, and thus their perspectives should also be considered in transportation policies (Schaller 2010).

Baghestani (2020) simulated travel demand using activity-based modeling under different scenarios of congestion-pricing implementation. The research found that congestion pricing in NYC may reduce 6.8% of vehicle miles traveled (VMT) and reduce 30% of travel time. Their research found that travel demand with different modes and vehicle occupancy levels is sensitive to the toll price, and trip attraction to the congestion pricing is sensitive to price. Moreover, at a network level, trips outside the CBD area may experience a slight increase for single occupancy vehicles (SOV), taxis, and public transit. Also, a decrease of around 33% could be observed for vehicle hours of delay and lane-mile congestion in the highest toll scenario ($20). Congestion charging may also improve air quality since models show a 7-18% reduction in PM2.5 under different toll-pricing scenarios (Baghestani, 2020). Despite the potential benefits of congestion pricing in NYC, previous research has disregarded the implications of congestion pricing for low-income workers who need to drive to central locations in NYC.

CONCLUSION

This chapter introduces and elaborates on the concept of congestion pricing as a progressive and sustainable policy to reduce negative impacts of the transportation sector, such as air and noise pollution or congestion. The chapter further overviews various congestion pricing programs and strategies and discusses the case of the cities of London and Stockholm as successful congestion pricing case studies in Europe. Finally, the chapter brings the discussions to the context of the US by examining the potential obstacles and benefits of congestion pricing in New York. Overall, while congestion charging is not a one-size-fits-all solution, it offers a promising strategy for cities seeking to alleviate congestion and foster sustainable urban mobility. The experiences of London and Stockholm provide valuable lessons for other cities considering similar measures, underscoring the need for comprehensive planning, public engagement, and continuous evaluation to achieve lasting success.

Glossary

- **Congestion pricing** is the amount of money required to enter a downtown district every day that is paid to lessen traffic (*Congestion Charge*, 2023).
- **High occupancy toll (HOT)** Vehicles with many people enter lanes. For use, there is a cost (particularly during rush hours), which promotes carpooling and provides cars with a less crowded route while easing traffic on nearby roads. A method of managing the demand for transportation that uses dynamic tolling to lessen traffic.
- **Traffic flow** comes from interactions between infrastructure and passengers. The components of traffic flow include flow, speed, and density.
- **Transportation policy** focuses on creating a collection of ideas and theories to attain specific goals in relation to the social, economic, and environmental situations as well as the operation and effectiveness of the transportation system (Transport Geography, n.d.).
- **Non-motorized transportation** is walking, cycling, and other forms of small-wheeled, human-powered mobility are all considered non-motorized means of transportation. These forms of transportation, except for walking, use non-motorized vehicles such as bicycles, skateboards, push scooters, wheelchairs, and rickshaws (Wikipedia, n.d.).
- **Metropolitan Transportation Authority (MTA)** is a public benefit corporation responsible for public transportation in the New York City metro area of the U.S. state of New York (Wikipedia, n.d.).

Prep/Quiz Questions

- Is the original London's congestion charging scheme a success? What are its strengths and weaknesses?
- What are the advantages and disadvantages of the expansion of congestion charging in Western cities?
- Would the London congestion charging scheme work in New York City or the DFW area?

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CHAPTER 5.

CASE STUDY III: CAR BANS IN MEXICO CITY

CHAPTER OVERVIEW

This chapter critically compares the implications of plate-based car restrictions in Mexican and Chinese cities for addressing traffic congestion and air pollution. First, drawing on Mexico City's No Driving Day Program **(Hoy No Circula)**, this chapter critically examines the implications of exemptions granted to new and fuel-efficient cars, including the rise of car ownership and replacing vehicles with more recent models. Next, the chapter examines behavioral responses to driving restrictions enacted by low-income drivers to circumvent rules. Finally, this chapter examines the equity implications of car restrictions that disproportionately burden low-income drivers who own older vehicles but drive significantly less than wealthier drivers.

Learning Objectives

- Identify reasons why plate-based car restrictions are widely implemented in cities in the Global South.
- Compare the implications of car restrictions in Latin American and Chinese cities and explain why car restrictions have different effects on car congestion and air pollution mitigation.
- Examine the indirect effects of exemptions to car restrictions in Mexico City, including the increase in driving and replacing the **vehicle fleet**, which allows higher-income residents to drive more often.
- Identify the equity implications of car restrictions for low-income commuters disproportionately affected by conditions.

WHAT ARE LICENSE PLATE-BASED RESTRICTIONS?

In the last few decades, policies such as license plate-based restrictions have become more prevalent in many countries in the Global South. These policies act based on the last digit of vehicles' license plate numbers to ban cars from being used in specific urban areas during particular times of the day or week. While there have been other policies, such as congestion charging or vehicle quotas (Nie, 2017), license plate-based restrictions are more common and accepted for targeting traffic congestion and air pollution. However, despite the popularity of supporting plate-based restriction policies, there is not enough evidence to prove that these policies successfully reduce traffic congestion and air pollution. The findings are mixed since studies may use different outcome measures and methodologies. Also, policy design, city context, behavioral responses, and enforcement levels in different cities and geographical areas may impact the the outcomes of studies on the effectiveness of license plate-based driving restrictions. Besides, studies may consider cities with varying policy limits regarding the type of vehicle affected by driving conditions. As a result, these studies may yield mixed findings.

Several studies found that people are encouraged to replace their old and high-polluting vehicles by the policies supporting exemptions for newer and low-emission vehicles (Barahona et al., 2020; Guerra & Millard-Ball, 2017; Rao, 2020; Xiong & Qin, 2020). However, These policies impact people of different socioeconomic backgrounds unevenly, as purchasing new, low-emission vehicles is often only feasible for higher-income individuals. Additionally, there is limited understanding of how these policies influence travel behavior and traffic patterns within cities. Data shows that after NAFTA and because of economic growth, many residents could buy a car for the first time. However, this was not the case for many other residents. Also, many people moved to the fringe, a movement that increased car ownership but did not increase car usage among low-to-moderate-income residents. The following graph (Figure 5.1) illustrates the 1984-1993 difference in gasoline consumption increase during the economic recession (1984-1988) and after (1989-1993) during economic growth.

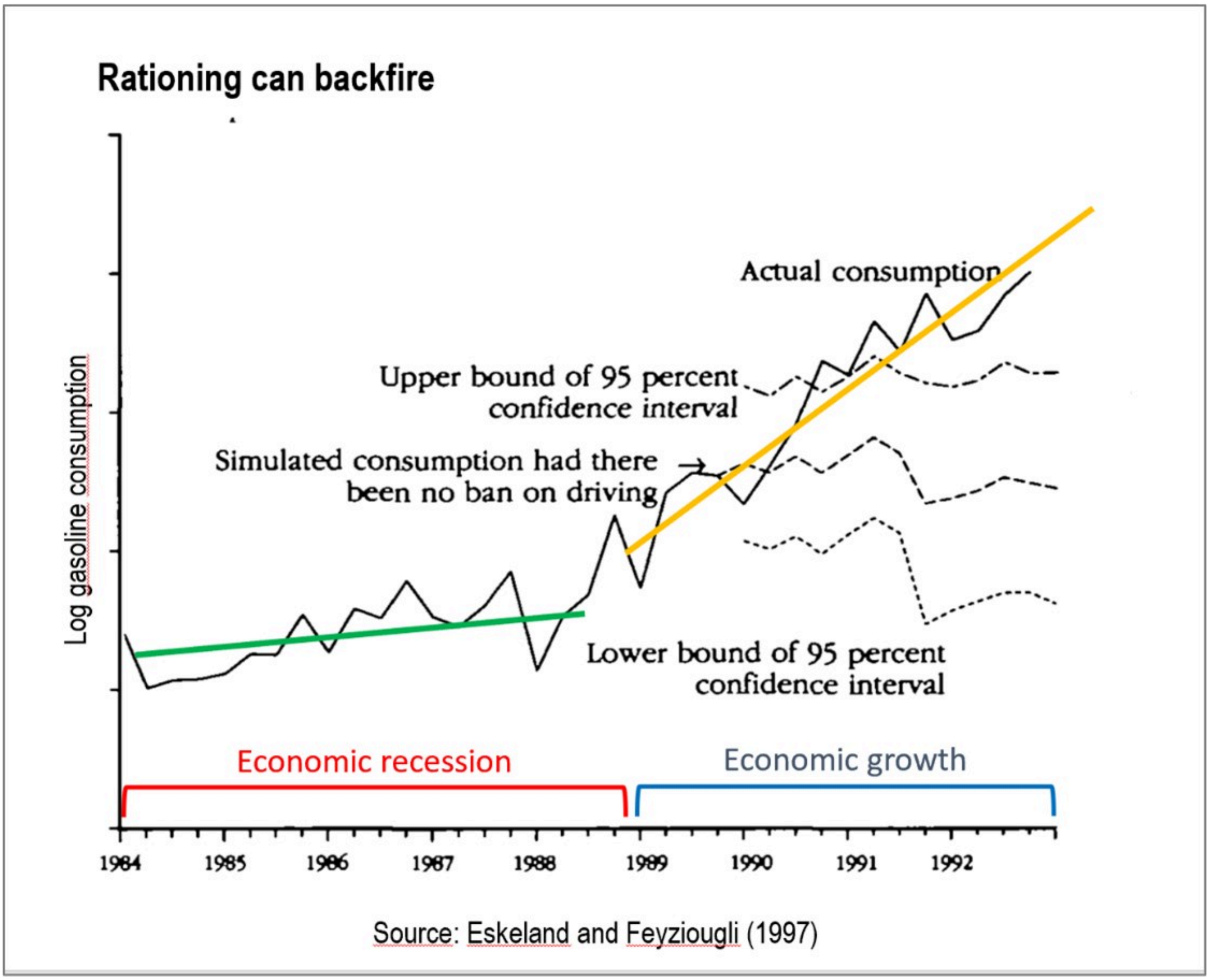

Figure 5.1 Gasoline consumption different increase rates (1984-1993)
Adapted from Eskeland and Feyziougli (1997)

Guerra and Reyes evaluated the impact of license plate-based restrictions (*Hoy No Circula*) on people's lives and travel behavior in Mexico City using three different methods of data collection, including 1) an extensive household travel survey (INEGI, 2017), 2) interviews in moderate-income neighborhoods, and 3) a focus group with moderate-income drivers. The collected data is combined and analyzed to explore how people with different socioeconomic conditions may react to Mexico City's *Hoy No Circula* driving restrictions. In its first years of implementation (beginning in late 1989), *Hoy No Circula* only included private cars in the restriction plan. Therefore, public transportation and state-owned vehicles were excluded from the restrictions. At that time, personal cars were prohibited from circulating in Mexico City and surrounding municipalities of Mexico State for one weekday per week from 5 a.m. to 10 p.m. The restrictions provided by this policy have changed throughout history. The following table (Table 5.1) summarizes the history of the *Hoy No Circula* policy.

Table 5.1 Thirty Years of Hoy No Circula

Year	Restriction Policy Conditions
1989	Implemented as a temporary program
1990	The implementation became permanent
1996	Applying exemptions for newer vehicles w/ catalytic converters
1999	Applying exemptions for cars under two years old and between 2-and-10 years that pass smog tests
2008	Adding more Saturday restrictions
2015	Using additional rules for older vehicles
2020	Applying exemptions for electric and hybrid vehicles

Moreover, the following graph summarizes the significant changes in the policy throughout the last two decades. Accordingly, it could be concluded that the government shifted its discourse from reducing car travel in the MCMA to solely renovating and improving the car fleet.

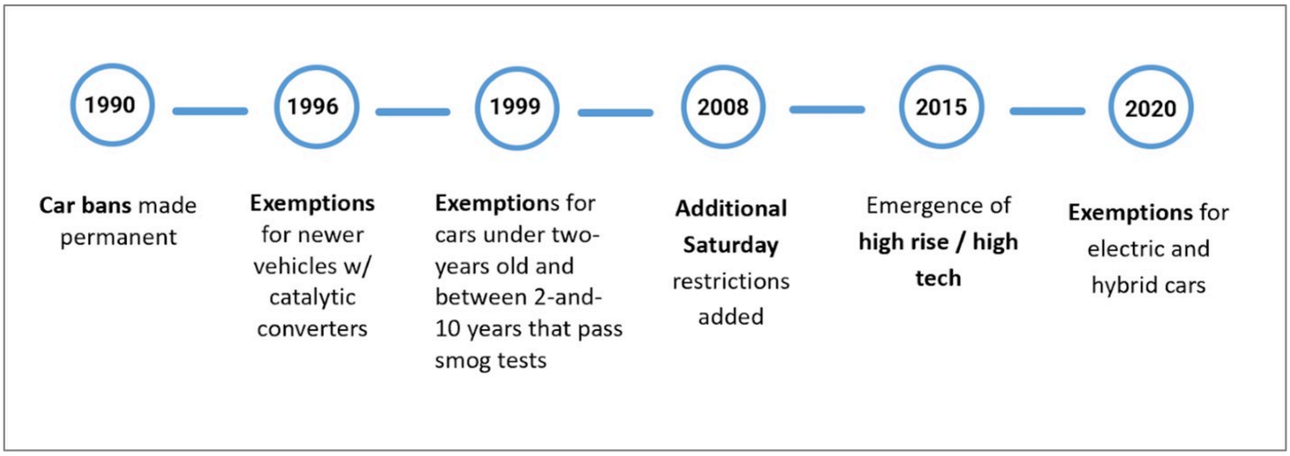

Figure 5.2 A timeline showing the significant Hoy No Circula policy changes.

Accordingly, vehicles with catalytic converters were included as exempted vehicles by 1997. After two years, all cars under two years old plus cars aged between 2-9 years that passed an exemption test were allowed by law to be excluded from the restrictions. To recognize the exempted vehicles, people were responsible for using stickers with hologram numbers associated with differing exemptions from the policy on their vehicle's windshield. In 2017 (when the study was conducted), four government-issued holograms were used to differentiate between restrictions for weekdays, Saturdays, and temporary pollution-emergency days. Data regarding these holograms were collected in the household travel survey. Table 5.2 shows how other holograms work on different days. Accordingly, on a non-pollution-emergency day:

- Holograms “0” and “00” are exempt.
- Hologram “1” is banned one weekday per week and one Saturday per month (5 a.m. to 10 p.m.)
- Hologram “2” is forbidden one weekday per week and all Saturdays (5 a.m. to 10 p.m.)
- Bans apply to all vehicles entering Mexico City and the surrounding municipalities of the metropolitan area.

Table 5.2 Holograms and restrictions associated with them

Weekdays	‘Plate’s last digit	Sticker color
Monday	5 or 6	Yellow
Tuesday	7 or 8	Pink
Wednesday	3 or 4	Red
Thursday	1 or 2	Green
Friday	9 or 0, and those with letters only or temporary plates	Blue

Source: https://en.wikipedia.org/wiki/Hoy_No_Circula

The license plate-based restriction policies have been evaluated by many scholars (Blackman et al., 2018; Davis, 2008, 2017; Eskeland & Feyzioglu, 1997; Gallego et al., 2013; Guerra & Millard-Ball, 2017); however, previous studies did not examine how and to what extent people’s travel behavior, air pollution, and congestion have been affected by *Hoy No Circula*. Previous studies assume that drivers generally comply with the policy and thus buy an extra second-hand vehicle to get to places during the restrictions, adversely affecting traffic congestion and pollution (Davis, 2008; Eskeland & Feyzioglu, 1997). However, recent studies challenged this compliance assumption. Guerra and Millard-Ball (2017) found that many commuters do not comply with the exemption policy. Instead of purchasing a new car, which would be expensive, they find more reasonable behavioral adjustments to avoid the procedure and the restrictions (Guerra & Millard-Ball, 2017). Also, people who own old and restricted vehicles may discover other solutions, such as only using their car for a few days during the week. Data reveals that only 3% of residents own non-exempt vehicles. This highlights the need for qualitative research to better understand how lower-income people respond to license plate-based driving restrictions, given the diverse reactions to exemption policies.

Restrictions limiting the number of cars on the streets will help reduce air pollution; however, many focus group participants complain about rules for old cars but poor regulations for old and inefficient buses and cargo trucks. According to the following graph (Figure 5.3), there is a positive association between car use and air pollution. Accordingly, after the economic recession ended in 1990, there was a spike in air pollution due to people’s ability to buy more cars (Figure 5.3)

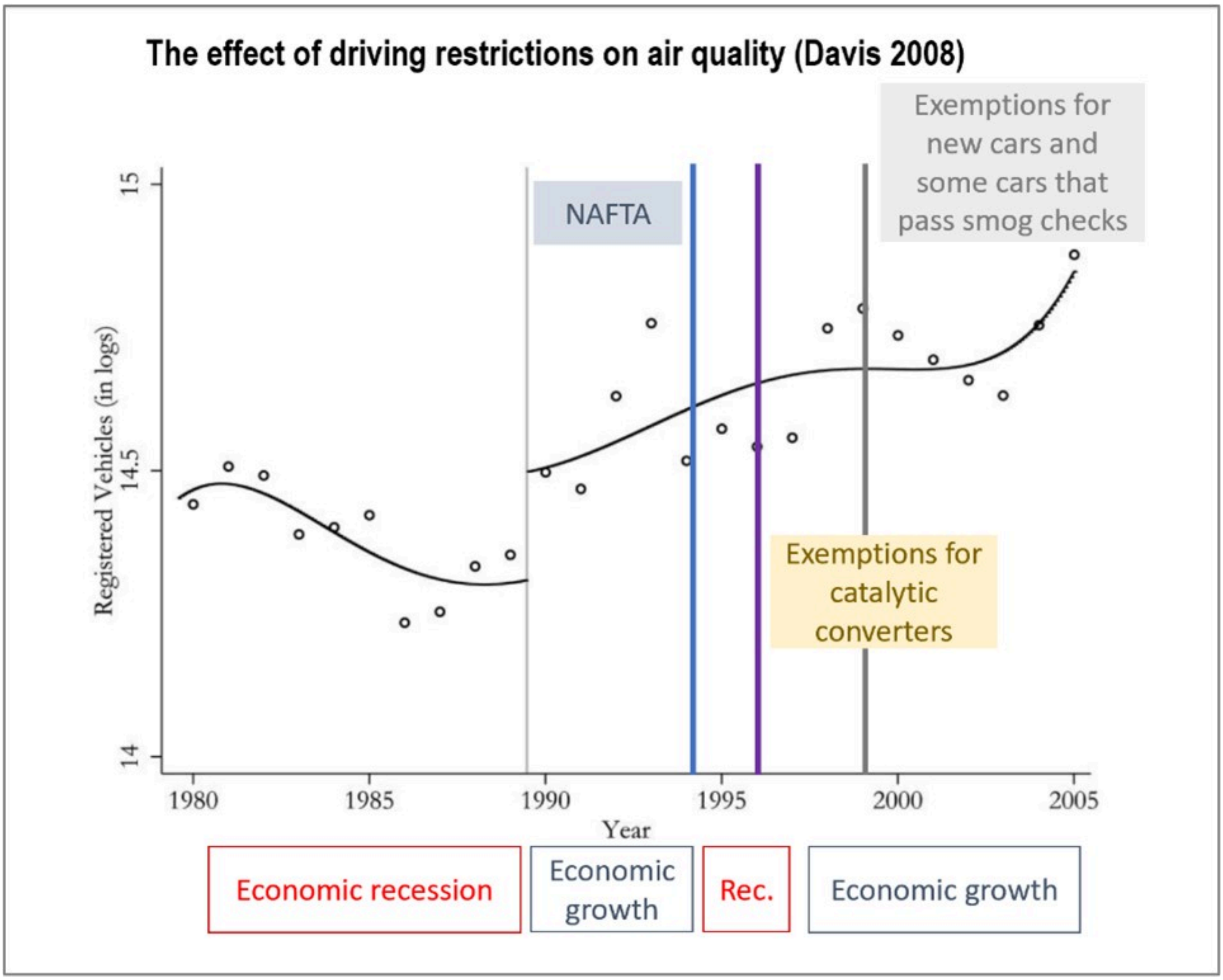

Figure 5.3 The effect of driving restrictions on air quality
Adapted from Davis, 2008

Behavioral Responses to License Plate-based Driving Restrictions

Research suggests that drivers have different behavioral responses to restriction policies. Therefore, car restrictions may work in certain places, for certain people, and for various reasons. However, at the same time, they are not 100% successful in all cases. Therefore, people's responses regarding purchasing new vehicles and their travel behavior on restricted and unrestricted days would differ depending on many factors. Below, we review some behavioral responses to car restrictions documented in Mexico City and Beijing.

VEHICLE PURCHASES

Data shows that most residents living in cities with driving restrictions, such as Mexico City and Beijing, do not own private vehicles. Some studies have discussed that if the regulations reduce the car value in cases like Mexico City, some residents would prefer to sell their cars and not purchase new ones (Blackman et al., 2018). For example, a study in 1997 in Mexico City discussed that in response to Hoy No Circula's initial implementation, most of the residents who owned a car stopped using their vehicle rather than buying a second car (Eskeland & Feyzioglu, 1997). However, some other residents may buy another vehicle (as a second car) and use it as the exempted vehicle, resulting in more driving (Davis, 2008; Eskeland & Feyzioglu, 1997). Therefore, buying and using a second car to frustrate the restriction could be one of the main reasons the driving restriction policies have not successfully controlled congestion and air pollution.

The responses of residents in other cities with driving restrictions may be different. For instance, in Beijing, Santiago, or Bogota, the population owning more than one car is less than 5%, and those with multiple vehicles typically have higher incomes. On the other hand, people may prefer to buy vehicles with lower emission rates to respond to the driving restriction policies in some cities. For example, Santiago has more restrictions on older and high-polluting vehicles (Barahona et al., 2020). Also, many of the cities in China have developed policies that exempt electric cars and, thus, have increased the sale of electric vehicles (Diao et al., 2016; Lu et al., 2020; Rao, 2020; N. Wang et al., 2017).

According to the collected data, while in Beijing, only 2.2% of households owned more than one car (Gu et al., 2017), in Mexico City, only 1.2% held at least two vehicles, likely subject to driving restrictions. Additionally, less than 5% of households in Santiago own more than one car, and many wealthier families own newer, exempt vehicles. Also, in Bogota, 3.3% of households reported having two or more cars or pickups on the 2011 household travel survey.

DRIVING ON RESTRICTED DAYS

Residents who own non-exempt vehicles will respond differently to driving restriction policies. Some people prefer to use other transportation modes, such as transit, taxis, or bicycles, for their trips. Therefore, these policies will result in more public transit, taxi, bike share, or bicycle use (Campbell et al., 2016; de Buen Kalman, 2021; Gu et al., 2017; Mohan et al., 2017; Xu et al., 2015; Yang et al., 2018), which is expected to reduce traffic congestion and air pollution. However, the findings are mixed and not wholly aligned with the expectations. Some other studies discussed that the increase in using different modes (public transit, taxi, and bicycle) did not reduce pollution or congestion (Davis, 2008, 2017; Guerra & Millard-Ball, 2017). Therefore, we must consider that the congestion caused by other transportation modes, such as taxis or low-occupancy forms of transit, might be the same or even more than that caused by private cars. Additionally, in China, the potential replacement for personal vehicles may vary from city to city (Zhang et al., 2019) and neighborhood (Cheng et al., 2020), depending on the available options and people's socioeconomic conditions. Therefore, in areas with lower public transit quality or people of higher income, it is more probable that people will use taxis than public transit (Cheng et al., 2020).

Another response from residents is to shift their trips to hours/day with no restrictions. While it is not very common to drive before or after restriction hours to respond to the policy mandates (de Grange & Troncoso, 2011; Gu et al., 2017; Guerra & Millard-Ball, 2017), many drivers choose to shift their trips to the days that their vehicles are not restricted (Gu et al., 2017; Guerra & Millard-Ball, 2017). However, not all families could use this approach to respond to the policy restrictions. Therefore, employing this solution is more prevalent among people who use their cars irregularly and are from moderate-income families owning one non-exempt vehicle in Mexico City (Guerra & Millard-Ball, 2017). Finally, a typical behavioral response to the restriction from drivers is to use their cars with no attention to the restricting policies (Guerra & Millard- Ball, 2017; Liu et al., 2018, 2020; Mohan et al., 2017; Wang et al., 2014). These behaviors are specifically common in areas with less enforcement, such as peripheral locations (Wang et al., 2014).

DRIVING ON UNRESTRICTED DAYS

Another significant reason these restrictions are not necessarily reducing congestion or pollution is that when drivers switch their trips from restricted to non-restricted days, the total driving is unlikely to be reduced. Some studies revealed that drivers are more likely to use roads that would reduce their travel time and consume the additional capacity of the streets (Cervero & Hansen, 2002; Downs, 2004; Duranton & Turner, 2011). Also, restricting specific vehicles on roads could significantly increase other types of vehicles. For instance, data shows that temporary restrictions for particular cars in Delhi, India, were compensated by increased travel from exempt auto-rickshaws, motorcycles, and buses (Mohan et al., 2017).

OTHER BEHAVIORAL RESPONSES

One of the other behavioral responses to the restrictions is cheating. While Davis (2008, 2017) assumes universal compliance, other scholars find evidence of noncompliance. For instance, Wang (2014) finds that nearly half of the regulated car owners violated the restriction rules in metropolitan Beijing and that violations are more likely to occur during peak hours, on social trips, and on trips outside of the city center, where presumably enforcement is weaker (Wang,2014). Also, Liu et al. (2020) examined license plate detection data and found 12% and 6% of vehicles are in violation during odd-even and one-day-per-week bans, respectively (Liu et al., 2020).

In addition, shuffling trips is another practice that residents use to respond to the restrictions. Some scholars, such as Gu et al. (2017) and Guerra and Millard-Ball (2017), found evidence that households shuffle their schedules around the banned days. This response is particularly convenient in Mexico City, where families use a prohibited vehicle on average fewer than two weekdays per week (Guerra and Millard-Ball,2017).

Therefore, in general, the following behavioral responses are detected to be practiced by people in response to the restriction policies:

- Shift time-of-day of travel
- Network effects (a fundamental law of traffic congestion)
- Buy a newer exempt car
- Shift to equally polluting taxis.

CONCLUSION

To answer the question of “Who drives in Mexico City?” the data collected and analyzed by Guerra and Reyes’ (2022) study, as well as the observations in the city, show that the higher-income population owns most new cars (*Hoy- No-Circula* exempt), and low-capacity buses fill the city’s roads. Only a trickle of old vehicles can be observed circulating in the metropolitan area during the day (Figure 5.4).

Figure 5.4 New and exempt cars on Mexico City metro area roads. Photos by authors taken in Tlalnepantla, Estado de Mexico, August 2020.

Highlights of Mexico City's car ban policy can be summarized as follows:

- *Hoy No Circula* does not improve air pollution or reduce traffic congestion. However, it has indirectly enabled the upgrading of the vehicle fleet owned by wealthier residents, while lower-income households have been unable to purchase a newer car to be exempted from the policy. The policy exempts only a specific subset of the population from driving restrictions.
- The policy disproportionately burdens lower-income drivers more likely to drive older, restricted vehicles.
- While some suburban households interviewed switch from car to transit on restricted days, most either:

    1. Drive infrequently
    2. Shuffle trips to other days or times of day
    3. Drive in specific locations and roads to avoid enforcement
    4. Bribe police or technicians.

Glossary

- **Hoy No Circula** (also known as "No-drive days") is the name of an environmental initiative designed to enhance Mexico City's air quality. Its direct translation from Spanish is, "Today [your car] does not circulate." Mexico City is surrounded on three sides by the State of Mexico, where a comparable coordinated program is in place (Wikipedia, September 20, 2022).
- **A vehicle fleet** is a collection of vehicles owned and maintained by a single company, nonprofit, or governmental body and frequently organized around a particular discipline (Nissan USA, December 18, 2023). Sometimes vehicle fleet loosely refers to a collection of vehicles in circulations.

Prep/Quiz Questions

- What are the potential effects of car bans on vehicles' ownership and usage?
- How are low-income commuters affected by car bans?
- What are their responses to car bans?
- What policies can support low-income commuters more and more effectively mitigate air pollution?

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CHAPTER 6.

CASE STUDY IV: PARKING IN SAN FRANCISCO

CHAPTER OVERVIEW

This chapter examines how parking requirements in U.S. cities affect urban density, congestion, and driving. The first part describes the problems of free, suburban, and parking requirements. The second part examines the actions some cities in the United States, including the Twin Cities in Minnesota, are implementing to address their parking challenges. The third part contrasts the benefits and drawbacks of the San Francisco Parking Management Program that seeks to curb **traffic congestion**. The last section concludes with takeaways for improving the implementation and efficiency of San Francisco's parking program regarding air pollution mitigation and equity.

Learning Objectives

- Compare the implications of free and extensive parking requirements in the suburbs of American cities for **urban sprawl**, congestion, and car dependency.
- Recognize the policies and actions some cities are implementing to address their parking challenges.
- Identify the benefits and potential drawbacks of San Francisco's parking management system regarding curb traffic reduction and air pollution.

THE IMPLICATIONS OF MINIMUM PARKING REQUIREMENTS

The rapid urbanization and expansion of cities to suburban locations, poor access to low-density transit areas, and minimum parking requirements induce car-oriented cities (Parmar, Das, & Dave, 2020). Minimum parking requirements determine the amount of land for parking that developers must include in land-use planning. Minimum parking stems from the notion that residential and commercial land use must accommodate residents' and users' parking demands during peak hours. Parking standards influence sprawl and low-density development and reduce available urban land for other uses, such as affordable housing, transit, or non-motorized transportation. Parking standards induce commuters to drive personal cars for different trip purposes due to the sense of available and free parking near their destinations. Local governments establish parking requirements. Many cities replicate strict minimum requirements from other cities. Table 6.1 shows some of the parking requirements for some land uses published by the city of Fort Worth, Texas. Parking requirements influence cities' urban form and thus the possibility to support (or not) sustainable mobility practices.

Table 6.1 Parking requirements for land-use planning in the city of Fort Worth

Land Use	Parking Requirement
Single-unit Residential Housing	1 to 4 parking
Housing Complex	1 parking per bedroom
Education Centers	1 space per 2 teachers and administrative staff 1 space per 4 additional employees 1 space per 3 students residing on campus 1 space per 5 students not residing on campus
Hospitals and Clinics	1 space per bed plus 1 space per each 4 nurses
Banks	4 spaces per 1000 square feet
Commercial Business, Retail Sales and Service	4 spaces per 1000 square feet
Restaurants and Cafeterias	1 space per 100 square feet

Source: Zoning Ordinance of the City of Fort Worth Code, 2022. by City of Forth Worth. (https://codelibrary.amlegal.com/codes/ftworth/latest/ftworth_tx/0-0-0-32923). In the public domain.

Rapid urbanization in the cities' outskirts increases the demand and supply of parking, especially in areas with services and jobs that attract workers and visitors. For decades, minimum parking requirements influenced cities' urban form and increased the costs of residential land use. Consequently, many commuters prefer places with free and extensive parking despite the high prices for land-use planning. Weinberger (2012) examined the implications of residential off-street parking on travel behavior in New York City. The study showed that off-street parking increases car driving. Minimum parking requirements influence parking behavior by increasing the demand for free parking and, at the same time, exceeding the available parking supply. Minimum requirements influence the urban form and travel behavior and impact the available land for alternative transportation modes. Seattle has implemented some progressive parking strategies. First 2006, the city granted flexible parking requirements in commercial zones. Later, in 2012, Seattle eradicated minimum parking requirements for multifamily zones in urban centers. Also, the city reduced minimum requirements for residential land use in urban centers with relatively good access to transit services (Weinberger 2012). A recent study found that modifying Seattle parking requirements has enabled land-use planning changes. Developers avoided erecting 18,000 parking spaces and thus saved $500 million between 2012 and 2017. More importantly, developers allocated more land to housing and green spaces (Gabbe, Pierce, & Clowers, 2020).

The costs of free parking

Parking requirement regulations negatively affect urban form by reducing density and undermining local governments' capacity to manage parking properly. Some cities have limited resources, such as technologies and infrastructure, to charge drivers for the externalities of parking. Externalities such as sprawl and congestion are (Shoup, 1997). In the late 1990s, Shoup estimated that the total amount of land dedicated for parking in the U.S. was as big as the state of Connecticut. It has only increased in size as cities have grown and with population growth in the last three decades. Also, expansive areas of parking undermine the affordability of residential land use. For example, a study conducted in San Francisco in 1997 found that requirements for off-street parking increased housing prices by $47,000 and thus increased the annual income potential buyers required for housing from $67,000 to $76,000 (Shoup, 1997). Residential land use with flexible parking requirements may increase housing supply, especially in more dense urban areas with access to public transportation.

Parking lots typically occupy 30% of the total land in multi-family areas and 60% of commercial land uses (Ferguson 2005). Empirical studies reveal that excessive parking areas decrease densities. Car-oriented cities and excessive parking surges transportation energy use and thus greenhouse gas emissions, undermining sustainability and **smart growth** (Cutter & Franco, 2012). Excessive parking also reduces the extent of impervious surfaces in cities and thus increases the risk of floods and the vulnerability of cities to torrential rains or extreme climate events. Smart growth, sustainability, and social equity advocates have called for significant changes in parking regulations (Wilson and Roberts, 2011).

Figure 6.1 Giant Commercial Parking. From "Big empty parking Lot," by Silveira, 2010. (https://commons.wikimedia.org/wiki/File:London_CC_12_2012_5037.JPG). CC-BY 2.0

Cutter and Franco (2012) found that excessive parking in US cities increases costs and thus reduces the profits and revenues for developers. Because the marginal value of building parking is less than the marginal value of urban land with infrastructure, the construction of excessive parking is not cost-effective for developers. Cutter and Franco (2012) call for a parking pricing policy that carefully understands how residents and users of buildings commute to understand their precise parking requirements. A comprehensive understanding of parking behavior that informs equitable parking pricing policy may reduce driving and cruising in urban areas (Cutter and Franco 2012).

CRUISING AND CONGESTION

When drivers cannot find a parking spot near their destination, they cruise until it is found. Cruising for parking occurs when drivers cannot find a suitable parking spot for their vehicles in terms of price and proximity to their destination. Cruising increases traffic, congestion, and air pollution, especially downtown or urban areas. Shoup (2006) found that cruising traffic during peak times accounts for 30-50% of total traffic in U.S. cities. Past studies revealed that around 30%

of the traffic was associated with cruising for parking in different cities during the 90s, and the average time to find a suitable on-street space ranged between 3.5 and 14 min (Shoup, 2006).

Transportation planners should understand the factors that affect parking behavior and the solutions to support sustainable mobility. Cruising for parking has economic implications for commuters because it increases gasoline consumption and vehicle miles traveled (VMT), resulting in higher travel costs and travel times. From the public perspective, cruising increases congestion, air pollution, and loss of economic activity. It is important to understand the factors determining the optimum parking pricing, which refers to an equilibrium or balanced relationship between curb and off-street parking, which minimizes cruising time. These factors include off-street parking availability, pricing, occupancy rate, and technological innovations to manage parking properly. Relatively expensive parking also increases cruising (Shoup, 2006). A proper policy to improve parking and reduce cruising should carefully understand parking costs and the implications for drivers with different socioeconomic backgrounds.

Transportation planners study travel behavior theory to understand parking demand in urban areas. Choice models help identify the factors that influence drivers' decisions for parking in different urban contexts. These studies suggest drivers prefer to park in a location just before their destination (Behrendt, 1940). Thus, distance to the destination is a significant factor influencing parking choices. Parking behavior is complex because numerous factors influence the final decision (Parmar, Das, & Dave, 2020).

Studies concur that social-economic factors such as income, age, parking availability, and space influence parking behavior. Complex models have addressed the limitations of previous studies. For example, Guo et al. (2013) compared two choice models. One model assumes that all drivers make decisions simultaneously, and the other model considers the variety of individual psychological characteristics. The results showed that the latter had a higher accuracy for prediction. Ottomanelli, Dell'Orco, and Sassanelli (2011) used a model to study behavior about uncertainty. In this model, the imperfect knowledge was about the pricing scheme, the enforcement of parking violations, the distance between parking spot and opportunity (destination), and the presence of congestion. Overall, the psychological and socioeconomic characteristics of drivers, the parking facility, and the characteristics of alternative parking impact choices. Also, parking pricing, cruising time, and walk time are more significant predictors of parking behavior than fuel cost and commuting time (Parmar, Das, and Dave, 2020). Scholars agree that informed, dynamic, and publicly available information on pricing policies, rather than free parking, can alleviate the auto-dependency rate, decrease car trips, and prevent the negative externalities of parking or the emergence of the proliferation of informal or illegal parking.

Figure 6.2 Informal Parking in (a) developed country, (b) developing country.
From "Informal settlements Kampala" By Ingle, 2012. (https://www.flickr.com/photos/gtzecosan/8410979706/). CC BY-SA 2.0
From "Cars parked on informal grass area at Victoria Park Station, Collingwood" By Mallis. 2020. (https://www.flickr.com/photos/philipmallis/49597976867). CC BY-SA 2.0

REASSESSING MINIMUM PARKING REQUIREMENTS

This section discusses the implications of minimum parking requirements, which often use simplistic methods to estimate the parking needs by building use and structure. These assessments consider the peak parking occupancy collected in surveys in suburban areas, which typically results in overestimating parking demand.

Some cities simply replicate the parking requirements of other cities, and thus the excessive or insufficient parking spreads. Alternative approaches could stop the spread of outdated or excessive municipal parking requirements. One alternative strategy could include curbside/on-street parking spaces to meet the minimum requirement. In addition, the transportation engineers and planners determining typical parking demand could consider the *average* parking demand instead of peak demand. This may be a more precise estimate of parking needs throughout the year. Excessive parking in U.S. cities also increases the rate of vacancy or underutilization of land. Studies in U.S. cities have reported a vacancy rate that ranges from 40 to 60% (Shoup 2006) and an oversupply of parking ranging between 30 to 90% in downtowns and between 20 to 66% in the suburbs (Weinberger & Karlin-Resnick, 2015). This means parking lots associated with vacant or low-occupied buildings are usually empty or underutilized. Thus, scholars recommend reducing vacancy to 35% because it will affect required parking (Shoup 2006). More recent strategies pose a vacancy rate of 15% in parking areas as an optimum goal to reduce parking-related traffic because parking supply and demand remain balanced. This strategy may prevent car spillovers on roads looking for parking while ensuring vacancy or availability in parking spots.

Scholars also propose shared parking as another solution to support sustainable parking practices. Businesses may benefit from shared parking as they have more flexibility for their businesses and spaces. The city may also benefit as less land is dedicated to parking, reducing the demand for services and infrastructure.

Scholars and practitioners also recommend establishing a maximum parking ratio, a strategy many European cities use. Also, reducing parking for transit proximity is another innovative strategy that draws on the assumption that commuters will drive less in areas with good transit access. If parking land is optimum, cities may increase their population densities, and thus commuters will be likelier to use transit or non-motorized modes of transportation.

Pricing parking is another effective strategy to reduce cruising and parking congestion. This policy may also benefit cities by generating revenues supporting numerous urban improvements. Revenues can be used to improve neighborhoods or allow green spaces for people and promote sustainable mobility practices. Pricing parking helps compensate for the negative externalities of driving and could foster transportation equity (Rutman et al., 2013). The Twin Cities, Minneapolis, and Saint Paul have examined the potential benefits of eliminating, to some extent, minimum parking requirements. These benefits include improvements in urban design and densities, the mitigation of traffic congestion and air pollution, the revitalization of neighborhoods, and a reduction in the costs of goods and services.

CASE STUDY: SAN FRANCISCO'S PARKING MANAGEMENT PROGRAM

This section examines the benefits and challenges of a pioneer program implemented in the San Francisco Area. In 2017, the San Francisco Municipal Transportation Agency (SFMTA) approved a program to manage parking demand using responsive pricing technology for on-street parking. This program uses state-of-the-art sensors and smart meters in parking lots. The logic behind demand-responsive pricing is that pricing will limit parking supply resulting in the balance between parking supply and demand. Prices fluctuate depending on the parking spots' occupancy rates. Drivers may choose to park in vacant parking spots and walk longer distances to their destinations or pay higher prices for spots in highly occupied locations. This program seeks to estimate the pricing cost to enable sustainable parking behavior properly. Parking management allows cities to efficiently manage parking in congested areas, such as San Francisco's downtown and its landmarks (Pierce and Shoup 2013).

The city of San Francisco first implemented a trial for its parking management program. This trial included seven pilot zones where sensors helped document the occupancy rate of curb parking on each space in all blocks within the zones. Sensors use occupancy variables to estimate variable pricing according to the levels of vacancy and the time of the day. The initial objective was to achieve an average occupancy rate between 60% and 80%. Parking is more expensive as occupancy increases, and the price decreases as occupancy decreases. Parking management allows motorists to make decisions depending on the price and proximity of parking to their destinations.

The implications of San Francisco's demand-responsive parking for mobility

San Francisco's management parking shifted occupancy from high to low in congested areas where drivers park for long periods. This program also contributes to a more uniform and homogenous distribution of parking demand across different neighborhoods rather than excessive or low demand in one area, such as downtown locations. Pierce and Shoup (2013) estimated parking demand price elasticities to examine this program's implications. Their study showed that price elasticities vary according to urban factors. Drivers are likelier to change their driving behavior in the commercial than in residential land use. Also, parking demand is more responsive to the policy in the afternoon than in the morning when changes are insignificant. This is explained by the fact that work and school trips occur in the morning while commuters conduct social recreation trips in the afternoon. Social recreation trips were associated with users of parking management.

Price is another factor that influences the behavioral responses of drivers. Elasticities fluctuate according to changes in prices. One interesting result from the San Francisco parking program is that price elasticities vary across different locations (even adjacent blocks), indicating that other factors besides price influence parking demand. For example, San Francisco's parking program mostly restricts drivers and thus barely affects **low-income commuters** who mostly use transit. Moreover, the San Francisco Transportation Authority uses revenues from the parking management program to support transit, supporting the commutes of low-income residents.

However, one possible challenge with this demand-responsive program is providing real-time data for drivers demanding to park. Another empirically observed issue is disabled placard abuse from users. Technological innovations to monitor compliance may help address this issue. Also, future research should use predictive models that help explain the behavioral responses of drivers to the policy. Furthermore, parking management should understand how parking behavior changes during holidays, celebrations, and parades. For example, the program does not sufficiently consider the increased parking demand during Christmas. The program should therefore consider changes in parking demand throughout the year.

The new San Francisco parking program aims to maintain an occupancy rate of around 80% to mitigate cruising by motorists (Arnott and Rowse 1999). Millard-Ball, Weinberger, and Hampshire (2014) found that the program effectively reduces cruising time. However, drivers can also park in alternative locations that lack metered parking, increasing driving and commuting distances. This occurs when strategic drivers choose to park in areas where parking is more expensive but for shorter periods of time (Glazer and Niskanen 1992). The temporal pattern of cruising also shows that the probability of a block being full and the average cruising time would rise drastically immediately after SF parking operation time. Most price-sensitive drivers delay their arrival until after the operating hours of the SF program.

Another challenge in implementing the program is the emergence of informal parking forms. Future and more comprehensive assessments of the efficacy of the San Francisco Management Program should consider various metrics or variables, including average occupancy in different block sizes and land uses (Millard-Ball, Weinberger, and Hampshire 2014). The San Francisco Management Program has developed a fine-grained database that could allow transportation planners to understand the effectiveness of responsive pricing better. The data can also be used to understand better how the program influences travel behavior and congestion.

CONCLUSION

This chapter unpacks the negative consequences and costs of minimum parking policies and standards in US cities and how they have contributed to sprawl, low-density, car-oriented land development pattern, and induced car trips. The chapter further elaborates on cruising for parking in congested areas as a parking behavior that significantly impacts traffic volumes on different corridors, such as an increase in VMT. This chapter reviews current programs across US cities that have tried reducing minimum parking requirements to free up land and reduce car trips. The case of the San Francisco parking program (SF-Park), which is a demand-responsive parking pricing scheme for on-street parking, shows how these new policies can adjust parking demand and supply, produce more parking vacancy rates, and more.

Glossary

- **Urban sprawl** is the rapid geographic expansion of towns and cities, commonly referred to as sprawl or suburban sprawl, which is typically marked by single-use zoning, low-density residential development, and an increasing reliance on private vehicles for transportation. Metropolitan sprawl is facilitated by the need to accommodate a growing metropolitan population (Rafferty, 2023).

- **Smart growth** focuses on establishing livable, well-designed communities to overcome issues with urban sprawl in urban planning and development. It promotes the preservation of open spaces, compact, walkable communities, effective public transportation, and diverse land uses (Jackson, D., & McGrath, R.,2021, July 15).

Prep/Quiz Questions

- What the notion behind "the cost of free parking" and how minimum parking requirements may affect the urban form and built environment?
- What is the effects of optimum parking pricing and how cruising for parking may be affected by parking pricing?
- Discuss some the alternatives some cities have adopted to reevaluate minimum parking requirements?
- What is a demand-responsive parking management system, and what kinds of built environment and transportation impacts it may have for cities?

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CHAPTER 7.

CASE STUDY V: CALIFORNIA HIGH-SPEED RAIL

CHAPTER OVERVIEW

This chapter critically examines the sustainable mobility benefits and limitations of **high-speed rail (HSR)** systems in European and U.S. cities. This chapter is divided into three sections. The first part examines methodological approaches to assess the costs and benefits associated with high-speed rail (HSR) systems from an environmental perspective. The second part illustrates the city factors that enable a high occupancy and, therefore, economic and ecological efficiency of high-speed rail (HSR) in Europe, reflecting on France's and Germany's experiences. The third part draws on **lifecycle assessment (LCA)** as a comprehensive methodological approach for evaluating the Greenhouse Gas (GHG) mitigation potential of the California High-Speed Rail System under various scenarios of occupancy and use. Finally, this chapter concludes with a critical analysis of California's barriers to implementing and completing an HSR line.

Learning Objectives

- Explore methodological approaches to examine the environmental effects of HSR systems.
- Deconstruct the demand assumptions for the California HSR project and identify considerations that may be the most problematic.
- Identify the barriers to the completion and implementation of the California HSR.
- Assess the challenges and opportunities posed by the California HSR, which may serve as a reference for the Dallas-Houston HSR project.

WHAT IS HIGH-SPEED RAIL?

High-speed rail (HSR) systems have been one of the most prominent transportation technologies in Global North cities over the past fifty years. HSR offers high-quality trips with shorter travel times for millions of passengers worldwide. HSR has been implemented in over 15 countries, including China, Japan, South Korea, China, Taiwan, France, Germany, Italy, Spain, Portugal, Belgium, the Netherlands, Norway, the United Kingdom, Sweden, Denmark, and the United States. Ridership data indicate that an average of 50 million passengers use this transportation system yearly in Europe, increasing by 2.6 since 1981 (Campos & de Rus, 2009). Despite the extensive attention that HSR has received during the past several decades, the viability of this system is still debatable due to its expensive building, maintenance, and operation costs. Thus, HSR systems could not be considered the most sustainable or economically viable transportation option for a country's transport policy. Therefore, it is crucial to investigate the benefits and costs of HSR from an economic, social, and environmental perspective. To better understand HSR and the implementation issues of this transportation technology, this chapter examines the costs and benefits associated with HSR systems. Construction and planning costs are some of the most significant costs associated with high-speed rail infrastructure. In addition, operation and service maintenance costs are other categories of HSR costs.

THE ECONOMIC COSTS OF HIGH-SPEED RAIL SYSTEMS IN EUROPE

Cost-benefit analysis helps planners understand transportation systems' construction, maintenance, use costs, and potential benefits. Factors determining HSR costs include urban city form, land-use values, construction complexity, topography, and urban density. Factors that affect the ridership and occupancy of HSR are influenced by the proximity and accessibility of the stations to dense cities and, thus, high ridership and occupancy. Another factor is the interconnections of HSR with other modes of transportation, such as subways. Scholars concur that one of the most successful systems, from the perspective of cost-benefit analysis, is the French system, followed by the German system. Ridership counts in France and Germany are remarkably high. In Europe, Italy and Spain have the lowest ridership.

A comprehensive understanding of the construction and operating costs for different locations and under various economic conditions will provide a more accurate analysis of the required number of passengers and services to make the HSR a sustainable transportation alternative. In terms of the definition of the high-speed rail system, the European Council Directive explains that the high-speed Infrastructure is of three different lines, including:

- High-speed lines constructed specifically capable of speeds typically equivalent to or more than 250 km/h.
- Conventional lines that have been explicitly improved may travel at 200 km/h.
- Due to geographical relief and town-planning restrictions, specially upgraded conventional lines have unique characteristics. As a result, the speed must be customized for each situation (Campos & de Rus, 2009).

While these definitions provide technical information about the HSR systems, they are insufficient to define the term since speed could change due to factors such as safety and noise control when the train reaches a tunnel or a densely urbanized area. Therefore, defining HSR based on speed alone could be misleading. On the other hand, while HSR and conventional railways are based on similar engineering principles, there are technical differences in building and maintaining high-speed railways. Therefore, the relationship between HRS and the existing traditional services, as well as how these two transportation options may be used, shared, and organized in the infrastructure, determines the economic definition of the HSR system. Accordingly, four different exploitation models based on the relationship between conventional service and HSR are defined by Campos and de Rus (2009):

- Model 1: Exclusive exploitation: Separation between HSR and service. Example: Shinkansen, Japan (1964)
- Model 2: Mixed high speed: High-speed trains run on new or upgraded lines, which helps reduce operating costs. Example: Train a Grande Vitesse (TGV), France (1981)
- Model 3: Mixed conventional: Some trains run at high speed. This model provides flexibility because it allows intermediate high-speed services on some routes. Example: Alta Velocidad Española (AVE)
- Model 4: Fully mixed: Maximum flexibility: high-speed and conventional services run on

each type of Infrastructure. Example: German intercity trains and Rome-Florence's HSR occasionally use traditional lines.

Cost-benefit Analysis of HSR Systems in Europe

Some specific aspects must be considered when building new HSR systems, including technical restrictions, design attributes, and geographic/topographic requirements. According to Campos and de Rus (2009), there are three high costs for building HSR systems' Infrastructure: planning and land costs, infrastructure building costs, and superstructure costs (Campos & de Rus, 2009).

Planning and land costs include various items, such as technical and economic feasibility studies, technical design requirements, land acquisition costs, and other related legal fees (e.g., licenses and permits). While these types of costs differ from project to project, they usually include 5-10% of total costs. The second type of cost is related to preparing the terrain and building the appropriate platform, known as the infrastructure building costs. While generally, these costs will include 10-20% of the total investment in new rail infrastructure, depending on the project characteristics, such as terrain type and price, the need for building bridges or tunnels, as well as other geographical obstacles, may increase these costs up to 40-50% of the entire investment. On the other hand, there is another type of cost called superstructure costs, which are related to rail-specific elements. These costs include guideways, sidings along the line, the signaling system, electrification, communication, and safety installations. Accordingly, superstructure costs represent 5-10% of the total investment in building a new HSR.

Data from a study conducted by Campos & de Rus (2009) shows that the average construction cost per kilometer in their sample of 45 HSR projects (including infrastructure and superstructure costs and excluding the planning and land costs) is about 17.5 million euros (varies between 6 and 45 million euros). Also, their analyses show that the cost of building infrastructure is higher in Asian countries (including Japan, Taiwan, and South Korea, except China) than in Europe.

In Europe, there are two groups of countries regarding HSR systems. First, France and Spain are operating their HSR with lower construction costs; however, these types of fees are identified to be higher in other countries, such as Germany, Italy, and Belgium (Campos & de Rus, 2009). The main reasons for this difference include:

- Geographical and topographical attributes
- The lower population density in certain areas
- Construction processes and characteristics vary from country to country.

There is a positive relationship between population density and building costs; therefore, in European countries where the population density is higher in locations where the HSR is built, the building costs will be much higher. Figure 7.1 provides a general overview of the average price per kilometer of some new HSR infrastructure in different parts of the world.

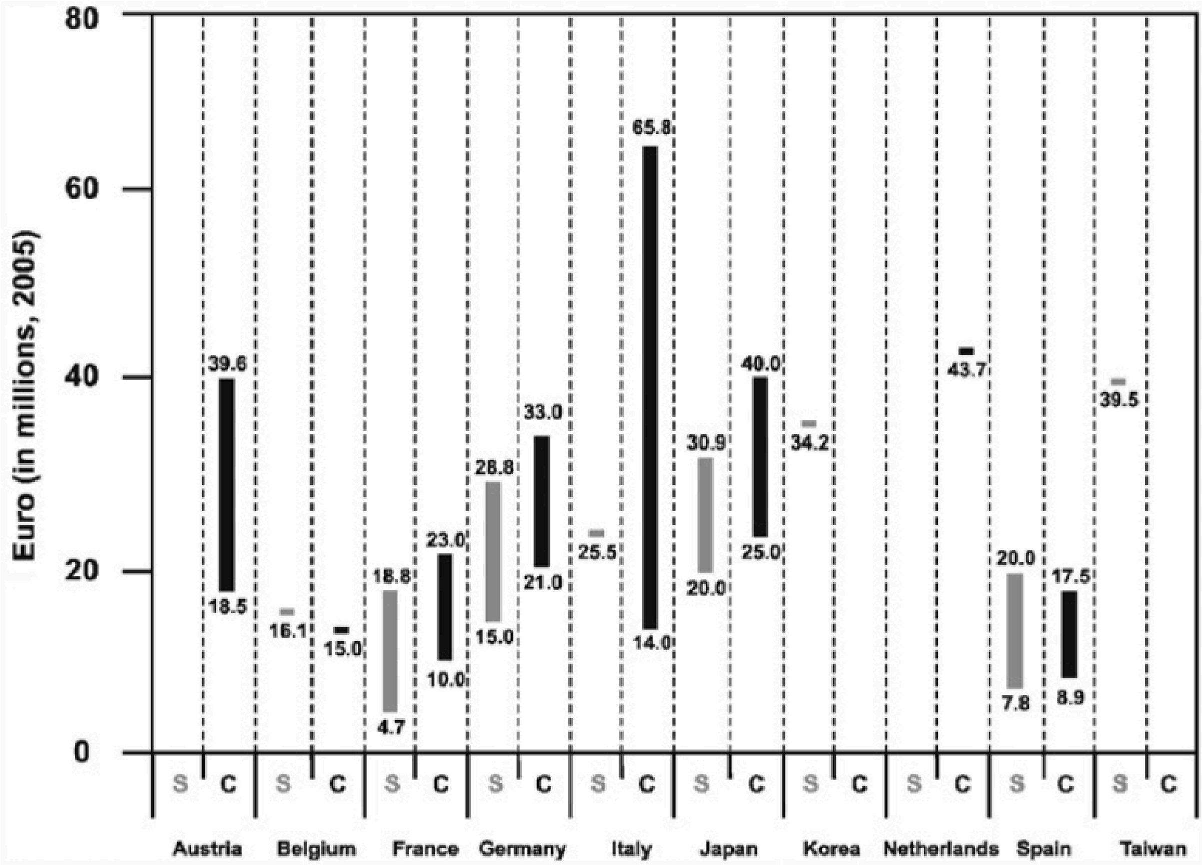

Figure 7.1 Average cost per kilometer of new HSR infrastructure. Notes: S ¼ Lines in Service; C ¼ Lines under Construction (2006), Source: HSR Database. They are elaborated from UIC (2005b). Data exclude planning and land costs. Source: Campos & de Rus, 2009.

Costs: Operating the HSR Systems

Operation costs are mainly categorized into two groups: Infrastructure and rolling stock. Infrastructure operating costs refer to the maintenance and exploitation of infrastructure, while rolling stock and train operating costs are associated with the provision of transportation. In the following part, these two types of fees are described in more detail.

Among the costs categorized as infrastructure operating costs, the most significant are the time, resources, and other materials needed to maintain and run the energy supply, signaling, guideway, terminal, station systems, daily traffic management, and safety systems (Campos & de Rus, 2009). Of the items mentioned as the infrastructure operating costs, some things are fixed expenses related to the safety and technical standards of operating the system; however, some other costs are not fixed, such as infrastructure maintenance (e.g., tracks).

The second category of operating costs of HSR systems is mainly related to transportation systems and trains, known as rolling stock and train operating costs. These costs are categorized into four main groups: shunting and train operations, rolling stock and equipment maintenance, personnel expenses, energy expenditures, and sales and administration (Campos & de Rus, 2009). The mentioned costs will differ for different systems and locations based on many factors, such as the expected traffic level or the technology used for the HSR. For instance, other trains in the Europe HSR network have other technical attributes. Different European countries developed their systems in various ways to best match their specifications and best serve their own countries.

Another cost associated with the operation of the HSR systems is the energy costs (consumption of energy required for trains), which are also different for different trains based on their characteristics. Also, the change in the speed will result in a change in energy costs, and energy increases dramatically when it exceeds 300 km/h. Data shows that the cost of energy for HSR in France is lower than in Germany by about 5%. While the energy source could explain the main reason for this difference (nuclear, cheaper), other factors, such as the organization providing the energy (directly/indirectly), also affect these costs. In addition, to train type and technical aspects, factors such as track-switching (known as shunting), the average period trainsets stay at the depot, train servicing, driving, and safety will also affect the operating costs. Costs related to these factors may also change based on the operational procedures used by different rail operators in other countries.

Costs: External Costs of HSR Systems

Another category of costs associated with HSR is environmental costs, which are noticeable in both infrastructure construction and operation procedures of HSR systems. Items include take-over of land, consequences of barriers, visual obstruction, noise, air pollution, and involvement in global warming (Campos & de Rus, 2009) Are among the highest environmental costs. Regarding environmental costs, HSR is usually compared to other transportation modes. The literature discusses that high-speed rail systems act better than different modes by shifting the traffic from air and roads to rail systems. However, to compare HSR with other modes in terms of pollution, since the sources of energy are different in different countries and there are many other factors affecting it, it is too complex to conclude whether HSR acts better than other modes in pollution emissions. On the other hand, past studies concur that HSR contributes less to air pollution and greenhouse gas emissions than private cars and airplanes (Campos & de Rus, 2009).

Table 7.1 Infrastructure maintenance costs of HSR by country and type of costs

Vehicle	Paris-Vienna	Paris-Brussels
Car	40.2	43.6
Rail	11.7	10.4
Air	28.7	47.5

Source: Campos & de Rus, 2009

The challenges of HSR, a European perspective

Historically, some problems associated with European HSR systems are identified as issues in developing a connected network with an integrated framework between different modes. However, evidence shows that the number and concentration of cities this emerging network serves are increasing. Three main issues have been identified regarding evaluating the HSR network (Vickerman, 1997), including competitiveness, network effects, and corridor development. In addition, the literature identifies three primary reasons for the emerging European HSR, including overcoming the limited capacity of the rail network with a more cost-effective option, increasing speed, and improving accessibility (Vickerman, 1997). Although the development of the HSR network in Europe was supported by the mentioned reasons to solve some of the transportation issues, it is discussed that this system has not achieved its dedicated goals (Vickerman, 1997). On the other hand, the HSR system affects the urban areas in Europe by increasing the concentration of economic activities in their surrounding areas. Therefore, the possible positive and negative economic externalities caused by HSR systems should be considered carefully regarding planning and policy intervention (Vickerman, 1997).

Moreover, the literature discusses some issues and problems associated with HSR systems (Vickerman, 1997). Accordingly, while accessibility and transportation costs could be improved through developing HSRs, these developments will create competitiveness, harming poorer regions since the more affluent areas are more capable of investing in the Infrastructure and benefitting from the advantages.

Besides, it has been discussed that the investment could result in regional growth, not the HSR network. Also, there is an argument that the whole network's quality affects the Infrastructure's effectiveness, so planning plays a critical role.

Therefore, while the significant outcome of HSRs is identified as improving competitiveness and shrinking the size of the geographical area, It is evident that not everyone has had equal and proportionate access to the network. We thus find a considerably more complicated pattern of spatial growth rather than a general shrinkage of area, with big outlying cities with new high-speed rail links benefiting at the expense of minor centers in more central regions. On average, Europe may become more competitive, but the impact on cohesiveness is considerably harder to foresee (Vickerman, 1997).

THE ECONOMIC IMPLICATIONS OF HSR FOR CITIES

While high-speed rail seeks to be a comfortable, safe, flexible, and environmentally sustainable mode of transport with environmental performance and socio-economic benefits, data reveals that the cost-efficiency (assessing construction costs, delays, cost overruns, and the use of high-speed lines) analysis indicates that the E.U.'s current long-term plan is unlikely to be achieved, and lacks a solid EU-wide strategic approach (European Court of Auditors, 2018).

The HSR network has not achieved many of its objectives, according to a European Court of Auditors assessment, despite significant expenditures made by the European system over the previous 20 years. The main shortcoming is the absence of an efficient network connecting various national lines. Sadly, this is because Commission lacks the legal tools and the authority to compel Member States to build lines as agreed. (European Court of Auditors, 2018).

The cost-efficiency analysis is a practical assessment to examine the viability of an HSR network.

The need for HSR is not the same in all places. Despite the positive perception of commuters towards HSR, European cities use only 45% of the capacity of HSR systems. As a result, operating and maintenance expenses could be higher than revenues. As a result, the European HSR's cost-effectiveness is under doubt. Additionally, there is a discussion about the HSR's sustainability in Europe, where it is said that this system is not as sustainable as anticipated. According to data, three of the seven finished lines have low passenger volumes, which leads to inefficient investment and a lack of system sustainability. Furthermore, nine of the 14 lines have minimal ridership, furthering Europe's HSR system's inefficiency (European Court of Auditors, 2018).

The HSR system is expensive not only in construction but also in maintenance. Accordingly, the average cost of constructing or maintaining one km (not considering the more costly tunneling projects) is about 25 million euros (European Court of Auditors, 2018). The cost increases dramatically by increasing the speed since the Infrastructure of the rails that tolerates very high speed is far more expensive; however, very high speed is not needed at all the locations that have been constructed. This factor has made the European HSR system particularly costly. Furthermore, although the number of HSR users has steadily grown since its emergence, there are still issues with low numbers of passengers, making some HSR systems unsustainable and generally ineffective. Data shows that "from roughly 15 billion passenger kilometers (PKM) in 1990, demand reached more than 124 billion PKM in 2016" (European Court of Auditors, 2018). Furthermore, data shows that about half of the funding provided by the E.U. co-funding for high-speed rail in Europe has been invested in Spain.

Another issue that significantly affects the efficiency of the HSR systems is the time gap between planning, constructing, and operating the system. In the case of European HSR, the average time from the start of work to the beginning of operations is around 16 years (Table 7.2). This time gap can increase significantly if the Infrastructure builds tunnels (European Court of Auditors, 2018).

Audited high-speed rail lines and Munich-Verona stretch	Planning started	Work started	In operation*	Years since planning	Duration of work in years
Berlin - Munich	1991	1996	2017**	26	21
Stuttgart - Munich	1995	2010	2025*	30	15
Rhin - Rhône	1992	2006	2011	19	5
LGV Est Européenne	1992	2002	2016	24	14
Madrid - Barcelona – French Border	1988	1997	2013	25	16
Eje Atlántico	1998	2001	2015	17	14
Madrid - León	1998	2001	2015	17	14
Madrid - Galicia	1998	2001	2019*	21	18
Milan - Venice	1995	2003	2028*	33	25
Turin - Salerno	1987	1994	2009	22	15
Munich - Verona	1986	2003	2040*	54	37

* Expected.

** 52 km not before 2018.

Table 7.2 Assessment of time from planning to operation

Source: European Court of Auditors, 2018

The European HSR system has been criticized for lacking a reliable cost-benefit analysis in the initial decision-making process. Transportation planners argue that 1) The expensive Infrastructure has been constructed in many locations where there is no need for high-speed rail, and 2) The cost-efficiency checks are not conducted regularly during construction and operationalization. Moreover, while HSR and conventional rail systems are expensive to build and maintain, HSR costs are significantly greater than traditional rail systems. Due to the potential for considerable cost savings, modifying existing lines to boost speed rather than establishing a very high-speed line should also be considered. (European Court of Auditors, 2018).

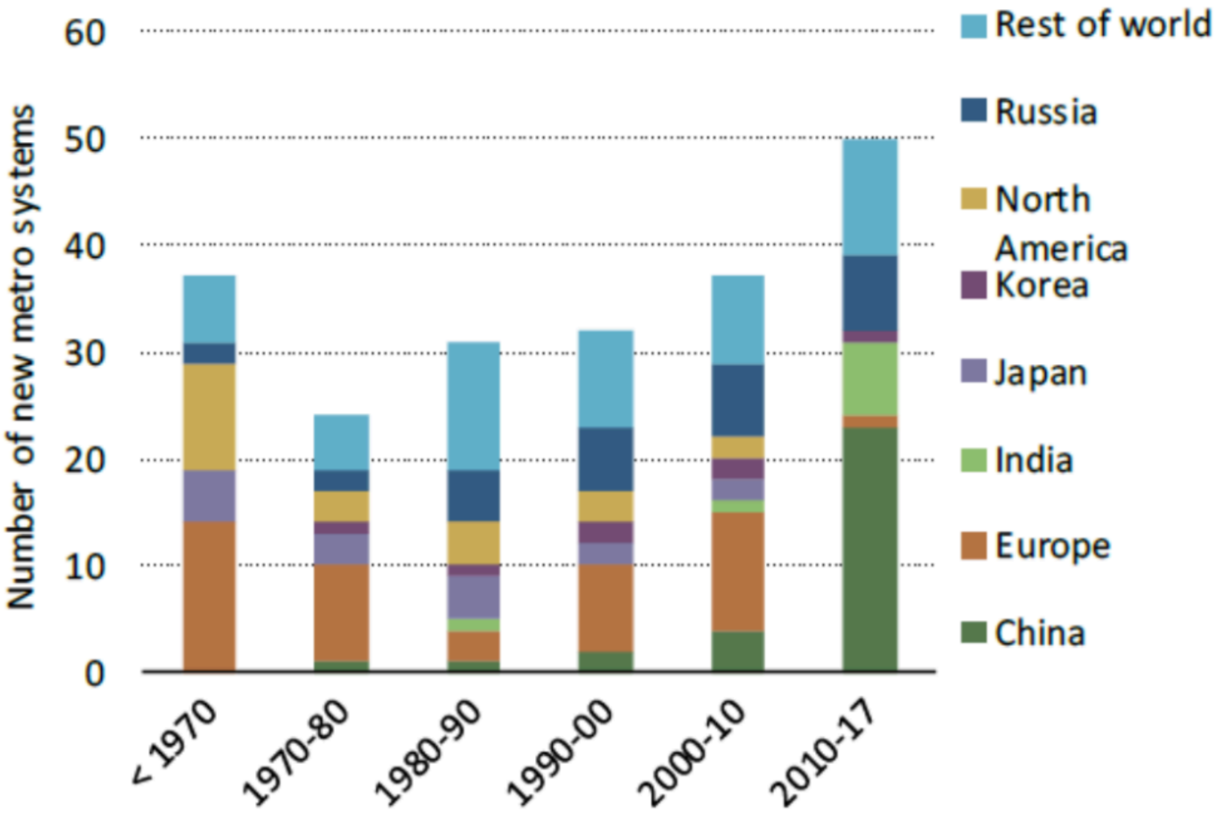

Figure 7.2 Overview of E.U. co-funding for HSR by member states between 2000 and 2017. (Source: European Court of Auditors, 2018)

This paper concludes that while HSR systems are advantageous in many ways, the European system lacks a thorough and long-term plan for cost-effectiveness and investments. It also brings up the concern that the long-term viability of the E.U.'s co-funding of high-speed lines is in jeopardy. Furthermore, cross-border construction should be streamlined since seamless and competitive cross-border high-speed rail operations remain a way off (European Court of Auditors, 2018).

Broader Panorama of the Recent, Rapid Expansion of HSR in Asian Cities

Asian nations began implementing the HSR system in the 1960s, with Japan being the pioneer in integrating it into its national transportation network. Japan opened its first high-speed rail link between Tokyo and Osaka in time for the 1964 Olympics (James, 2009). However, this situation has changed over the past 50 years, with India and China expanding more of the HSR networks in their transportation system and Japan stopping the expansion of this system. The following figure (Figure 7.3) shows how the growth of the HSR system has changed during the past 50 years worldwide. Note how, while the HSR expansion has experienced a meager rate in Europe, the number of new metro systems has dramatically increased in China after 2010.

During the past two decades, rapid development has happened in China's HSR network, and China is surpassing the rest of the world in terms of expanding its HSR system. This rapid development has resulted from the enormous funding from the Chinese government (Nunno, 2018). While the planning phase for China's HSR started in the early 1990s, the system did not withdraw its operation until 2008. HSR trains in China cover speeds between 250-350 km/h, and By 2025, the network is anticipated to be over 38,000 km, and by 2035, it will be around 45,000 km. (Nunno, 2018). This length of HSR networks in China is more than all HSR network mileage in the rest of the world. Accordingly, China's HSR is the most extended network globally and is reported to be the most extensively used network globally. The length of the HSR network in China was already about 37,900 km by the end of 2020 (Xinhua, 2021). Thus, China's HSR has been profitable for the government. China's most profitable high-speed rail line connects Beijing to Shanghai, two major economic zones in China. Thai Line reported over $1 billion in net operating profit in 2015 (Nunno, 2018).

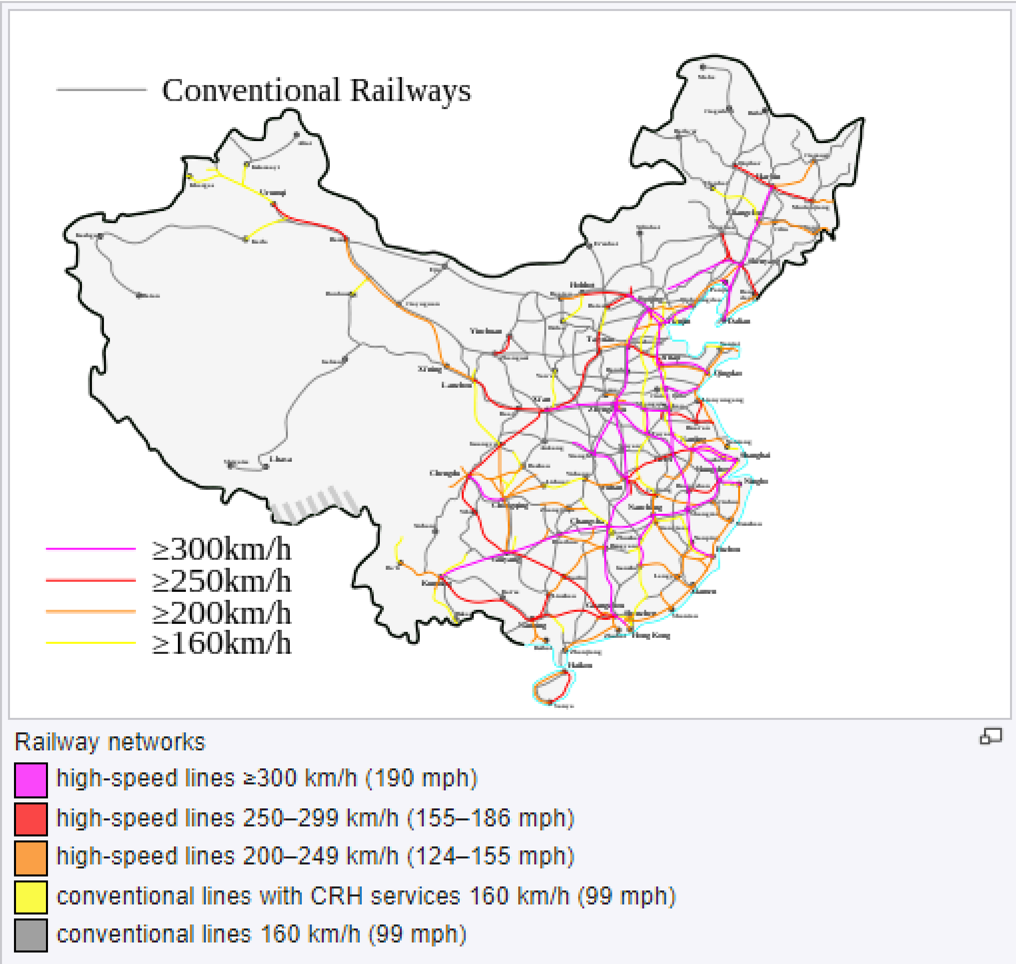

Figure 7.3 The conventional and HSR network in China by speed Source: https://en.wikipedia.org/wiki/High-speed_rail_in_China, [Public Domain]

The HSR system in China has drawn criticism, most notably that it is not cheap for the majority of citizens. The Chinese government, in response, claims that the HSR has boosted economic productivity and competitiveness over time and is a quick and dependable form of transit in some of the most densely inhabited places. Additionally, it has been stated that the Chinese HSR system is more energy-efficient and promotes energy independence since it uses fewer resources to convey people and commodities on electric trains (Nunno, 2018). Data shows that due to the expansion of HSR in China, domestic airlines were obliged to lower rates, halt specific shorter intercity routes, and cancel regional flights, particularly those under 500 km. As a result, more people currently travel by high-speed rail in China than by domestic airplanes (Nunno, 2018).

ENVIRONMENTAL IMPACT ASSESSMENT OF THE CALIFORNIA HSR

The California HSR (CHSR) system aims to connect the metropolitan areas and mega-regions of the state. In addition to providing a more convenient and faster transportation mode as the primary goal, the California HSR is claimed to contribute to creating jobs, a cleaner environment, and preserving agricultural and protected lands (hsr.ca.gov, 2021). The first phase of the network will connect Los Angeles to San Francisco. This trip will be under three hours by train traveling 200 miles per hour. The second phase will extend the network to Sacramento and San Diego. The California HSR will cover 800 miles and pass through 24 stations (hsr.ca.gov, 2021). The following map provides an overview of the California HSR network, the lines, and the stations included in this network (Figure 7.4). Accordingly, the time to travel between the significant mega-regions using the HSR system in California is shown in the following table (Table 7.3).

Table 7.3 Travel time between cities in California through HSR

San Francisco – Los Angeles Union Station	**2 Hours and 40 Minutes**
Oakland – Los Angeles Union Station	2 Hours and 40 Minutes
San Francisco – San Jose	30 minutes
San José – Los Angeles	2 Hours and 10 Minutes
San Diego – Los Angeles	1 Hour and 20 Minutes
Inland Empire – Los Angeles	30 Minutes
Sacramento – Los Angeles	2 Hours and 10 Minutes

Source: hsr.ca.gov, 2021 – California High-Speed Rail Authority.

The California high-speed rail is a publicly funded project and is under construction. In 2008, the voters agreed on the planning, construction, and implementation of the CHSR. The structure of CHSR began in 2016, and since then, there have been numerous active construction sites, with more anticipated each year (hsr.ca.gov, 2021). According to the Build HSR California, The California High-Speed Rail Authority's November 2021 Construction Update highlights the progress on the nation's first high-speed rail project. With more completed projects and significant advancement on others, there is steady progress across all high-speed rail construction packages from Madera to Wasco (buildhsr.com, 2021). However, the construction of the CHSR has experienced a slow process and many delays due to different reasons, including technical issues, political-related issues, funding issues, and, more recently, the impact of the COVID-19 pandemic in 2020 and 2021 (constructionreviewonline.com, 2021; Manata, 2021).

On the other hand, the CHSR has been discussed as not being entirely successful. It has been argued that the project suffers from management turmoil, problems with procuring land, funding, budgeting, and engineering issues, and is far behind schedule. Currently, 119 miles of right-of-way are under construction in the Central Valley. Still, an additional 52 miles are necessary to extend the system to Merced and Bakersfield to make an influential HSR system segment (hsr.ca.gov, 2021). The following map (Figure 7.5) details the project's status (as of April 2021).

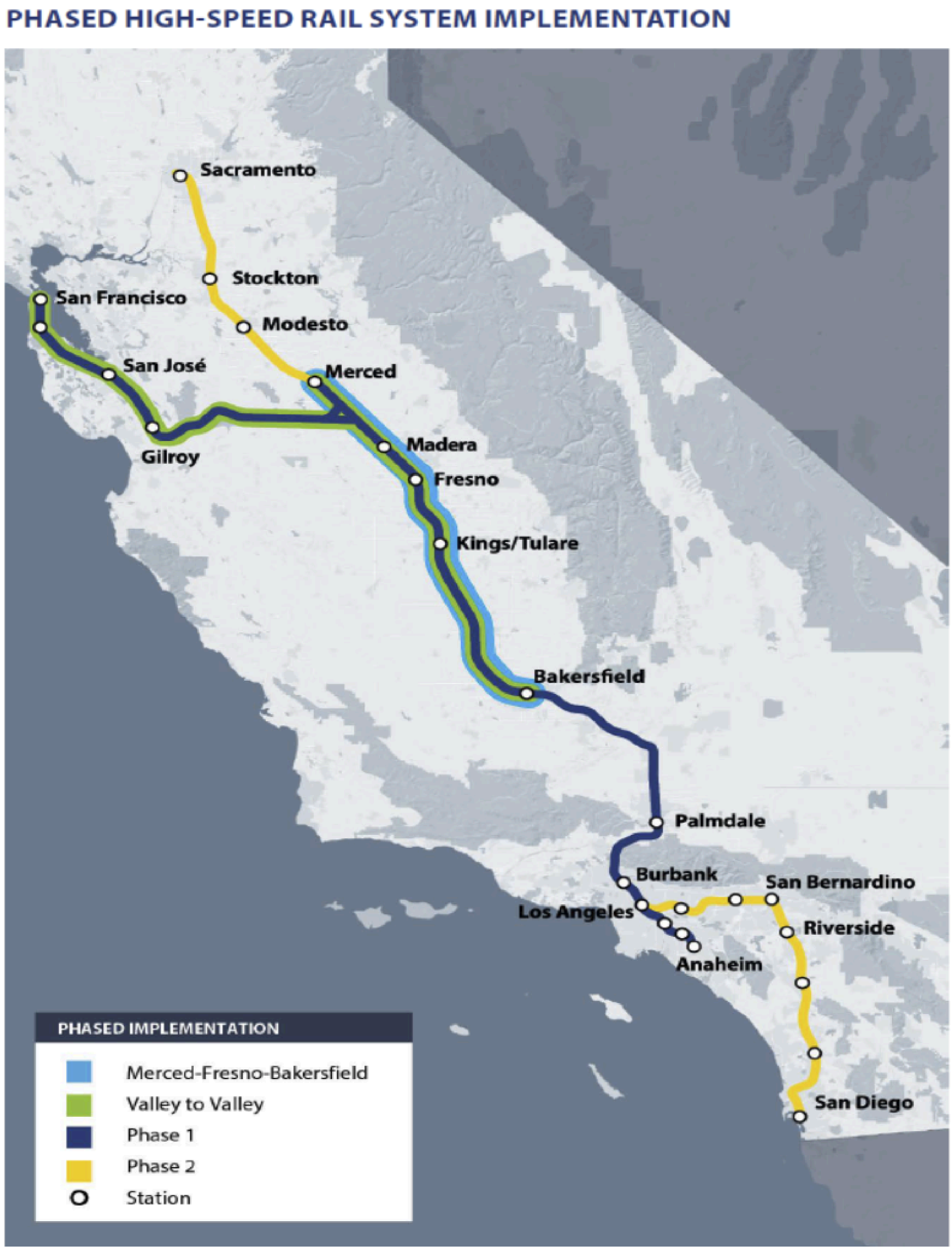

Figure 7.4 California HSR system implementation and stations by phase Source: hsr.ca.gov, 2021 – California High-Speed Rail Authority, Public Domain

Figure 7.5 California HSR project status, April 2021, Source: Shannon1 – Own work, [CC BY-SA 4.0](), [https://commons.wikimedia.org/w/index.php?curid=103645672.]()

Therefore, the Merced-Bakersfield line will become the first HSR line in the U.S. This segment of the CHSR, known as Phase 1-section one, covers 65 miles of the whole CHSR network and will be operational by 2029 (builhsr.com, 2021). This section of the network is highlighted in blue in Figure 7.5. One of the primary debates/critiques of the HSR is that the first phase, which connects Merced to Bakersfield, is low-density and does not connect important cities. Therefore, the prospects of occupancy are pretty low. This situation may be a lousy antecedent for completing the whole system. The following table (Table 7.4) provides a detailed overview of all stations in phase 1 of the CHSR project, their status, and expected completion date.

Phase 1 [edit]

All stations in this table represent proposed service. Station names in italics are optional stations that may not be constructed. In most cases existing stations will be re-purposed for high-speed rail service, with the exception of completely new stations

Station	Location	Status	Completion[34]	Connecting rail services
Transbay Transit Center	San Francisco	Existing, train station and connecting tunnel unfunded	postponed	Caltrain (BART, E Embarcadero, F Market & Wharves, Muni Metro via pedestrian tunnel)
San Francisco–4th and King Street		Existing, modifications needed	2031	Caltrain, Muni Metro, E Embarcadero
Millbrae Intermodal Terminal	Millbrae	Existing, modifications needed		BART, Caltrain (AirTrain (SFO) via BART)
Diridon Station	San Jose	Existing, modifications needed		ACE, BART, Caltrain, Capitol Corridor, Coast Starlight, VTA Light Rail
Gilroy	Gilroy	Planning agreement in place		Caltrain
Merced	Merced	Planning agreement in place	2029 (CVS)	ACE, San Joaquin (train)
Madera	near Madera Community College Center	Planning agreement in place		San Joaquin (train)
Fresno	Fresno	Planning agreement in place		San Joaquin (train)
Kings–Tulare Regional Station	near Hanford			Cross Valley Corridor *(planned)*
Bakersfield	Bakersfield	Planning agreement in place		San Joaquin (train)
Palmdale Transportation Center	Palmdale	Planning agreement in place	2033	Metrolink, Brightline West *(planned)*
Hollywood Burbank Airport	Burbank	Planning agreement in place		Metrolink
Los Angeles (Union Station)	Los Angeles	Existing, modifications needed		Coast Starlight, Metro, Metrolink, Pacific Surfliner, Southwest Chief, Sunset Limited, Texas Eagle
Norwalk–Santa Fe Springs	Norwalk	Optional, no decision made		Metrolink, Metro *(planned)*
Fullerton	Fullerton			Metrolink, Pacific Surfliner
Anaheim (ARTIC Station)	Anaheim	Existing, modifications needed	postponed	Metrolink, Pacific Surfliner

Note: The California High-Speed Rail Authority considered a mid-peninsula station in Redwood City, Mountain View, or Palo Alto, but it was removed from the business plan in May 2016 due to low ridership projections, although the possibility was raise

Table 7.4 Stations, status, and expected completion date for phase 1 of California HSR,

Source: https://buildhsr.com/construction-updates/

California high-speed rail: A Lifecycle Assessment of environmental impacts

The decrease in fuel usage and, thus, GHG emissions is one of the debatable advantages of HSR. The majority of environmental impact evaluations, however, only look at the usage phase and ignore the environmental effects of building infrastructure. More significantly, these ecological effects presumptively reflect high occupancy rates for HSR. This presumption can be incorrect and harmful. Therefore, an environmental impact assessment requires a thorough analysis and evaluation of the lifecycle phases connected with transportation systems, including the HSRs, to understand how the HSR helps reduce fossil fuel consumption and air pollution. As a result, we focus on the Lifecycle Assessment (LCA) method in this section to better understand how California HSR affects the environment. Therefore, we use Chester and Horvath's (2009) work Lifecycle Assessment of High-Speed Rail: The Case of California. LCA, a thorough methodological approach, is used by Chester and Horvath (2009) to assess the environmental effects of HSR and contrast it with other forms of transportation. They cover all these environmental effects, including building, usage, and upkeep.

The development and investment of the HSR system require careful consideration of many factors, including technological, social, economic, and environmental choices. For instance, California HSR (CHSR) is a sizable project that has received significant funding. As a result, there has always been discussion about how efficient the system is; but in recent years, this discussion has been increasingly focused on energy and environmental choices. Environmental evaluations frequently compare the energy consumption per trip, GHG emissions, and other emissions of various modes of transportation (auto, heavy rail, and airplane) by considering vehicle operation. To enable policymakers to analyze both the direct consequences of vehicle operation and the indirect effects of the cars, Infrastructure, and fuel consumption, the environmental evaluation should comprise various methods. Although high-speed rail has the potential to be the least energy- and greenhouse gas-intensive mode of transportation, sustaining high occupancy would need careful planning and ongoing investment.

Environmental trade-offs might also happen. High-speed rail, for instance, might reduce energy use and greenhouse gas emissions per journey. However, the existing electrical mix may increase "SO2" emissions, negatively affecting human health and environmental acidification (Chester & Horvath, 2010).

Investing in CHSR will result in a higher and better level of passenger service and reduce door-to-door travel time and travel costs. Accordingly, the following figure (Figure 7.6) shows the door-to-door travel time between downtown San Francisco and downtown Los Angeles based on the modality. However, many scholars and critics argue that such a new system's final and actual outcomes could differ from what it is expected to deliver (Chester & Horvath, 2010). When considering the improvements of HSR in lowering travel time, travel cost, GHG emissions, and energy consumption, the lifecycle components beyond the electricity needed to move vehicles and their corresponding emissions are not considered (Chester & Horvath, 2010). Thus, considering other emissions sources, such as manufacturing and maintaining the cars and infrastructure construction and maintenance, is essential. To assess the environmental tradeoffs of the CHSR, a lifecycle perspective against other modes should be considered and evaluated so that all environmental impacts and associated costs would be apparent to policymakers (Chester & Horvath, 2010).

Figure 7.6 Door-to-door travel time between downtown San Francisco and downtown Los Angeles by mode.
Source: https://www.eesi.org/papers/view/fact-sheet-high-speed-rail-development-worldwide.

Regarding the factors that need to be captured by the lifecycle assessment, Chester and Horvath (2010) mention that energy inputs and emission outputs for all three categories of vehicles, Infrastructure, and fuel production should be considered. Therefore, we could evaluate critical components for each type, including construction/production, use/operation, maintenance, and end-of-life aspects. This article, thus, argues that the existing environmental assessments of HSR primarily focus on the direct effects of electricity use and corresponding power plant emissions from train functional operation energy requirements. They do not consider other factors that may indirectly affect the environmental assessments of the HSR systems. The following table provides a comprehensive understanding of what should be considered in the LCA. Specifically, Table 7.5 indicates three sections: the lifecycle components (operation, manufacturing, and maintenance by mode), the infrastructure components by methods, and the fuel components.

Component	Automobiles	Rail	Aircraft
		Vehicle components grouping	
Active operation	Running Cold start	Running (propulsion)	Take off Climb out Cruise Approach Landing
Inactive operation	Idling	Idling Auxiliaries (heating, ventilation, air conditioning, and lighting)	Auxiliary power unit operation Startup Taxi out Taxi in
Manufacturing (facility construction excluded)	Vehicle manufacturing Engine manufacturing	Train manufacturing	Aircraft manufacturing Engine manufacturing
Maintenance	Vehicle maintenance Tire replacement	Train maintenance Train cleaning Flooring replacement	Aircraft maintenance Engine maintenance
Insurance	Vehicle liability	Crew health and benefits Train liability	Crew health and benefits Aircraft liability
		Infrastructure components grouping	
Construction	Roadway construction	Station construction Track construction	Airport construction Runway/taxiway/tarmac construction
Operation	Roadway lighting Herbicide spraying Roadway salting	Station lighting Escalators Train control Station parking lighting Station miscellaneous (e.g., other electrical equipment)	Runway lighting Deicing fluid production Ground support equipment operation
Maintenance	Roadway maintenance	Station maintenance Station reconstruction Station cleaning Track maintenance	Airport maintenance
Parking construction and maintenance	Roadside, surface lot, and parking garage parking	Station parking	Airport parking
Insurance	Infrastructure benefits and liability (e.g., automechanics and construction workers)	Non-crew health insurance and benefits Infrastructure liability insurance	Non-crew health and benefits Infrastructure liability
		Fuel components grouping	
Gasoline, diesel, jet A, and electricity production	Gasoline and diesel fuel refining and distribution (includes through fuel truck delivery stopping at fuel station. Service station construction and operation is excluded)	CAHSR operational electricity generation upstream requirements HRT diesel fuel extraction, transport, refining and distribution CAHSR electricity transmission and distribution losses CAHSR and HRT infrastructure electricity generation upstream requirements CAHSR and HRT infrastructure electricity transmission and distribution losses	Jet fuel refining and distribution

Table 7.5 Lifecycle components included in modal inventories

Source: Chester & Horvath, 2010.

In addition, another critical factor when performing environmental assessments is the rates and the patterns of using different transportation modes. Data shows that in California:

- Vehicles: 90% of trips and 75% of passenger kilometers traveled (PKT)
- Heavy Rail Transit (HRT): 1% of journeys and 1% of the PKT
- Air: 9% of trips and 24% of PKT

There is uncertainty regarding the ridership estimates and occupancy rates in any group of transportation modes. For instance, trains may have 650-1200 seats depending on the ridership forecasts and train characteristics. Furthermore, the system's potential energy and environmental performance will change significantly depending on the range of ridership.(Chester & Horvath, 2010). Therefore, when evaluating the lifecycle environmental performance of the CHSR system, we need to consider both the low and high occupancies with their corresponding PKT. Furthermore, the soft and high occupancy rates should also be compared for all modes, including automobiles, HRT, and aircraft. Therefore, realistic ridership numbers are applied to capture the potential occupancy ranges (Chester & Horvath, 2010). The following table overviews ridership estimates based on high and low occupancy rates.

Table 7.6 Ridership Estimates and occupancy uncertainty

Occupancy	1200 pass/train	Five seat-car	120 seat-airplane
High	1200 (100% occupancy)	Five passengers	81 passengers
Low	120 (10%)	One passenger	24 passengers

Source: Chester & Horvath, 2010.

Figure 7.7 shows each mode's lifecycle energy and emissions performance at low and high occupancy. Because the environmental performance is spread among many passengers, the per-PKT energy and emissions are at their lowest during periods of high occupancy. (Chester & Horvath, 2010)

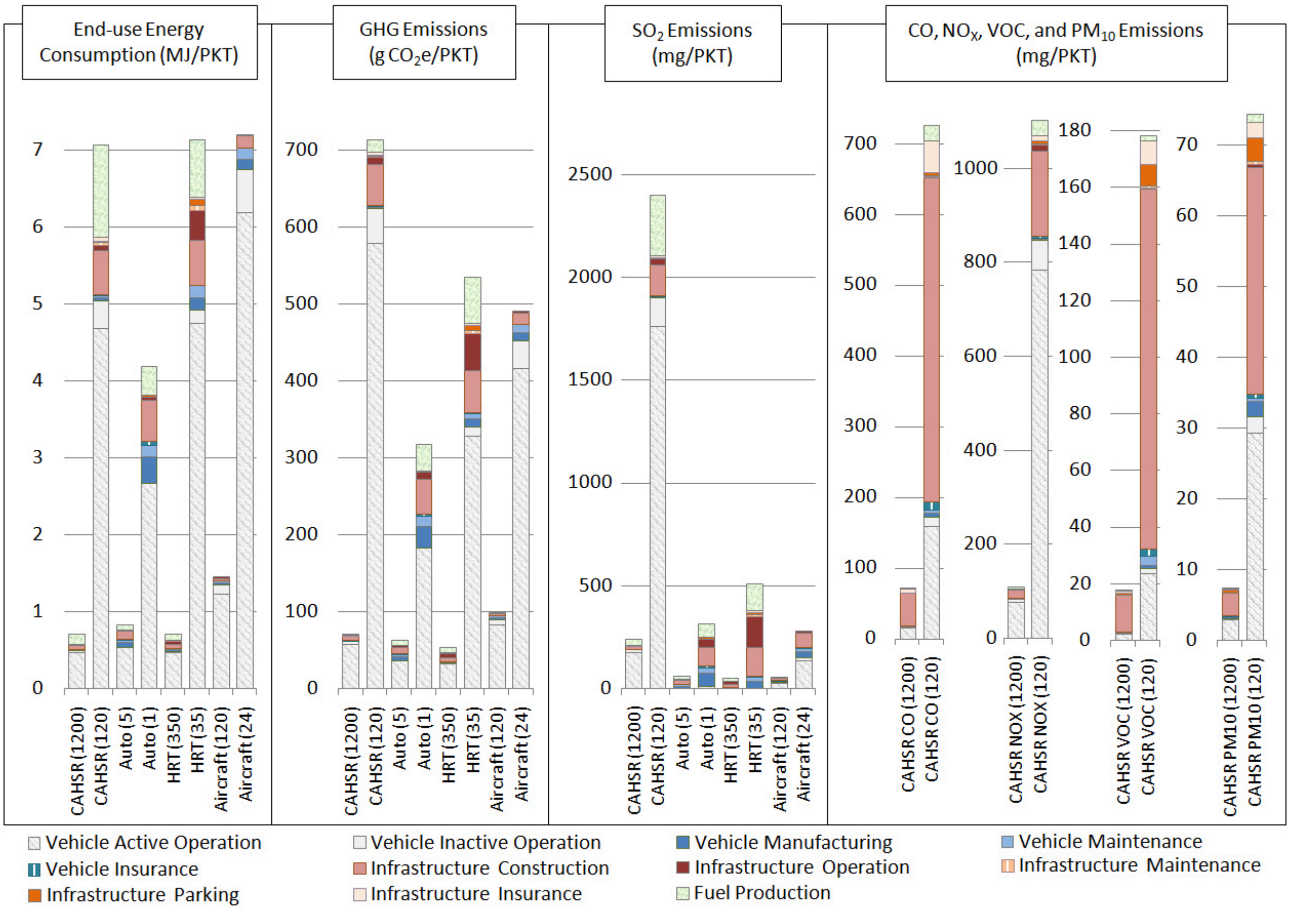

Figure 7.7 Energy and emissions lifecycle results per PKT for each mode, Source: Chester & Horvath, 2010.

The consensus is that spending money on a new HSR system will lower transportation energy use and greenhouse gas emissions. However, these advantages may only be realized under specific conditions since several factors impact the HSR system. Therefore, breakeven points demonstrating the degree of utilization at which the modes compete may be determined by assessing the energy consumption and GHG emissions of the four methods from low to high occupancy. The following figure (Figure 7.8) shows the range in energy consumption and GHG emissions per PKT as vertical bars. Figure 2 illustrates the possibility for improvement, even if a mode may not be as ecologically beneficial as another mode at average occupancy. For instance, filling vacant seats for a journey that will take place regardless might enhance the environmental performance of the way at a possibly lower cost and resource investment than alternatives. Some methods also have much greater occupancy levels than others (Chester & Horvath, 2010).

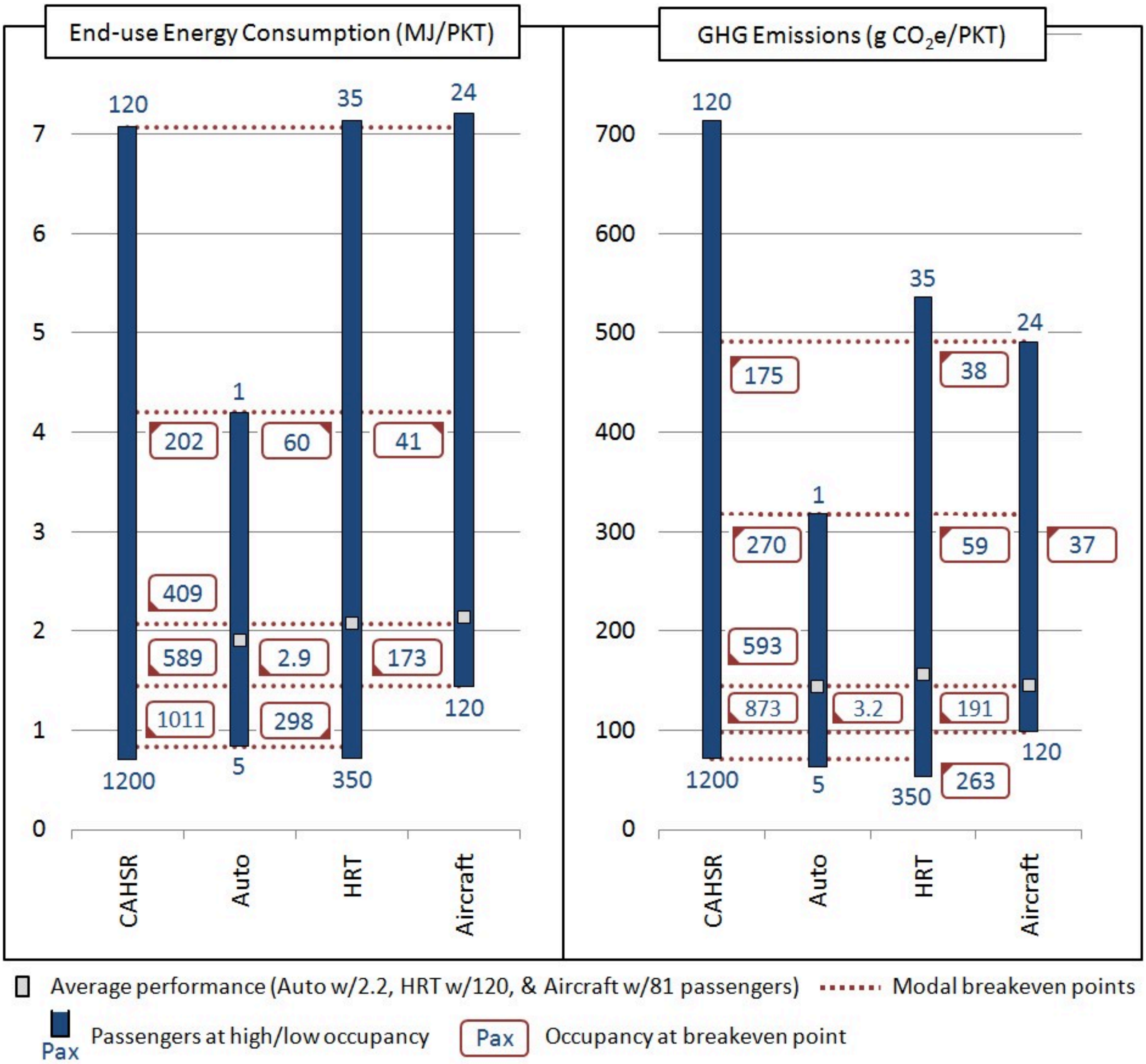

Figure 7.8 End-use energy consumption and GHG emission passenger equivalencies
Source: Chester & Horvath, 2010.

The following table (Table 7.7) shows the rates of investment return based on different modes in three categories: low occupancy, medium occupancy, and low occupancy.

	Automobiles, HRT, and air at low occupancy, CAHSR at high occupancy	Automobiles, HRT, and air at high occupancy, CAHSR at low occupancy	Automobiles, HRT, and air at mid-level occupancy, CAHSR at mid-level occupancy
CAHSR loading	75%	25%	50%
Automobile passengers	2	2.5	2.25
HRT loading	25%	75%	40%
Air loading	50%	90%	85%
CAHSR energy ROI	8 years	Never	28 years
CAHSR GHG ROI	6 years	Never	71 years

Table 7.7 Modal usage assumptions and outcomes for return on investment. (Note: Loading denotes the percentage of seats filled.)

(Chester & Horvath, 2010)

In addition to energy and GHG emissions, the impacts of releasing other emissions should be considered when performing environmental assessments for HSR systems. For example, according to what was discussed in this section, California HSR may have lower GHG emissions under occupancy rates and conditions. "Occupancy ranges are highlighted instead of average ridership to stress the broad range in the environmental performance of the modes. Moreover, the accessibility and frequency of service are two important factors affecting potential CAHSR ridership" (Chester & Horvath, 2010).

LCA is the most comprehensive methodological approach to measure GHG because it considers the construction, maintenance, and operation of transportation systems and the use phase. The driving factor in environmental impact assessments is the occupancy rate. A high use rate is suitable for mitigating GHG emissions, and low use rates mean adverse ecological impacts.

HOUSTON-DALLAS HSR

Data shows that among all states in the United States, Texas has the highest rate of GHG emissions, and most of this emission rate refers to transportation. After considering the positive impacts of HSRs and knowing that the Houston-Dallas corridor is the busiest route in Texas, developing and implementing a high-speed rail system to connect these two mega-regions in Texas have become a widely discussed solution in recent years. However, as discussed in the previous section, to comprehensively understand the actual environmental impacts of HSRs, we need to provide a lifecycle assessment of the Houston-Dallas HSR. Therefore, we inform this section by referring to the article Lifecycle Environmental Impact of High-Speed Rail System in the Houston-Dallas I-45 Corridor by Chipindula et al. (2021).

According to the analysis done by Chipindula et al. (2021), Infrastructure is the most critical category in emissions when doing the lifecycle process, with more than 80% of the total emissions in all types (Table 7.8). On the other hand, the impact of vehicle emissions is almost insignificant (a minimal amount of emissions) when compared to Infrastructure. In addition, all three categories of infrastructure construction, vehicle material processing, and operation phase use large volumes of diesel and gasoline to operate equipment, contributing to the negative environmental impacts caused by fossil fuel use. Figure 7.8 shows the analysis of the cumulative energy demand for two main categories, Infrastructure and vehicle (LCA of Houston-Dallas HSR).

Emissions (VKT/year)	Unit (millions)	Total	Vehicle	Infrastructure
Carcinogens	kg $C_2H_3Cl_{eq}$	600	7.09	593
Non-carcinogens	kg $C_2H_3Cl_{eq}$	1026	11.28	1015
Respiratory inorganics	kg $PM_{2.5eq}$	142	8.26	133
Ionizing radiation	Bq C-14_{eq}	711072	36587	674485
Ozone layer depletion	kg CFC-11_{eq}	3.73E-03	5.37E-05	3.67E-03
Respiratory organics	kg C_2H_{4eq}	93.13	0.13	93.00
Aquatic ecotoxicity	kg TEG water	3515678	78123	3437555
Terrestrial ecotoxicity	kg TEG soil	1226840	18452	1208388
Terrestrial acid/nutri	kg SO_{2eq}	918	21.0	897
Land occupation	m^2org.arable	2966	3.96	2962
Aquatic acidification	kg SO_{2eq}	293	7.33	285
Aquatic eutrophication	kg PO_4 P-lim	26.2	1.00	25.2
Global warming	kg CO_{2eq}	50438	1960	48478
Non-renewable energy	MJ	674094	27437	646658
Mineral extraction	MJ	8224	21	8203

Table 7.8 Life cycle HSR system emissions by midpoint characterization (20-year operation)

Source: Chipindula et al., 2021.

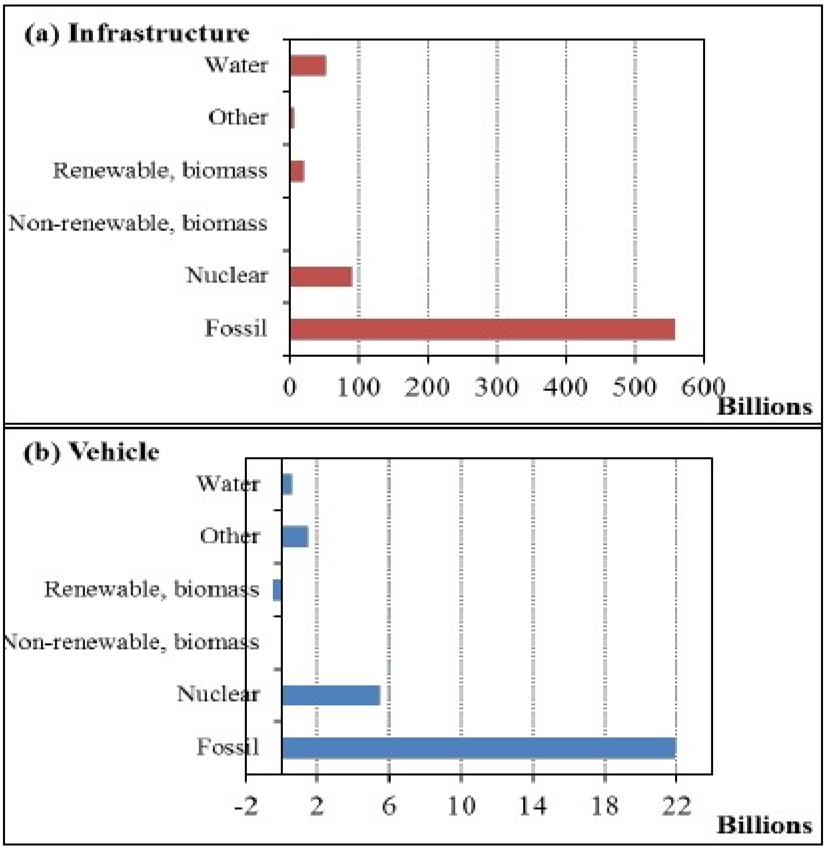

Figure 7.9 Analysis of cumulative energy demand for (a) infrastructure; and (b) vehicle. Source: Chipindula et al., 2021

The findings of this analysis indicate that, throughout the 20-year design life of the HSR system, total GHG emissions from the lifespan of the vehicles would be 9.695 kgCO2eq/VKT, with the principal source of GHG emissions—the use of fossil fuels during vehicle operation—accounting for 97% of the GHG emissions. Total lifetime GHG emissions for the Infrastructure would be 239 kgCO2eq/VKT, of which 94% are attributable to the building. With a cumulative effect of 58% across all damage categories, Infrastructure is the primary source of end-point impacts on the human health category (Chipindula et al., 2021).

CONCLUSION

This chapter examines the high costs of implementing, building, and operating High-Speed Rail Systems in European countries. Prices vary according to countries' existing transportation infrastructure, urban form, and interconnection with other transportation modes, such as subway or light-rail systems. Importantly, this chapter critically examines, drawing from the principles of lifecycle assessment, the implications of California HSR. According to Chester and Horvath (2010), the environmental benefits of HSR in terms of GHG mitigation potential will depend on the system's ridership. This reveals the importance of ridership for successfully implementing HSR in U.S. Cities. In addition, an interconnected HSR in highly urbanized and populated areas may increase ridership.

Glossary

- **Cost-benefit analysis** is a methodical methodology to assess the financial viability of proposed projects or policies. It entails weighing the costs of carrying out a certain project or policy against the potential benefits to society. The objective is to decide if the project or policy is worthwhile to pursue and whether the benefits exceed the costs. (Investopedia, August 26, 2021)
- **High-speed rail** is a passenger rail transportation that travels much faster than other rail traffic. The European Union has established specific parameters, such as 200 km/h (120 mph) for modified tracks and 250 km/h (160 mph) or faster for new routes. (https://railsystem.net/high-speed-rail)
- **Life-cycle assessment (LCA)** is a methodology for assessing environmental impacts associated with all the life cycle stages of a commercial product, process, or service. (Khadour, 2011)

Prep/Quiz Questions

- What can transportation planners learn from the European HSR system? Please draw on the examples of France, Germany, and Spain.
- Broadly, what are the advantages and disadvantages of HSR?
- Are the assumptions of demand for the California HSR reasonable? What considerations can be the most problematic? What are the most significant barriers to implementation?

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CHAPTER 8.

CASE STUDY VI: SUSTAINABLE TRANSPORTATION IN LATIN AMERICA: BUS RAPID TRANSIT SYSTEMS IN CURITIBA, BRAZIL AND TRANSMILENIO IN BOGOTA, COLOMBIA

CHAPTER OVERVIEW

This chapter examines sustainable transportation solutions for medium-sized cities. The first part describes the integrated, transit-oriented development policy implemented in Curitiba, Brazil, which enabled one of the most extensive **Bus Rapid Transit (BRT) systems** globally. The second section critically examines the successes of the first phase of the bus rapid transit system in Bogota, known as the TransMilenio. Next, this chapter critically unpacks the equity and efficiency challenges of the second and third phases of the Trans Milenio. Finally, the chapter concludes with a critical analysis of the benefits of bus rapid transit systems and the barriers to effective implementation.

Learning Objectives

- Compare transportation systems, including rail-based public transit and bus rapid transit, from a cost-benefit analysis perspective.
- Summarize the mobility challenges faced by Brazilian cities and identify the urban planning factors and policies that led to the development of an integrated, transit-oriented system in Curitiba, Brazil.
- Examine how the TransMilenio BRT in Bogotá impacts residents' commutes and analyze which groups benefit more from its Phases 1 and 2.
- Analyze the competition between informal transport, such as privately owned and operated buses, and the BRT system on Avenida Septima in Bogotá.
- Identify broader lessons from bus rapid transit systems in Latin America that can be adapted for use in other cities worldwide.

WHAT IS BUS RAPID TRANSIT?

In recent decades, the landscape of urban areas has been heavily influenced by the prevalence of cars, leading to significant changes. However, scholars and decision-makers agree that car-dominated cities are unsustainable, leading to various transportation-related challenges. These challenges include increased congestion, air pollution, accidents, environmental degradation, energy depletion, visual intrusion, a decline in public transit use, and limited accessibility to essential services for underserved populations.

As a result, many countries are seeking cost-efficient public transport systems that require minimal government investment while being affordable to operate. Rail systems, including heavy rail, metro rail, and light rail transit, have often been considered popular options for developing efficient public transit (Hensher & Golob, 2008). However, developing road-based public transit and improving bus systems are considered more affordable options, particularly in developing countries and cities (Hensher & Golob, 2008; Pojani & Stead, 2015). For many residents, road-based public transit is often the only means of accessing jobs, education, healthcare, and other essential services (Pojani & Stead, 2015). Bus systems, in particular, are significantly less expensive to construct than rail systems and subways.

Despite this, the quality of road-based public transit services in many cities worldwide is often inadequate to meet the mobility needs of their rapidly growing populations. Bus services, in particular, are frequently seen as unreliable, uncomfortable, inconvenient, and even dangerous (Pojani & Stead, 2015). In response, policymakers and planners have introduced low-cost strategies, such as designating specific lanes for buses and using technology like traffic lights that prioritize buses. These measures aim to improve the quality of bus services.

However, these strategies alone have not always been sufficient to enhance transit efficiency, especially without dedicated bus lanes. In the past two decades, a more effective solution has emerged: the construction of bus lanes separated from other traffic by barriers, cones, or other physical features. These separated lanes, located on the curbside or in the middle of the roadway, are exclusively for public transit use (Pojani & Stead, 2015). This system is known as Bus Rapid Transit (BRT). BRT is a bus-based mass transit system that has become an attractive alternative to rail transit in both developing and developed countries (Hensher & Golob, 2008; Pojani & Stead, 2015).

Bus Rapid Transit (BRT) can be implemented in two types: full BRT and light BRT. Both types operate on dedicated rights-of-way but differ in capacity and integration.

Full BRT is a comprehensive system with features like high-quality interchanges, integrated intelligent card ticket collection, and efficient passenger throughput. It is best suited for larger cities as it can transport up to 45,000 passengers per hour per direction, which can exceed the capacity of many rail services (Nakamura, Makimura, & Toyama, 2016; Pojani & Stead, 2015). Notable examples of full BRT systems are found in cities like Bogotá, Colombia, and Curitiba, Brazil, which are known for their efficient and cost-effective public transport systems (Hensher & Golob, 2008; Pojani & Stead, 2015). The characteristics of a full BRT system include dedicated lanes, off-board fare collection, and platform-level boarding, all of which enhance service speed and reliability.

Light BRT, on the other hand, involves some dedicated rights-of-way but with less integration of services and fares compared to full BRT (Hensher & Golob, 2008). Light BRT systems typically handle around 13,000 passengers per hour per direction and are more appropriate for medium-sized cities (Pojani & Stead, 2015). These systems are more limited in scope but still provide significant improvements over conventional bus services.

Cities' experiences with BRT systems offer valuable lessons, particularly regarding the allocation of limited urban space, which is often a contentious issue in the Global South. In these regions, there is intense competition for space among various activities. Private mobility, especially car-oriented infrastructure, often dominates, shaping the urban landscape, form, and citizens' travel choices (Sheller & Urry, 2000). Prioritizing different modes of transport within a city reflects broader political and economic considerations.

The experience of Mexico City serves as a case study to understand how conflicts over space can be resolved to successfully implement BRT systems. This city has managed to allocate dedicated rights-of-way for its BRT, overcoming significant spatial constraints and competing interests. Mexico City launched its first phase of the BRT project in 2005, beginning with a route along Avenida Insurgentes, a major financial and business corridor. The implementation faced opposition from various stakeholders, including commuters, residents, business owners, and street vendors. Concerns about potential negative impacts on businesses, communities, and historical buildings were raised. Opponents argued that the BRT line provided access to the historic downtown area and would primarily serve tourists, but it failed to address congestion issues in the old downtown area. Additionally, some feared that the project would displace poor urban residents, informal buses, and street vendors.

The conflicts were resolved through protests and negotiations involving the government, organizations, and transportation entities. As a result, the route was adjusted, moving it further away from central parts and narrow streets. Despite initial challenges during the first months of operation, the BRT system received positive feedback from commuters, who found it more convenient than traditional buses, which were often unsafe and uncomfortable (Goedeking, 2024). A survey revealed that one-third of respondents switched to BRT from the metro, and 9% switched from cars. Due to its success in improving mobility and the relatively low costs of construction and operation, the BRT system in Mexico City expanded from one to seven lines over the past two decades, serving different areas of the complex Mexico City Metropolitan Area (Vergel-Tovar & Landis, 2022).

Another successful BRT model is Transantiago in Santiago, Chile, which was initiated in 2007. This system involved a feeder and trunk network with fare integration between buses and the metro. Like in Mexico City, Transantiago faced protests and public outrage before implementation, leading to decisions to increase the number of buses and provide more government subsidies. The initial plan, outlined in Santiago's 2000 master plan, proposed exclusive bus lanes to meet rapidly growing demand. However, delays occurred due to funding cuts from bus projects in favor of freeway and metro projects.

Transantiago's BRT system was implemented on three types of streets: narrow streets with mixed traffic, streets with exclusive lanes marked on the ground, and 50 kilometers of bus-only lanes in the center of streets. In some cases, street capacity was increased to accommodate the bus lanes. Despite these efforts, the implementation faced opposition, particularly on major arterials where residents were concerned that dedicated bus lanes took up too much space and made it harder to cross the street. Critics argued that the system primarily benefited commuters from peripheral areas, rather than the local population.

To address public concerns, the government shifted focus from main corridors requiring large spaces to roads that avoid displacing cars. This approach aimed to minimize conflicts and preserve space for housing, businesses, and local schools while expanding the BRT network.

Metro-quality services
Location of busways in the median of the roadway rather than the curb
An integrated network of routes and fares
Closed high-quality stations that provide level access between the platform and vehicle floor
Pre-board fare payment/verification
System management through a centralized computerized control center
Clear route maps, signage, and real-time displays that are visibly placed within the stations/vehicles
Frequent and rapid service
Modern, clean vehicles
Special physical provisions to ease access for the physically disabled
Marketing identity
Clean vehicle technology
Superior images and customer service (i.e., clean busses and uniformed staff)
Entry to the system is restricted to prescribed operators and a limited number of vehicles (closed system).

Source: Pojani & Stead, 2015

Strong commitment and support from political leaders and governments are crucial to making bus rapid transit (BRT) systems possible and practical. The best outcomes occur when the public and private sectors collaborate. More than 150 cities worldwide have operational BRT systems, with at least 70 of these cities located in Asia, Africa, and Latin America (Pojani & Stead, 2015).

BRT systems offer numerous benefits. Studies have shown that they significantly improve local travel conditions and the quality of public transit. BRT systems reduce travel time and are generally more reliable than conventional bus systems. When appropriately configured, BRT systems can transport more passengers per hour than many rail systems. Hensher and Golob (2008) found that both metros and BRT systems could offer capacities ranging from 20,000 to 40,000 passengers per hour, comparable to twice the seating capacity of Madison Square Garden. However, there is a stark difference in the upfront costs: BRT systems cost between $5 to $20 million per kilometer, while metros range from $30 to $160 million per kilometer (Ardila-Gomez & Ortegon-Sanchez, 2016; Hensher & Golob, 2008). Users also find BRT systems to be a comfortable and reliable mode of public transport (Pojani & Stead, 2015).

BRT systems are also more sustainable, helping cities address environmental issues. Buses in a BRT system typically use natural gas, electricity, or biofuels, which are more environmentally friendly than fossil fuels. This shift reduces energy consumption and emissions (Pojani & Stead, 2015).

Another significant advantage of BRT systems is their cost-effectiveness compared to other types of public transit, such as rail, subways, or metros. BRT systems, which are much less expensive, can effectively replicate the functionality and amenities of modern rail-based systems. Generally, a BRT system is four to twenty times less costly than a light rail transit (LRT) system and ten to one hundred times less expensive than a metro system (Hensher & Golob, 2008). Depending on the project's size and complexity, BRT systems cost between $1 million to $8 million per kilometer. Even in cities with higher labor costs, BRT implementation costs typically remain under $10 million per kilometer. Additionally, BRT systems can operate without subsidies at reasonable fares (around $1 per ride) if well-planned. Other appealing features include quick implementation timelines (1–5 years), adaptability to limited spaces, historical areas, and business districts with narrow route segments (Pojani & Stead, 2015).

The literature highlights two primary factors influencing the attractiveness of transportation projects to governments and the media: infrastructure costs and patronage levels. Figures 8.1 and 8.2 illustrate these factors, respectively.

1. **Infrastructure Costs**: Figure 8.1 demonstrates the variation in infrastructure costs per kilometer, ranging from $53.2 million/km to $0.35 million/km. The figure indicates that infrastructure costs are generally lower in Asia and Latin America compared to other regions (Hensher & Golob, 2008).
2. **Patronage Level**: Figure 8.2 depicts the ridership rates as passengers per hour per direction for different cities. This measure is crucial in assessing the efficiency and capacity of the transportation system in serving the public.

These two factors—cost and patronage—are critical in evaluating the feasibility and success of BRT systems and other public transportation projects. They help determine whether governments consider a project a worthwhile investment and an attractive topic for media coverage.

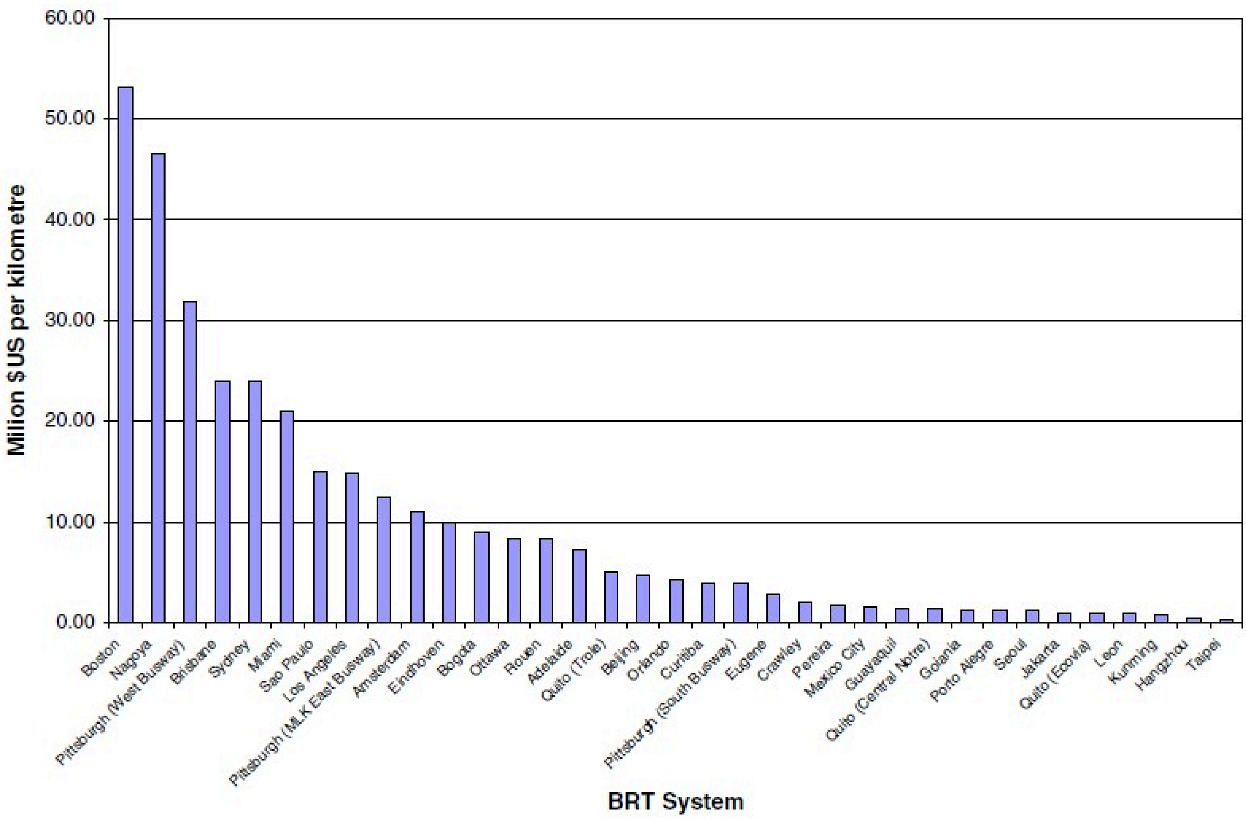

Figure 8.1 *Total infrastructure costs ($m) per kilometer (2006), Source: Hensher & Golob, 2008.*

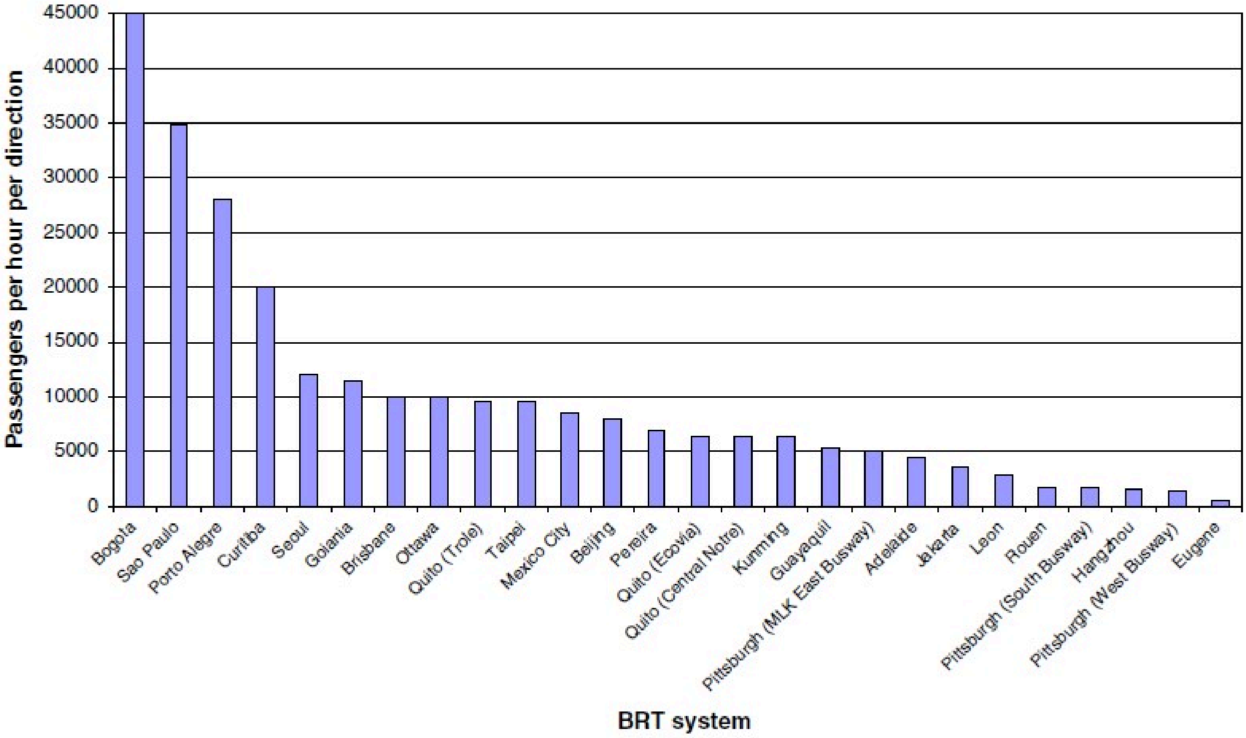

Figure 8.2 *Peak ridership (2006), Source: Hensher & Golob, 2008.*

The Benefits of Bus Rapid Transit Systems for Cities

BRT systems offer a range of benefits. Studies have shown that they significantly improve local travel conditions and the quality of public transit in many cities. BRT systems help reduce travel time and are generally more reliable than conventional bus systems. However, there are challenges associated with the development and implementation of BRT systems in many countries. These challenges include "rushed implementation, tight financial planning, excessive occupancy levels, early deterioration of infrastructure, poor supervision of the system, and insufficient user education during initial implementation" (Pojani & Stead, 2015). While these issues often stem from inadequate policy-making and financial planning rather than the BRT system itself, they can negatively impact public and political perceptions of BRT, leading to the view that it is a "second-best option compared to rail."

One of the most significant advantages of BRT systems over other modes is their lower capital costs. Depending on the planning model and local conditions, including labor, land, and other costs, the cost of BRT lines per kilometer can be one-eighth to one-fourth that of building fixed-route light rail infrastructure. However, while BRT systems often show better numbers on paper regarding operating and development costs, their real-world advantages can be less apparent.

BRT systems are typically implemented in densely populated areas with narrow streets. In these settings, high foot traffic and other modes of transport make securing or preserving right-of-way challenging. This can lead to increased station dwell times and reduced reliability. As ridership grows, BRT systems can also face operational challenges. Overcrowding can increase egress and access times, causing spikes in dwell and boarding times during peak hours. For example, in the case of TransMilenio, travel demand increased by 30% between 2005 and 2010, while bus capacity only grew by 2%. This led to decreased desirability and reliability of the system, causing many middle-class riders to switch to other modes of transport, including motorbikes (Vergel-Tovar & Landis, 2022).

Additional issues in BRT planning include rushed implementation, tight financial budgeting, infrastructure deterioration, and incomplete implementation of fare collection systems, leading to delays. The political economy of cities and regions often does not favor BRT over light rail expansion, as BRT is perceived as less capable of stimulating or redirecting land use development patterns and fostering growth. The use of shared right-of-way with private cars also creates a negative perception of BRT among many people. These factors often position BRT as an alternative approach when light rail expansion is too expensive or not feasible (Hidalgo & Gutiérrez, 2013).

Despite these challenges, BRT systems have become an attractive option for politicians and cities seeking to complete development projects quickly, often before election cycles. For example, in Guadalajara, Mexico, BRT corridors have been built in less than two years, highlighting the relative ease and speed of BRT development compared to rail systems.

Hook et al. (2010) provide an in-depth analysis of the CO_2 impacts of two BRT systems: those in Bogota, Colombia, and Mexico City. Greenhouse gas (GHG) impacts of transportation are influenced by four primary factors: the level of travel activity (A), the modal structure (S), the fuel intensity (I), and the carbon content of the fuel used (F) (Hook et al., 2010).

This analysis primarily focuses on the changes in modal structure (S) to understand how BRT systems affect GHG emissions (Hook et al, 2010). The methodology, introduced by Jürg Grütter, a consultant for the Clean Development Mechanism (CDM), measures this factor. According to this methodology, BRT projects can reduce GHG emissions by encouraging passengers to switch from private cars to buses, by optimizing the type of bus used (e.g., switching from a 12-meter bus to an 18-meter articulated bus), or by increasing the occupancy rate (e.g., increasing the average number of passengers per bus from 60 to 150). These changes contribute to a more efficient use of fuel and lower emissions per passenger kilometer.

The planning and development of the Bogota BRT system began in 1999, and since then, it has been recognized as one of the most successful BRT systems worldwide. The transportation agency, TransMilenio, has established an 84 km bus network with 114 stations and 1,080 articulated buses operating on dedicated lanes. The buses' average speed is approximately 27 km/h, carrying about 1.5 million passengers daily. TransMilenio was the first project to obtain Clean Development Mechanism (CDM) credits for reducing greenhouse gas (GHG) emissions per transported unit (Hook et al., 2010).

According to the CDM methodology, the reduction in GHG emissions is calculated based on the difference between the emissions produced by the project and the emissions that would have been produced if the passengers had used their previous modes of travel. This methodology assumes that the number of passengers and the distance they travel remain constant, with the only change being the mode of transport. Alternatively, it considers that the same transport mode is used, but the number of passengers increases when using the BRT system (in Bogota, bus capacity increased from 60 to 160 after the implementation of the BRT system).

The emissions resulting from the BRT project and the baseline emissions were calculated and compared for different years, as presented in Table 8.2. Scholars found that the GHG mitigation potential of BRT systems depends on the extent to which commuters continue to use buses over time. Table 8.3 compares the estimated and actual GHG emissions associated with the TransMilenio system in Bogota from 2006 to 2010. Although TransMilenio significantly reduced emissions and congestion in its early years, subsequent phases and system expansion have not been as effective. Some users switched to informal transit or cars, resulting in higher actual emissions than estimated from 2006 to 2010. Therefore, GHG assessments of BRT should carefully consider traffic and ridership changes, as Hook and colleagues suggested (Hook et al., 2010).

According to Hidalgo et al. (2013), the implementation of the TransMilenio system has generated various impacts. Labor force participation and employment balance increased after the system was implemented in Bogota. The revenue generated by this system in the form of taxes on income, sales, industry, and vehicles has also increased post-implementation. Crime statistics reported an 85% reduction between the period before (1999-2000) and after (2001-2002) the implementation of TransMilenio (Hidalgo et al., 2013).

Regarding land development and price impacts, results have shown positive impacts (increased land prices) within 1 km of the new BRT service. Moreover, depending on the socio-demographic composition of neighborhoods, the research found positive land price impacts for areas within walking distance of TransMilenio. However, in the immediate vicinity of stations, prices have dropped due to noise pollution and safety issues. The impact of transit systems on land prices is, however, an ongoing debate that requires careful investigation to build robust knowledge (Hidalgo et al., 2013).

TransMilenio's success in expanding service and providing an attractive transportation option has garnered attention from transportation planners in many other cities facing rapid growth and limited land availability. Asian cities like Taipei (Taiwan), Nagoya (Japan), and Seoul (South Korea) have added BRT lines to their regional public transit systems instead of expanding metro systems. China has also rapidly developed BRT systems in many of its fast-growing cities, which may not have the financial resources to build metro systems.

Table 8.2 Emissions Reduction from Trans Milenio Phases

	Emissions Reduction (Tons Co2 equivalent)	
Year	**Estimated**	**Actual**
2006	94,567	59,020
2007	134,011	70,109
2008	230,201	68,813
2009	304,432	
2010	298,719	
2011	336,735	
2012	327,276	
Total	1,725,940	
Annual Average	246,563	

Source: Hook et al., 2010

Leakage Factor	Emissions Reduction (tons CO2 equivalent)
Road construction	-229,424
Bus manufacturing	-56,826
Fuel production	-243,389
Traffic rebound effect	-43,328
Mixed traffic speeds	77,421
Load factors	0
Note: A negative number represents an increase in emissions.	

Source: Hook et al., 2010

Mexico City, Mexico

The first BRT corridor in Mexico City started its implementation in the 2000s. This system has 262 micro-buses and 90 buses, of which 97 buses are articulated with higher capacity (160 passengers for each bus) and better fuel efficiency. This BRT system operates along 20 km of roadway on a reserved right-of-way. In 2006, Rogers adopted Gretter's methodology and estimated that the CO2 emissions would be reduced by 25,887 tons per year due to the implementation and use of this new BRT corridor in Mexico City. Accordingly, 18,000 tons would be avoided by replacing many smaller and less fuel-efficient buses with a smaller number of larger and more fuel-efficient vehicles. Also, emissions fell by another 15,000 tons because of improved mixed-traffic vehicle flow along the BRT corridor. Road construction would result in one-time direct emissions of 38,600 tons. Because of conservative modal shift assumptions, only about 5%, or 1,300 tons of CO2 reductions, were expected to result from the modal shift (Hook et al., 2010). Although CDM rejected the results reported by Rogers for Mexico City, after using the Grutter method, the results were quite the same, showing a significant reduction in CO2 emissions (Hook et al., 2010). The results of the decline in CO2 emissions due to Mexico City BRT implementation are shown in Table 8.4.

Table 8.4 Emissions Reductions from Mexico City BRT Corridor (Metrobus InsurgentsCorridor)

	Estimated Reduction (tons CO2 equivalent)	
Year	**Rogers Methodology (9)**	**Grutter Methodology (8)**
2006	25,415	
2007	27,688	
2008	26,849	13,540
2009	25,989	26,816
2010	25,521	26,554
2011	24,949	26,292
2012	24,401	26,032
2013		25,771
2014		25,512
2015		12,627
Total	181,209	183,144
Annual average	25,997	26,163

Source: Hook et al., 2010

Comparison of CO_2 Emission Reductions: Bogotá vs. Mexico City BRT Systems

Three main characteristics of BRT systems impact CO_2 emission reductions:

1. **Projected Modal Shift**
2. **Load Factor (passenger-km/bus-km)**
3. **Speed** (Hook et al., 2010)

Differences in emissions reductions between the Bogotá and Mexico City BRT systems can be attributed to several factors:

- **Modal Split**: Bogotá and Mexico City saw a similar percentage of passengers shifting from private automobiles and taxis to the BRT system. However, an additional 13% of passengers in Mexico City shifted from the underground metro system (see Table 8.5). Since Mexico City uses a mix of hydroelectric, thermal, and natural gas energy, the shift from metro to bus may not have achieved the anticipated CO_2 reductions. This could explain why the CO_2 reduction per kilometer for Bogotá's BRT system was twice as high compared to Mexico City's.
- **Impact on Mixed Traffic**: The BRT system improved mixed-traffic flow in both Bogotá and Mexico City. In both cities, the BRT systems removed mixed-traffic lanes used by buses and informal low-capacity vehicles, contributing to overall emission reductions (Hook et al., 2010).

Table 8.5 Previous modes used by BRT passengers in Bogota and Mexico City

	Bogota%	Mexico City%	Jakarta%
Bus	91.4	78	55
Car	2.4	6	7
Taxi	5.5	3	4
Nonmotorized transport	0.5	0	0
Metro	n/a	12	n/a
Motorcycle	0.0	0	18
Three-wheeler	0.0	0	2
Induced traffic	0.2	n/a	n/a

Source: Hook et al., 2010

LAND-USE PLANNING AND THE BRT: LEARNING FROM CURITIBA

The development of BRT systems typically follows two main approaches:

1. **Comprehensive Model**: This approach is usually led by central governments and involves creating a mobility plan that estimates travel demand for different socio-demographic groups. It proposes various transit facilities and aims to integrate the BRT system with existing transportation networks and development plans. This model is advantageous because it ensures the BRT system is well-integrated with other transport options and development initiatives.
2. **Incremental Development Model**: This approach involves implementing BRT on a smaller scale, targeting specific areas or corridors with pressing congestion or pollution

issues. It provides a quick response but may not integrate as seamlessly with existing conditions. Due to its speed and flexibility, this model is often favored in rapidly growing cities, particularly in Asia (Hidalgo et al., 2013).

We refer to Curitiba, Brazil, to illustrate how long-term land-use planning and transportation integration can create sustainable BRT systems. Curitiba is renowned for its innovative and integrated approach to BRT and land-use planning. Curitiba's model has been studied extensively for its success as the first city globally to implement a BRT system fully.

Curitiba's BRT System: A Model of Integration

Curitiba has successfully integrated transportation and land-use planning for over 35 years. Developed with a long-term vision, the city's BRT system serves as an exemplary case. The development of Curitiba's BRT system followed three critical phases:

1. **Planning Concepts and Aspirations (1943-1970)**: Early ideas and planning efforts laid the groundwork for future transportation systems.
2. **Plan Implementation (1972-1988)**: During this period, Curitiba implemented the Integrated Transit Network (RIT), which became a model for BRT systems worldwide.
3. **Metropolitan Growth and Advancements (1988-Present)**: The system has continued to evolve, expanding and improving to meet the growing city's needs.

In the 1970s, Curitiba initially planned an LRT system, but due to high costs, the city shifted to a trunk-and-feeder bus system with dedicated median lanes. This approach eventually led to developing the world's first comprehensive BRT system. In 1980, Curitiba began establishing the RIT, and in 1990, the Urban Development Authority of Curitiba (URBS) was responsible for transportation planning and management (Lindau et al., 2010).

Curitiba's BRT System Components

The Integrated Transit Network (RIT) in Curitiba includes:

- A longitudinally separated median busway
- Tube stations with level access and prepayment facilities
- Integrated pricing across various services
- Controlled dispatch at terminal stations
- Specialized services, including express routes, feeder services, and central fare collection

By 2007, Curitiba's RIT operated with a fleet of 2,600 buses, providing 2.26 million trips per working day and covering 483,000 km daily. The system includes 72 km of bus corridors, 347 tube stations, and 29 urban terminals (Lindau et al., 2010). The gradual and strategic implementation of RIT components has allowed Curitiba to develop a highly efficient and sustainable BRT system.

Curitiba's experience demonstrates that a well-planned and integrated approach to transportation and land use can result in a successful and scalable BRT system. The collaboration between the Institute for Research and Urban Planning of Curitiba (IPPUC) and URBS has been crucial in achieving these results, setting an example for other cities worldwide.

1970s	1980s	1990s	2000s	2010
Bus stop shelters	Tube stations			Real-time information
Conventional buses	Articulated buses	Bi-articulated buses	Cleaner buses	B100 articulated buses
Open terminals	Closed terminals (Paid area)			
Paper & coin-based ticketing(manual)			Electronic ticketing	
Trunk & feeder services	Inter-neighborhood Direct (Ligerinho)	Special services		Overtaking at busway stations
Urban services	Dispatch at terminals	Metropolitan services		Real-time control

Source: Lindau et al., 2010

With the addition of the new Green Line corridor in 2009, Curitiba's BRT system introduced more sustainable and practical features, such as cleaner vehicles and fuels, increased capacity, and improved commercial speed. This RIT corridor embodies all aspects of a modern, complete BRT system. In March 2010, the system was further upgraded by introducing a new method of passing lanes at stations. This upgrade involved repositioning stations and removing parking spaces to make room for a new route and additional buses. These new buses share the busway but do not stop at every station, increasing the corridor's capacity to 20,000 people per hour in each direction, according to data from URBS. The commercial speed also increased to 25 km/h (Lindau et al., 2010).

Curitiba's success in integrating buses into its public transportation system and developing a BRT system lies in the effective integration of transportation and land-use planning. This success is made possible through strong political leadership and collaboration, innovative problem-solving, adherence to plans, effective use of new technologies, and consistency and continuity in planning and execution.

BRT implementation can lead to significant changes in the built environment and its dynamics. One of the most commonly documented impacts is the increase in land and housing stock prices. Research shows that land values near BRT systems often rise, which can have a substantial impact on the local population. Studies indicate that South American and Asian cities have experienced more pronounced increases in property values compared to U.S. cities with express bus systems. A 2018 case study in the U.S. found that public transit-related price increases were similar across BRT, light-rail, and heavy-rail systems, suggesting a higher net return on capital investment when spent on BRT development (Ingvardson & Nielsen, 2018).

BRT investments can also induce residential and commercial development, although the empirical evidence on these impacts is still limited (Vergel-Tovar & Landis, 2022). The significance of these impacts is closely tied to accompanying land-use policies. Curitiba, for example, has successfully integrated land use and transit planning over 40 years of BRT implementation, encouraging high-density development along BRT corridors. In contrast, cities like Quito and Bogotá have seen development concentrated around BRT stations, with limited corridor-wide growth.

Inducing urban development and redevelopment through BRT implementation has proven to be challenging and context-dependent. For example, Bogotá has seen more commercial development induced by the TransMilenio system, with diverse and intense redevelopment around BRT corridors connecting key activity areas. Successful infrastructure implementation, when accompanied by appropriate land-use policies, can lead to consistently increasing ridership. Research shows that BRT ridership is higher when the surrounding environment aligns with the principles of transit-oriented development (TOD) (Vergel-Tovar & Landis, 2022).

Balancing the Benefits and Challenges of BRT Systems

As discussed in previous sections, Bus Rapid Transit (BRT) is recognized as a cost-effective transportation option for sustainable urban mobility. Successful BRT implementations worldwide have demonstrated numerous benefits, including environmental friendliness, improved mobility, enhanced accessibility, and more significant equity in transportation. BRT systems are also believed to impact land and property values positively. Although there is no complete consensus on the extent of BRT's influence on the land market, empirical studies suggest that in some cases, such as in Bogotá, Colombia, better access to BRT stations can lead to increased residential property values (Rodríguez & Targa, 2004).

Research by Rodríguez and Targa (2004) explores how the BRT system in Bogotá has altered residents' commutes and how these impacts have evolved for different beneficiary groups. Additionally, the study examines the relationship between multifamily apartment rentals and accessibility to BRT station locations (Rodríguez & Targa, 2004).

While BRT is revolutionizing public transit systems worldwide, numerous empirical studies in Latin America have highlighted its effectiveness and success. Despite BRT's growing popularity, particularly in the last two decades, questions remain about its effectiveness as a mass-transit option. From a decision-maker perspective, some disadvantages of BRT include its limited ability to encourage economic development compared to light rail and heavy rail systems. Investors favor developing residential, commercial, and office spaces around rail lines and stations rather than bus lanes and stations. Concerns exist regarding the negative externalities associated with BRT services, such as noise and pollution. However, these adverse effects could be mitigated by using compressed natural gas (CNG) as fuel for BRT vehicles, thereby reducing the environmental impact of fossil fuels.

Policymakers often argue that light rail transit (LRT) infrastructure has a more permanent and visible presence, which could lead to more significant public transit commitment and attract more private-sector investment and land development around stations. Nevertheless, more research is needed to fully understand the impact of BRT on land development, investment attraction, and the relationship between BRT accessibility and land values (Rodríguez & Targa, 2004).

In contrast to Curitiba, where BRT investments and land-use developments are closely integrated, the effects of BRT on proximity-related externalities, accessibility, and land development remain unclear in many other cases. Therefore, this section focuses on Bogotá to assess the impact of BRT accessibility on land development. As the capital of Colombia and one of the densest cities in the world, Bogotá faces significant mobility challenges despite its relatively low car ownership rate compared to other major Latin American cities. Over the past few decades, numerous efforts have been made to address these issues, though many have failed.

However, the city has undertaken several mobility and urban development initiatives in the last two decades to implement sustainable transportation strategies (Rodríguez & Targa, 2004). In 1999, Bogotá invested in an extensive BRT network built between 1999 and 2000. It began operations in late 2000 with two main corridors. This new network will cover 80% of the city's daily transit trips.

Data show that implementing the BRT system has dramatically improved mobility and accessibility in Bogotá.

The BRT system now spans 42.5 km of dedicated busways and accommodates around 800,000 one-way trips daily. In fact, TransMilenio transports more passengers than the public transportation networks of several major cities worldwide (Rodríguez & Targa, 2004). Additionally, the transformation of a busway corridor plagued by safety issues, pollution, and aesthetic concerns into a modern BRT system has led to significantly reduced travel times, lower noise levels, and fewer greenhouse gas emissions, making Bogotá's case unique (Rodríguez & Targa, 2004).

A study analyzed the impact of local physical accessibility to BRT stations on residential land value and rental prices by selecting a 1.5 km buffer area around two main corridors of the BRT system in Bogotá. Other factors, such as housing characteristics, were controlled for in the analysis. The results demonstrated that higher rental prices for multifamily residential units were associated with improved accessibility to BRT station sites. Properties located five minutes closer to stations saw rental prices increase by 6.8% to 9.3%, reflecting property owners' value on proximity to BRT stations (Rodríguez & Targa, 2004).

Understanding the impacts of BRT station accessibility on land value under Bogotá's current conditions helps planners anticipate how such accessibility could shape future land-use planning. As the BRT system expanded from 42.5 km to several hundred kilometers, it significantly affected accessibility and affordability to different land uses. The authors suggest that as the system grows, BRT will become more competitive with other modes of transportation, such as private vehicles, enhancing its overall usability and value to customers. This competitive advantage is expected to correlate with increased land values (Rodríguez & Targa, 2004).

In the following paragraphs, we will analyze how informal transport, consisting of privately owned and operated buses, competes with the BRT system in Bogotá. We will also discuss how the Phase 3 expansion did not benefit low-income commuters and how BRT competes with **informal transportation**, which is more affordable and flexible for these commuters.

Although TransMilenio has been lauded as a successful model for improving urban transport in Bogotá, it has recently faced severe criticism for various reasons, including cost, ownership structure, design efficacy, and, most notably, its failure to address transportation issues in the city effectively (Gilbert, 2008). Despite its success, it is unfortunate that the BRT system in Bogotá has failed to serve the city's poor and underserved populations adequately.

Research shows that in both developing and developed countries, the two primary reasons people opt to use private vehicles are the lack of reliable public transit and rising incomes. However, private cars are unsustainable for various reasons, including increased congestion, higher air pollution, diminished quality of life, and reduced economic productivity. Latin American countries have not been exempt from the negative impacts of increased car ownership. To counter these issues, many cities worldwide have developed rail transit systems. However, rail systems, such as subways, metros, and light rail, have challenges, including high construction and maintenance costs, limited coverage, and unequal service to minority and low-income populations. In this context, a well-designed bus system is the best way to address the problems associated with rising car usage and the limitations of rail transport (Gilbert, 2008).

The BRT system is notably one of the most reliable and efficient public transit options. BRT can transport nearly as many passengers as rail systems but is much cheaper to build and maintain. As mentioned in previous sections, Curitiba pioneered the BRT model, which other Latin American cities, including Bogotá, have since adopted. The collaboration between the public and private sectors in Bogotá's BRT implementation has led to positive outcomes. However, the system, particularly the TransMilenio, has faced challenges and criticism. For example, passenger numbers have declined as many riders have returned to traditional buses. Additionally, fares have increased relative to wages and the cost of other bus services, and some aspects of the Phase 3 expansion have been controversial (Gilbert, 2008).

Table 8.7 outlines the construction plan for different phases of the BRT system in Bogotá. Data collected by surveying residents shows that 19% of respondents in 2005, 18% in 2006, and 14% in 2007 cited TransMilenio as their primary mode of transportation. By 2007, the system carried an average of 1.3 million people per workday (Gilbert, 2008).

Phase	**Corridors**	**Length(km)**	**Program**
1	3	42.4	1999-2002
2	3	42	2003-2004
3	3	61.3	2005-2009
4	4	51.3	2012-2015
5	4	45.6	2016-2019
6	3	40.9	2020-2023
7	4	39.6	2024-2027
8	1	63.5	2028-2031
Total	25	386.6	

Source: Gilbert, 2008

The local criticism regarding the Bogota BRT started when Phase 2 began in 2004. The first group of complaints was related to three main issues, including 1) the traffic congestion caused by the construction of the system, 2) the decay of the road surface, and 3) the deteriorating condition of the bus stations. The second group of criticism was mostly concerned with overcrowding, delays to the bus system, and passenger protests regarding the decrease in the system's services. The third group of complaints was about safety and security issues, indicating the risk of robbery, primarily because of overcrowding. Finally, the fourth group of issues was related to the decline in the technical problems of the system. Undoubtedly, this confluence of pests is to blame for the declining approval ratings. Compared to other forms of transportation, the public awarded Trans Milenio an excellent rating when it first began operating; in 2001, it scored a 93% acceptance rating. However, only 66% of respondents believed the service was still outstanding or excellent in 2007 (Gilbert, 2008).

Moreover, one of the most critical questions regarding the efficiency of the Bogota BRT system relates to its state of equity and affordability. This is an essential issue since most of the city's population is low-income, and the system's construction is highly subsidized. Current data show that most users of the BRT system in Bogota are middle-income people; however, the low-income population is the majority. The main reason for this issue is related to the network's expansion and the areas covered by the network; Transmilenio's current routes do not reach large areas of poor settlement, and the fares charged are more expensive than those in the traditional system. Furthermore, although future c corridors will cover a much broader socio-economic cross-section of the city, the subsequent and recently expanded phases (Phase 3) do not prioritize routes that pass through poor areas (Gilbert, 2008).

Therefore, removing competition is the most appropriate way to solve the issue. The small-scale owners and drivers must negotiate a political agreement to do this. Due to unfair competition, TransMilenio is not transporting as many passengers as the present fleet of articulated buses can accommodate. Buses are still parked in the garages, and TransMilenio tariffs have climbed due to rising costs and stagnant passenger volume. If nothing is done to halt the illegal buses and speed up the scrapping program, TransMilenio may find itself in a dangerous downward spiral. It won't be able to convince clients to switch from the existing system, which is less expensive and would need to raise prices once again to survive (Gilbert, 2008).

Last but not least, a considerable portion of public money is spent on building Bogota's infrastructure. Making space for personal automobiles, taxis, and standard buses accounts for a large part of the expense of building corridors. If public policy could limit the number of private cars using Bogotá's streets, the infrastructure cost may decrease, and the number of passengers might grow (Gilbert, 2008).

Local criticism of Bogotá's BRT system began intensifying during Phase 2, which started in 2004. Complaints were grouped into four main categories.

1. **Traffic and Infrastructure Issues:** The first set of criticisms focused on traffic congestion caused by the system's construction, the deterioration of road surfaces, and the worsening condition of bus stations.
2. **Operational Challenges:** The second group of complaints revolved around overcrowding, delays, and declining service quality, leading to passenger protests.
3. **Safety and Security Concerns:** The third category highlighted safety issues, particularly the increased risk of robbery due to overcrowding.
4. **Technical Problems:** The final group of complaints concerned the system's declining technical performance.

These issues contributed to a significant drop in public approval. When TransMilenio launched in 2001, it received a 93% approval rating. However, by 2007, only 66% of respondents rated the service as excellent or outstanding (Gilbert, 2008).

Equity and affordability have also become critical issues for the Bogotá BRT system. Although the system was heavily subsidized and intended to serve the entire population, current data indicates that most BRT users are middle-income despite the city's majority low-income population. The main reasons are related to network expansion and coverage. TransMilenio's routes do not adequately reach many poor neighborhoods, and its fares are higher than those of the traditional bus system. While future corridors are expected to cover a broader socio-economic range of the city, the recent expansion (Phase 3) has not prioritized routes through low-income areas (Gilbert, 2008).

Addressing the competition from informal transport is crucial for improving the BRT system's efficiency. TransMilenio is not carrying as many passengers as possible due to competition with illegal buses. Many articulated buses remain unused in garages, and fares have increased due to rising costs and stagnant ridership. If no action is taken to eliminate illegal buses and accelerate the scrapping of outdated vehicles, TransMilenio could enter a dangerous downward spiral. The system may struggle to attract customers from the cheaper, existing alternatives and may need to raise fares again to stay afloat (Gilbert, 2008).

Lastly, the cost of building Bogotá's infrastructure, particularly the space allocated for private cars, taxis, and standard buses, consumes a significant portion of public funds. If public policy were to limit the number of private vehicles on Bogotá's streets, infrastructure costs could decrease, and passenger numbers on public transit might increase (Gilbert, 2008).

CONCLUSION

This chapter introduced Bus Rapid Transit (BRT) as a successful and cost-effective public transit solution. BRT has become a popular response to traffic congestion, environmental pollution, and other transportation challenges, particularly in developing cities. The benefits of BRT systems are numerous, ranging from reductions in pollution and travel time to shifts in travel behavior, increased labor force participation, higher tax revenues, and rising property values near BRT corridors. By examining some of the most successful BRT implementations, we highlighted the significant impact BRT can have on the urban transportation landscape.

BRT systems show considerable promise regarding social equity. For example, an analysis of Bogotá's TransMilenio BRT system reveals that lower-income riders experience greater reductions in travel time compared to middle-class users. Additionally, BRT users often benefit from more efficient routes and network designs, resulting in lower fares than conventional buses, as seen in cities like Mexico City, Bogotá, and Lagos.

However, the research on BRT impacts is not uniformly positive. Some studies report mixed or contradictory results, indicating minimal improvements in job access for low-income populations or more significant time savings for middle- and high-income groups rather than for the poor.

Further research is needed to evaluate BRT's potential to encourage a shift away from car use, particularly in North American cities where solo driving remains a significant issue. A comprehensive analysis should explore the factors of the built environment that are essential for a successful BRT system and how these benefits can enhance social equity in car-dependent American cities.

Glossary

- **The bus rapid transit (BRT) system** is a top-notch bus-based transportation system that offers metro-level capabilities for quick, pleasant, and economical services (Institute for Transportation and Development Policy, n.d.).
- **Informal transportation** is often composed of tiny cars that a single person owns, operates, or leases.

Prep/quiz/assessments

- Please compare the benefits and challenges of the subway system vs. the BRT system. You can address this question by reading about the BRT TransMilenio in Bogota, Colombia, and Subway Line B in Mexico City.
- How do Phases 1 and 2 of the BRT TransMilenio change the commutes of residents in Bogota? Who benefits more from Phases 1 and 2?
- After the success of Phases 1 and 2, what benefits and challenges does Phase 3 present? More specifically, how do informal transport, privately owned and operated buses, compete with the BRT system in the Avenida Septima?
- What are the limitations of BRT as a transport policy?
- What can Global South and North cities learn from Trans-Milenio's case study?

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CHAPTER 9.

CASE STUDY VII: NON-MOTORIZED TRANSPORTATION IN EUROPE AND THE UNITED STATES

CHAPTER OVERVIEW

This chapter is divided into three sections. The first part explores the characteristics of non-motorized transport in the U.S., including commuters and infrastructure. The second part compares how the multimodal infrastructure of the cities of Copenhagen and Vienna allows most commuters to bike. The third part examines the environmental benefits and equity challenges of New York City's bike-sharing program.

Learning Objectives

- Summarize the broader lessons from multimodal and non-motorized transportation in Vienna and Copenhagen.
- Classify the challenges of non-motorized transportation across U.S. cities, including infrastructure, safety issues, land-use planning issues, and others.
- Describe the potential benefits of the bike-sharing system in New York.
- Identify communities where NYC's bike-sharing system may be expanded to support transportation equity.

THE CHALLENGES OF NON-MOTORIZED TRANSPORT IN THE U.S.

Biking and other **non-motorized transportation** are the most equitable and efficient means of achieving **sustainable mobility** goals. Many cities worldwide support non-motorized transportation, such as walking or biking, to foster sustainable, low-carbon commutes while improving public health and environmental quality (Banister, 2008). Cities worldwide have succeeded in increasing the share of cyclist commuters by implementing comprehensive policies supporting bike infrastructure (Pucher et al., 2010). A comprehensive biking policy may include diverse types of strategies and programs, such as infrastructure provision, pro-bicycle programs, supportive land-use planning, restrictions on car use, and better integration with public transit. Examples of infrastructure provisions include wayfinding signage, off-street paths, colored lanes, shared lanes, car-free zones, bicycle stations, and parking.

Further strategies to integrate biking with public transit include implementing parking at rail stations and bus stops, bike racks on buses, and rail cars. Despite the recent progress of biking infrastructure, the lack of such car-restrictive policies in the U.S. explains why bike usage is lower than in other countries. The safety of cyclists plays a key role in strengthening a bike ridership. Consequently, areas having higher bike ridership decrease the risk of injuries and fatalities. Because cyclists commonly use roads, they become visible to motorists. Thus, drivers gradually become more vigilant and sensitive to the safety of cyclists.

Factors That Influence Biking

Previous studies found that active travel (biking and walking) is influenced by the quality and safety of non-motorized transportation, the socio-demographic characteristics of the population, and the built environment. Kamel, Sayed, and Bigazzi (2020) developed bike-ability measures to examine and compare different cities. Their assessment indicates that the attractiveness of cycling determines bike-ability. This is influenced by land-use planning, cycling infrastructure quality, topographic and weather conditions, and the spatial distribution of bike lanes. Another factor determining bike-ability is access to other modes of travel, such as buses and subway systems. Safety is another relevant determinant that impacts bike ridership. Safety refers to the likelihood of collisions of various transportation modes, including drivers, pedestrians, and cyclists.

Several studies have focused on distinguishing built environment factors affecting biking attractiveness. Network connectivity, which refers to the extent of intersection density and a block's characteristics (size, length, quality), influences active commuting. Bike lane interruptions undermine biking as cyclists are displaced to mixed traffic or must take longer alternative routes (Schoner and Levinson 2014). Land-use mix is another explanatory variable for an environment's bike-ability. Since most land use in U.S. cities is residential, its layout receives a low value from the lens of diversity and attractiveness for bikeability. Other built environment factors include biking facilities in the transportation network, such as separated bike lanes, separated paths, bike boulevards, and traffic-calming design. Studies have shown that household and population densities positively correlate with bike ridership (Schneider and Stefanich 2015).

Considering most of these factors and safety measures, Kamel et al. (2020) developed a statistically calibrated Bike Composite Index (BCI) index to measure urban bike-ability. This index uses various variables, including cyclist-vehicle crashes, Vehicle Miles Traveled (VMT) and Bike Kilometers Traveled (BKT), bike network density and coverage, topography, bus stop density, land-use diversity, and residential density. The BCI highlights the need for investments in promoting biking infrastructure in high-demand areas and adopting policies prioritizing biking over other means of transportation, especially private cars. With a general understanding of the biking explanatory factors in cities, we further the discussion in this chapter by presenting North American and European case studies.

Biking in the U.S.

Because most U.S. cities have car-oriented transportation systems and low-density land-use patterns, bike usage is low in the United States. On average, only 0.6% of the workers reported biking, according to the US Census Bureau (2010). In contrast, this number for Austria is 27%, of which only 37% is for leisure (Harms & Kansen, 2018). Despite the recent efforts of U.S. cities to support biking, the share of biking trips is still far less than in several European countries. Most adults in U.S. cities bike solely for recreational purposes. In contrast, for their European counterparts, biking is one of the main modes of transportation, especially for daily job commutes (Pucher & Dijkstra, 2003).

Despite the recent progress of biking infrastructure in some U.S. cities, the lack of comprehensive transportation policies to reduce car driving undermines biking and non-motorized transportation. In the U.S., biking is perceived as unsafe because the transportation network is mostly occupied by cars. Individual policy interventions are not sufficient for promoting biking. Thus, a mix of coordinated policies, carefully considering the city's urban form, the biking culture, and the transportation needs of commuters, are needed to support non-motorized transportation (Pucher, Dill, and Handy 2010).

Portland, Oregon, is an exceptional case among U.S. cities with higher levels of bikeability. Dill (2009) attributed the high bike-ability rates of this city (4.2% for daily job commutes) to its robust bike infrastructure. Bicycle boulevards contribute to a decrease in car traffic in these areas. Bicycle boulevards run parallel to major roads and intersect with them using traffic-calming features that prioritize bicycles over motor vehicles. In Portland, these boulevards are primarily located in older neighborhoods where the dominant street pattern follows a grid system of small blocks. About half of the total Bicycle Miles Travel (BMT) occurs on roads with bicycle lanes, paths, or boulevards. However, these facilities only comprise about 8% of the available network (Dill, 2009). This comparison illustrates the critical role of bike infrastructure on ridership.

Dill (2009) found that cyclists consider numerous factors when planning a route, including bike lane availability, road quality and signs, and the possibility of riding on an off-street bike path or trail and avoiding hills. In addition, this study suggests that cyclists tend to combine their biking trips to several destinations. This tendency, in turn, means that mixed-land uses, residential and commercial, can encourage biking. Overall, Dill (2009) illuminates the role of biking infrastructure, mixed land uses, and well-connected street networks to enhance bike ridership in U.S. cities effectively.

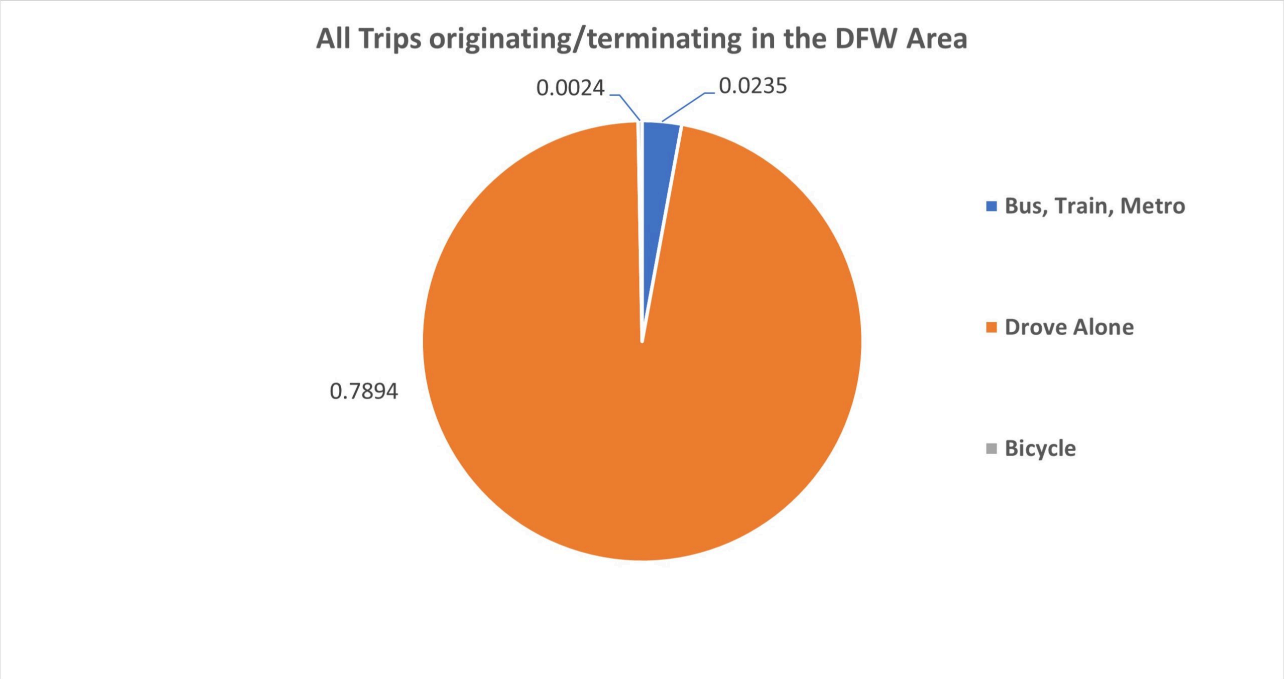
SUSTAINABLE MOBILITY AND BIKING IN EUROPEAN CITIES: LESSONS FROM COPENHAGEN AND VIENNA

This section examines cities that have successfully improved **sustainable transportation** through biking. Many European cities practice car- restrictive policies combined with compact, mixed-use development, which encourages the use and attractiveness of transit use and non-motorized transportation. Examples of restriction policies include increasing the cost of vehicle ownership, limiting the parking supply, and reducing car speeds, which reduces overall driving rates.

Copenhagen, Denmark

Copenhagen has continually succeeded in increasing bike ridership throughout the years. Copenhagen is one of the world's best biking cities because of commuters' sustainable travel behavior. The city has used three mechanisms to foster biking: market-based instruments, command-and-control approaches, and soft policy measures. Copenhagen uses multifaceted and coordinated transportation policies and market-based instruments like taxation or subsidies to influence travel behavior. **Congestion pricing** is an example of a market-based instrument. Command-and-control instruments or hard policies regulate different standards on goods and services. These standards are applied to urban design and land-use planning for travel behavior. Soft policies support socially desirable decisions and promote information in support of these decisions (Gössling, 2013). Examples of soft policies include campaigns to promote biking as a healthy and environmentally friendly transportation choice. Although studies concur that biking share has dropped globally while car use is still increasing, in some European cities, the trend is the opposite, and a renaissance has taken place in the last two decades (Gilbert and Pearl, 2007).

Historically, Copenhagen's commuters have preferred biking as their primary mode of transportation, even during the 1960s and 1970s when the car boom was sweeping cities worldwide. This historical and cultural preference remained significant through the 1980s and 1990s when the city implemented the first free bike-sharing program (Jeppesen, 2011). This rich history of biking in Copenhagen enabled a consolidated infrastructure for biking that allows 84% of all Copenhageners access to a bike. As a result, 68% of the commuters biked at least once a week, accounting for 1.2 million kilometers (about 745645.43 miles) traveled by bike in a working day (Gössling, 2013). Figure 9.1 shows the share of all intracity trips by different modes in Copenhagen, where biking has the second highest share.



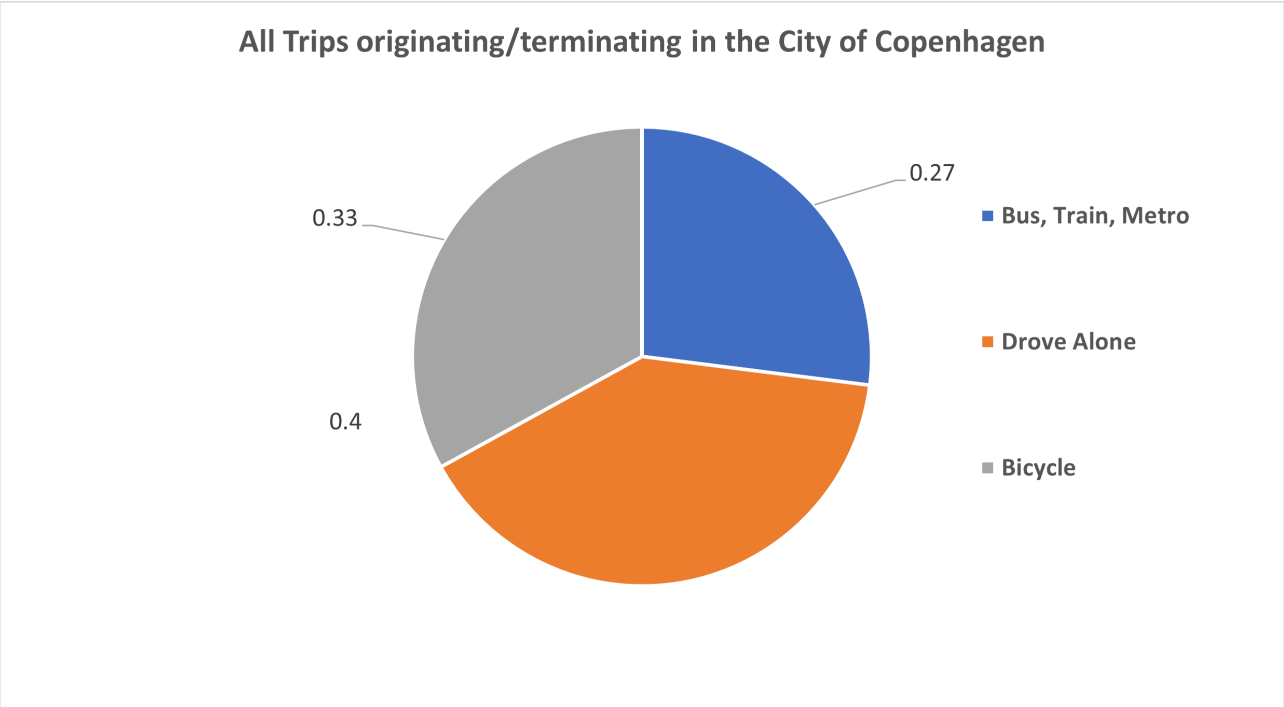


Figure 9.1 Modal share of urban trips in the City of Copenhagen Source: Adapted from Gössling, 2013.

Copenhagen uses key performance indicators (KPIs) to monitor biking. These indicators include the share of commuting cyclists, the percentage of cyclists that feel safe, total cycled kilometers, average cycling speed, the number of cycling tracks, green routes, and bike parking spaces on roads and pavements. The adoption of these performance indicators and the historical willingness of citizens to bike have led to the development of several command-and-control measures categorized as "physical infrastructure," "comfort and service," "technology development," and "regulation" (Gössling, 2013).

Copenhagen's robust biking infrastructure includes green cycle routes, biking superhighways, curbed ramps connecting elevated cycle tracks with roads, skewed rubbish bins along tracks, and footrests for cyclists. Bike services include green wave for cyclists, bike butlers at five metro stations that lubricate chains, and pump-up tires. Technological capabilities include planting LED (Light Emitting Diode) road sensors that warn drivers of approaching cyclists at intersections. Further command-and-control measures in Copenhagen include regulating and enforcing one-way streets with imitated parking spaces for cars while requiring bike parking spaces for different land uses such as commercial (0.5 bike parking spaces per employee) and residential (2.5 bike spaces per 100 m2) (Gössling, 2013).

Soft measures also support biking in Copenhagen. These measures carefully understand cyclists' needs, educate citizens about the societal benefits of biking, and communicate how programs and policies support biking. Soft measures disseminate three initiatives: a desirable and sustainable urban future, individual and societal benefits, and opportunities for participation and engagement in **transportation policy** making.

We learn from Copenhagen that a suitable combination of measures, policies, and programs enhances sustainable and equitable commutes. Also, the success of biking is explained by the historical roots of environmental movements that called for biking and pedestrian infrastructure rather than roads and highways. It is, therefore, uncertain that the renaissance of biking will overcome the growth of driving in other cities. However, momentum for biking trips can occur (despite rising car numbers) when residents and governments collectively support biking infrastructure. As exemplified by Copenhagen and other European cities, as the number of cyclists increases to reach a critical mass, cyclists become visible, thus improving perceptions of safety and, consequently, the number of cyclists (Jacobsen, 2015).

Vienna, Austria

Vienna is another illuminating city that has successfully enabled sustainable transportation modes. The city has decreased the share of car trips from 40% to 27% from 1993 to 2014 (Buehler, Pucher, & Altshuler, 2017). The critical point in Vienna's success is a coordinated package of coherent and reinforcing land-use and transportation policies that increase driving costs while improving the attractiveness of walking and biking conditions (Buehler, Pucher, and Altshuler, 2017). The city of Vienna, like Copenhagen, has a long history of resistance to cars. The city's urban form remains compact and monocentric with mixed-use development, allowing short trips, which enable commuters to walk to public transport (Csendes and Opll, 2006). Moreover, the widespread public opposition to the construction of motorways (autobahns) during the 1970s and 1980s crippled car-dependent transport plans and paved the way for sustainable mobility.

Parking management strategies and car-restrictive measures have enabled the city to realize a substantial modal shift toward sustainable transportation. As a result, 52% of total commuters use transit for daily trips, 76% at least once a week, and 88% at least once a month (Buehler, Pucher, & Altshuler, 2017). Since 1993, parking management has limited parking supply through price increases and minimized curb parking time. Despite initial opposition to the plan, **traffic congestion** on roadways quickly started to drop after its introduction. However, the government builds off-street self-financing parking garages to maintain the parking supply balance.

Additionally, restrictive car travel programs such as high taxes and fees on car purchases and ownership have allowed the city's multimodal and comprehensive transport policy to succeed.

Importantly for sustainable mobility, the government supports a multimodal transportation system that connects the U-Bahn (metro) with car-free zones, bike paths, lanes, and parking throughout the city (Buehler, Pucher, and Altshuler, 2017). The city implemented policies that helped improve and expand high-capacity transit (the U-Bahn subway). The previous existence of a tramway since 1910 enabled the construction of the subway. The coordination of these policies is essential for the city's success. For example, the tram's ridership increased during the expansion of the U-Bahn, from 242 million in 1990 to 294 million in 2013 (Buehler, Pucher, & Altshuler, 2017). The public transit investment funding structure has been devised to support regional coordination of the whole project. "Whereas the city of Vienna owns and operates the U-Bahn, the federal government owns and operates the regional S-Bahn rail system. The federal government also finances 80% of S-Bahn capital costs, excluding station upgrades, and 100% of S-Bahn operating subsidies for a basic level of service, defined by the 1999 Federal Public Transport Act as the level existing in 2000" (Buehler, Pucher, and Altshuler, 2017, p.15). Local resources for public transit projects come from passenger fare revenues, taxation of large employers, and revenues from on-street parking and city-owned parking garages. These resources are mainly allocated to public transit improvement, park-and-ride facilities, and bike infrastructure (Vassilakou, 2015).

Improving walking and cycling conditions is a complementary part of Vienna's integrated and coordinated package of sustainable transport policies. In Vienna, 95% of the access/exit trips to and from public transit are done by walking. Walking accounts for 28% of all trips (Buehler, Pucher, & Altshuler, 2017). The city supports walking by expanding pedestrian and car-free zones, designing shared streets prioritizing walking and biking, and traffic-calming design techniques. Despite the initial opposition of different businesses and motorists towards cycling lanes on the city's streets, a six-fold expansion of biking facilities was observed in the city in the past two decades. Additionally, installing traffic-calming infrastructure on 75% of the streets further reinforced cycling, allowing for the introduction of the bike-sharing system called CityBike in 2003 (Buehler, Pucher, & Altshuler, 2017). Several factors, including funding mechanisms, transportation infrastructure, and policies, contribute to the success of sustainable transportation modes. The cooperation of federal and local governments, stakeholders, and coalitions supports the realization of Vienna's multimodal transportation system (Buehler, Pucher, and Altshuler, 2017). These multi-faced practices of sustainable transport policies generate valuable lessons for other cities.

BIKE SHARING IN NEW YORK CITY: AN EQUITY PERSPECTIVE

This section examines the experience of New York City's bike-sharing programs and their environmental and social equity implications. Bike-sharing systems (BSS) have existed for decades in European countries. In the U.S., these systems are relatively new but rapidly growing (Parkes et al., 2013). The effectiveness of BSS in reducing car driving and congestion depends on social participation and the subsequent modal shift from private cars to biking (Wang and Zhou, 2017).

Amsterdam housed the first bike-sharing system in 1965. In the first implementation phase, it failed quickly due to theft issues and a lack of security. ICT systems and fixed-docking stations enabled a new generation of BSS, which increased from 13 to 855 from 2004 to 2014 (Fishman, 2016). The anticipated benefits of BSSs can be classified into four categories: 1) congestion and air pollution mitigation, 2) flexible mobility and transportation connection improvements, 3) health promotion, and 4) consumer financial savings. To assess the benefits of BSS, Wang and Zhou (2017) conducted an empirical study to understand the relationship between BSS and congestion using data from 96 U.S. urban areas from 2005 to 2014. This study indicates that bike-sharing programs have mixed effects on cities across the U.S. For example, larger cities benefit more from bike-sharing programs on congestion reduction than smaller cities. Because big cities have better public transit systems, BSS stations near public transit hubs increase multimodality and encourage people to use these facilities. While controlling for population growth, the study also acknowledges that cities with BSS tend to have congestion growth at a slower rate than cities without BSS.

The impact of BSS on other sustainable modes, such as public transit ridership, has been scrutinized by previous studies. A recent study by Campbell and Brakewood (2017) showed that every thousand bike-sharing docking stations along a bus route is associated with a 1.69% fall in daily unlinked bus trips on roads in Manhattan and Brooklyn after controlling for the expansion of bike lanes. These findings show how BSS can reduce congestion by facilitating public transit and promoting multimodal and sustainable transportation (Wang and Zhou, 2017). However, BSSs may have serious social and spatial equity implications that need careful consideration and performance evaluation before and after implementation.

This section examines the equity implications of Citi Bike, the largest bike-sharing program in New York City. With a high percentage of the population living in high poverty, New York City is a good case study to examine the implications of spatial equity and health benefits associated with bike-sharing programs. Citi Bike in NYC was launched in 2013 with 335 bike share stations and around 5,400 bikes. This program was concentrated around the CBD of lower Manhattan and adjacent parts of Brooklyn. 2015 this program underwent its first expansion phase by adding contiguous neighborhoods in 114 new stations. The initial mapping of the Citi Bike stations showed that 40% of the stations were in high-income tracts. In contrast, very high-poverty census tracts have access to less than 10% of the stations even after expansion in 2015 (Babagoli et al. 2019).

This situation reveals equity issues in expanding biking infrastructure in New York City. The stations are located disproportionately in wealthier neighborhoods. However, after system expansion, the average duration of daily Citi Bike utilization increased by 41%. The number of premature deaths prevented yearly increased from two to three, emphasizing the mortality benefit of such active and sustainable transportation infrastructure (Babagoli et al., 2019).

This study indicates that bike-sharing programs can support cycling and improve health outcomes, even in racially and economically segregated cities. Due to the association between bike station proximity and shared bike usage, we can conclude that with an equitable bike-sharing program that provides easy access to everyone, especially disadvantaged groups, planners can reduce inequality and enhance multimodal transportation usage while supporting public health (Babagoli et al., 2019). Expanding the Citi Bike program into poorer neighborhoods may even bring higher benefits for transportation equity. Fewer residents from higher-poverty neighborhoods were bike-share members; however, after adjusting for **spatial accessibility**, residents from higher-poverty neighborhoods utilized the bike-share system more than residents from lower-poverty neighborhoods (Ogilvie and Goodman, 2012).

Moreover, several benefits are associated with BSS programs, such as improved cognitive function and productivity, increased sustainable access to jobs and education for all groups, and normalizing bike usage, especially in a highly car-oriented context. The NYC Better Bike Share Partnership, consisting of multi-sectoral stakeholders, was launched in 2015 to increase Citi Bike membership. This partnership has taken considerable steps toward equity and inclusion of this program by including representatives from community-based organizations, hospitals, and public housing to diversify bike-share riders through more inclusive programs and policies (Babagoli et al., 2019). Partnerships promoting biking may serve to promote biking as an efficient, healthy, affordable transportation mode. More importantly, biking infrastructure may support the commutes of the poorest commuters who often bike because they lack access to reliable cars.

SUMMARY

This chapter discusses the challenges and benefits of bike infrastructure and usage based on experiences in American and European cities. First, the chapter examines the built environment and sociodemographic factors influencing bike usage, including street connectivity, safety, block size, and land use mix. Next, this chapter provides some insights into the factors that undermine bike usage in US cities as a primary mode of transportation. Also, it highlights the city of Portland as an illuminating American city that has successfully supported bike infrastructure and use. Next, the chapter delves into the case studies of Copenhagen and Vienna as two of the most bikeable cities in Europe and worldwide. Finally, this chapter describes some equity challenges associated with bike-sharing programs drawing from the case of New York.

Glossary

- **Non-Motorized transportation** is walking, cycling, and other forms of small-wheeled, human-powered mobility are all considered non-motorized means of transportation. These forms of transportation, except for walking, use non-motorized vehicles such as bicycles, skateboards, push scooters, wheelchairs, and rickshaws (Wikipedia, n.d.).
- **Sustainable mobility** includes the critical notion of access to mobility, regardless of income or location. Also, equity in accessibility, with particular attention to more vulnerable groups of the population and geographical areas at risk of social exclusion (Neste, n.d.).
- **Spatial accessibility** is the ease with which community inhabitants may physically access facilities, which is referred to as spatial accessibility.

Prep/Quiz Questions

- What can transportation planners learn from Bixi and the European cycling infrastructure? Please draw on the examples provided from Vienna and Copenhagen.
- What are the challenges of non-motorized transportation in the United States? You can categorize these issues into classes: lack of multimodal transportation infrastructure, safety issues, land-use planning issues, etc.
- More specifically, in New York City, what are the strengths and weaknesses of Bixi as a bike-share provider?

- How equitable is the access to the Bixi system among the residents of New York City? Who benefits the most from it? Should Bixi expand its area of operation beyond NYC? If so, where should it be developed?

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PART III.

SECTION 3 GREENHOUSE GAS EMISSIONS, CITIES, AND MOBILITY

CHAPTER 10.

TRANSPORTATION AND CLIMATE CHANGE MITIGATION: A LIFE-CYCLE ASSESSMENT PERSPECTIVE

CHAPTER OVERVIEW

This chapter is divided into three sections. The first examines the significance of transportation for domestic and global GHG (Greenhouse Gas) emissions in the United States and provides a global perspective of how this contribution varies in other countries. The second uses life-cycle assessment as a comprehensive methodological approach to estimate **GHG emissions** associated with constructing and using transportation systems. Next, the chapter examines the transportation sector's contribution to national and global GHG emissions.

Learning Objectives

- Explain the benefits of **Life Cycle Assessment (LCA)** as a methodological approach to measuring the contribution to GHG emissions and air pollutants by transportation.
- Estimate the significance of transportation, specifically private transport, to domestic and global GHG emissions.
- Compare how the share of transportation-related GHG emissions differs between developed and developing countries, identifying the factors that drive these differences.
- Contrast how driving, public transit, and non-motorized transit use rates vary among U.S. cities.
- Estimate the **carbon footprint** associated with commuting patterns across various U.S. cities.

CITIES, TRANSPORTATION, AND CLIMATE CHANGE MITIGATION

Large cities are the most significant contributors to GHG emissions because they concentrate the largest populations and activities. As mentioned in Chapter 1, U.S. cities are among the top emitters of GHG emissions associated with transportation partly due to urban form-related variables, including low-population density, fewer public transportation options, and difficult access to public transit. On the other hand, European cities are more compact and have various mobility options. As a result, low-density communities, like those in the United States, where most individuals commute between their places of origin and destinations alone in private vehicles, have greater transportation energy consumption. Cities in the Global South tend to have even denser populations and greater access to public transportation. Therefore, these cities consume less energy for transportation than developed-world cities do. In addition, people typically walk and take public transportation in the **Global South** (Guerra et al., 2020). As a result, Global South cities tend to contribute less to GHG emissions and use less energy than most developed-world cities, mainly low-density and automobile-dependent ones.

As discussed in Chapter 1, the contribution of urban residents to GHG emissions largely depends on several factors, including population density and the proximity of residences to job locations. For example, residents of compact urban areas in central locations contribute significantly less than residents in the suburbs, as exemplified by Toronto, Canada, in the study conducted by Norman et al. (2006). Therefore, GHG assessment requires a thorough understanding of urban densities and how commuters use motorized vehicles, transit, and non-motorized transportation systems to get to places.

Climate change mitigation of greenhouse gas emissions is one of cities' and countries' most critical environmental and social challenges. Cities are essential in climate change mitigation because they contribute to 70% of global GHG emissions, projected to reach 76% by 2030 (Chambers & Nakicenovic, 2008). As mentioned in Chapter 2, another significant issue that imperils commuters worldwide and transportation systems is the connection between transportation and climate change. Extreme climatic events threaten vehicles' infrastructure, procedures, and urban mobility, even though transportation energy usage is the primary source of GHG emissions in U.S. cities (Jochem et al., 2016; Moretti & Loprencipe, 2018).

However, the contributions of cities in the North and the South significantly vary. Developed cities in the **Global North** are the largest emitters of GHG emissions due to the large concentration of population, activities, and unsustainable energy-use practices. Table 10.1 illustrates how the contributions of countries and cities differ. Large cities with high population densities allow efficient and widely used transportation systems while enabling non-motorized transportation and economies of scale. For instance, Buenos Aires contributes less than smaller Argentinian cities, such as Avellaneda, and its contribution is less than the national average in Argentina. Likewise, U.S. cities in the Northeast, like Philadelphia, which tend to have dense urban centers and relatively good transportation, contribute less than car-dependent cities, such as Austin, Texas. European countries illustrate how tight urban areas moderate the contribution of GHG emissions. The national average is smaller in countries like Norway and France than in their capital cities.

Interestingly, China's national average GHG emissions (3.25 TCO2 per capita) are smaller than big, modern cities like Shanghai (12.6 TCO2e). Shanghai could be among the world's top 40 countries in terms of GHG emissions if it were an independent country. China's large population densities and the low energy consumption of residents in urban and rural areas may explain China's low per-capita contribution. However, because China is still rapidly urbanizing, its contribution to GHG emissions is growing, and now it is the most significant contributor if we consider the total emissions of the entire population (Hoornweg, Sugar, & Trejos Gómez, 2011).

The contribution of cities and countries to GHG emissions highly depends on how economies use energy and resources. To better mitigate GHG emissions, researchers should carefully understand how different economic sectors, such as buildings and transportation, use energy and resources. As mentioned in Chapter 2, the fastest way to reduce car driving and thus mitigate greenhouse gas emissions in the transportation sector is to improve commuters' access to multimodal transit, such as the interconnection of the subway, buses, and biking infrastructure. Also, land-use planning can help reduce car driving through enhanced community design, walkable streets, and diversified land uses. Fostering greater densities, above 40 people per hectare, mixed-use complexes integrating residential and commercial land use, and accessible linkages to public transportation hubs are alternate growth patterns that might enable sustainable cities. Sustainable mobility demands excellent land-use planning and transportation integration to reduce commuting times and facilitate multimodal shifts. A population with the proper density can improve quality of life by reducing reliance on cars.

Another factor is the extent of population densities and peoples' income and energy-use practices. Low-income residents use less energy and contribute less to emissions than wealthier families. However, cities may influence energy consumption. For instance, despite the average income in Denver ($65,400) being lower than that of the New York Metro area ($73,000), the average energy consumption of an NYC resident was nearly half that of a Denver resident. This discrepancy is mainly attributable to higher urban density in New York and lower dependency on private cars for daily commutes. This situation reveals that cities offer the most significant opportunities to reduce the energy consumption of buildings, infrastructure, and residents' transportation practices while supporting social justice. In addition, cities matter for climate change because low and emerging countries and cities in the Global South are perhaps the most vulnerable to extreme climate events, even though they tend to contribute less to GHG emissions (Darmstadter, 2010).

Also, GHG emissions vary significantly at the neighborhood level. For example, a study by Vandeweghe and Kennedy (2007), which analyzed the consumption-based and production-based transport emissions by census tracts for Toronto, found that residents in the city core produced 6.42 tCO2e per capita compared to 7.74 tCO2e per capita for residents in the surrounding suburbs. These suburbs were mainly affluent neighborhoods with high auto dependency and old, inefficient homes. Additionally, they found that the lowest emission was 1.31 tCO2 per capita for a dense inner-city area with good access to public transportation. Also, the highest emissions were 13.02 per capita in distant suburbs.

Cities and regions are the focal points of climate change mitigation due to the high concentration of emissions in these areas. Still, they provide a unique opportunity to mitigate per-capita GHG emissions through local policy tools, which can directly and promptly affect residents' travel behavior and energy-use practices (Hoornweg, Sugar, & Trejos Gómez, 2011). As explored in previous chapters, some cities have used comprehensive transportation and land-use planning policy approaches and have combined several interventions, including parking pricing, **congestion pricing**, and dense and integrated land developments. These cities include Singapore, Stockholm, San Francisco, and London. They all have influenced commuter travel behavior and support sustainable communities. The initial step for devising policy tools to address climate change and GHG emissions is to explore the sources within each urban settlement. For example, a highly industrialized city may produce high production-based emissions, while a knowledge-based economy in a city with public transit may produce significantly lower emissions.

Table 10.1 Average per-capita CO2 emissions of cities and countries in the Global South and North. A comparative perspective

Country GHG emissions (tCO2e/capita)	
Argentina	7.64
Buenos Aires	3.83
Avellaneda	6.53
Norway	11.69
Oslo	3.5
China	3.4
Shanghai	11.7
India	1.33
Delhi	1.5
France	8.68
Paris	5.2
Italy	9.31
Bologna	11.1
Czech Republic	14.59
Prague	9.4
USA	23.59
Austin	15.57
Philadelphia	11.1
Los Angeles	13
Mexico	5.53
Mexico City (City)	4.25
Mexico City (Metro Area)	2.84

Adapted from "Cities and greenhouse gas emissions: Moving forward" by Hoornweg, D., Sugar, L., & Trejos Gómez, C. L., 2011, *Environment and Urbanization, 23*(1), p.211, Copyright 2011 by International Institute for Environment and Development (IIED)

LIFE-CYCLE ASSESSMENT IN TRANSPORTATION

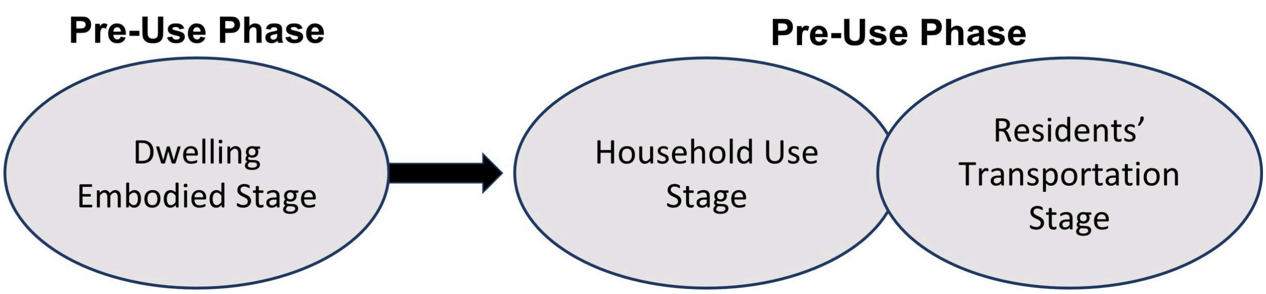

Figure 10.1 Life-Cycle Assessment. A comprehensive environmental impact assessment to evaluate residential land use and transportation systems. Adapted from "A comprehensive assessment of the life cycle energy demand of passive houses" by Stephan, A., Crawford, R. H., & De Myttenaere, K., 2011, Applied energy, 112, 23-34, p.25, Copyright by 2013 Elsevier Ltd.

Life-cycle assessment (LCA) is an **Environmental Impact Assessment** method for thoroughly assessing energy use and greenhouse gas emissions associated with buildings, infrastructure, and technological innovations (Fuller & Crawford, 2011; Ramesh et al., 2010; Stephan et al., 2011). Data about systems, technologies, and infrastructure can be separated into two main life-cycle phases: embodied and operating. The embodied phase (also called the construction phase) includes the use of energy, resources, and materials that result from the manufacture of building materials, the transportation of materials to the construction site, the construction of infrastructure and technological innovations, and demolitions, as well as the disposal and recycling of materials (see Figure 10.1). In transportation, the operating phase includes using energy, resources, and materials that result from using infrastructure or transportation, which means commuters use them during a trip.

LCAs of residential land-use Planning in developed-world Cities

This section analyses significant LCAs (**Life Cycle Assessments**) of residential land use in established cities to determine the energy usage in residential land use and transportation. In Toronto, low-density suburban development is 2-2.5 times more energy intensive in terms of energy use and GHG emissions than high-density, urban core development, according to Norman and colleagues' full life-cycle assessment, which included embodied energy, operating energy, and residents' transportation energy (Norman et al., 2006). Additionally, they discovered that inhabitants' fuel use is influenced by transportation energy since suburban development boosts automobile utilization (Norman et al., 2006). An in-depth analysis of the energy use of typical single-family homes in Belgium was performed by Stephen et al. in 2011. They discovered that home energy usage was primarily driven by transportation, which accounted for 34-51% of the whole life-cycle energy consumption, and domestic appliance operation, which accounted for 24% of the total life-cycle energy consumption (Stephan et al., 2011a). According to the LCA findings of Norman et al. (2006) and Stephan et al. (2011a), transportation energy dominates residential energy usage in the total life-cycle of energy when taken into account. Accordingly, it can be deduced from prior GHG evaluations that urban density and the accessibility of housing projects to transportation networks affect how much fossil fuels commuters consume to go to and from places of residence to areas with plenty of jobs (Fuller & Crawford, 2011; Lee & Lee, 2014; Stephan et al., 2011a).

i. Methodological debates

Methodological debates regarding the use of LCAs in residential land use analysis focus on the scope of life-cycle assessment. In other words, LCAs of residential land use differ in the extent to which life-cycle phases are analyzed. Although transportation energy accounts for the highest energy use in residential developments, most LCAs completely disregard it (Ramesh et al., 2010). Most GHG assessments in the housing sector examine dwelling embodied energy or operating energy use but ignore residents' transportation energy use (Verbeeck & Hens, 2010). Stephen et al. (2011a) argue that a more holistic approach to assessing energy use in dwellings is indispensable to effectively mitigating GHG emissions in residential land-use planning. They suggest widening the typical scope of analysis, currently restricted to household energy use, to also account for dwelling embodied energy, including incremental housing construction practices over time (Verbeeck & Hens, 2010), but more importantly, to account for residents' transportation energy (see Figure 10.2) (Stephan et al., 2011a).

ii. Limitations of life-cycle assessment

This section discusses some of the limitations of the life-cycle review of residential land use as an environmental impact assessment method developed and implemented in the context of developed cities. Also, this section considers that LCA has been informed solely by quantitative approaches that cannot explain the complex nature and extent of energy use in residential land use. In doing so, the section explores the possibility of informing LCA with the qualitative assessment that may better explain the complexity of energy use in land-use residential planning.

Most GHG assessments in the housing sector have been conducted in developed-world cities, particularly in North America and Europe (Ramesh et al., 2010). Therefore, it can be argued that there is a poor understanding of the contribution to GHG emissions of housing units in these cities. This situation suggests that a life-cycle assessment of residential land use in developing global cities could better understand energy use characteristics and extent and compare different types of residential development (Stephan et al., 2011a).

The second methodological debate over previous LCAs in the residential sector suggests that for life-cycle assessment to be practical, it must include the complete life cycle of the housing unit as an interconnected system incorporating sub-systems. An incomplete review of the housing unit's life cycle can lead to an incomplete and misleading understanding of related energy use. In the case of residential land use, the housing unit can be considered a system that includes dwelling units, infrastructural elements, people using energy in dwelling units, and people conducting everyday transportation activities to and from those units (Stephan et al., 2011a).

Third, life-cycle assessment overly relies on quantitative methods, particularly statistical analysis and surveys. LCA has been widely applied in engineering to compare the environmental impacts of well-defined systems, such as conventional cars and electric automobiles (Matsuhashi et al., 2000). Therefore, engineers should use planning research methods to complement the current quantitative methods in LCAs. These planning methods include surveys, in-depth interviews, and the collection of oral stories of residents to reveal the complex nature of energy use and the obstacles and opportunities to supporting climate change mitigation and, at the same time, keeping the living conditions.

EXAMPLES OF LCA IN TRANSPORTATION

This section examines past LCAs, exploring how the built environment and transportation infrastructure influence GHG emissions. Integrated transportation and land use (ITLU) life-cycle assessment can yield information about behavioral changes associated with urban transformation, informing decisions about urban infrastructure policies regarding environmental outcomes (Chester et al., 2013). ITLU-LCAs assess the ecological impacts of residential land use and transportation associated with residential and commercial travel and identify socially and economically sensitive land-use configurations that may support climate change mitigation and housing affordability.

Chester et al. (2013) examined the environmental implications of the Phoenix light rail infrastructure. Changes in energy use, GHG emissions, and other pollutants have been monitored and assessed for over 60 years due to investment in transit-oriented developments (TOD). This study selects different types of neighborhoods (low-income with vacant lots, middle-income and detached housing units, and areas near downtown) for analysis. One of the critical factors for TOD development is the 0.5-mile walking distance from the station (Cervero, 2004); thus, sites meeting this criterion were selected. This study considered four development scenarios, including (i) low-density development on vacant and surface parking by constructing single homes, (ii) high-density residential development along with multistory commercial spaces, (iii) new construction on vacant lands and parking surfaces and the reuse of existing buildings, and (iv) demolition of all residential, commercial, and industrial buildings in the lowest quartile of market value and replacing them with new high-density mixed-use buildings. This study revealed that infill development with the availability of public transit amenities has a great potential to reduce life-cycle energy consumption and GHG emissions. Moreover, social benefits were anticipated with more intense and denser development.

This comprehensive LCA assessment found that transportation and building are responsible for 22-51% and 22-44% of energy consumption and GHG emissions, respectively. Commercial activities have 1.9-3.3 times more significant effects than residential ones. 31% saving in life-cycle energy consumption can be achieved in scenario 1, and in the other three scenarios, this saving can be as high as 42%. Analyzing scenario 1, which only focuses on infill development, shows that locating households near transit stations rather than sprawled neighborhoods produces an opportunity to shift from private cars to mass transit and shorter travel, resulting in significant savings in life-cycle energy consumption. Based on scenario 2, substituting a single home with a mixed-use high density will increase these savings by 38. For the construction phase, high-density residential development produces 1.5-3 times more energy impacts per dwelling unit in the construction phase but generates 10% less energy use in 60 life-cycle spans. Exploring the four scenarios for commercial land use shows that locating commercial establishments closer to the core with access to public transit reduces automobile use for shopping trips, reduces the distance of average shopping trips, and induces shopping trips via public transit even from outside the area. It is interesting that in scenarios 2-4, nonresidents' energy use reductions are 2.2-4.4 larger than reductions from residents inside the TOD area. Such findings suggest that implementing environmental policies and programs can benefit city-wide. In general, it can be stated that LCA can yield various kinds of conclusions for different phases, which is crucial for policymakers in designing programs. Built environment and land-use planning significantly influence environmental issues like energy savings and GHG emissions. However, understanding the interplay between various factors, from the building phase, electricity provision, travel behavior, travel costs, etc., is crucial for long-term planning and design (Chester et al., 2013).

The induced impacts of the built environment as a result of the interplay between individual building construction and urban scale is another subject that this chapter intends to unpack. The energy consumption of the building and transportation sectors will likely increase between 20% and 44% from 2009 to 2035 (Birol, 2010). Induced impacts in this subject refer to interactions between individual buildings and their surrounding context. In a study in Munich, Germany, Anderson, Wulfhorst, and Lang (2015) examined the induced impacts associated with buildings and the urban context via transportation measures using a life-cycle assessment perspective. These measures include the transportation use phase and the embodied effects of transportation infrastructure and vehicles. Munich's rich transportation network supports mass transit, walking and biking, and automobiles. For this analysis, three types of development in Munich were selected: city center, city periphery, and district locations (outside Munich).

A preliminary analysis of the dataset used in this study showed that Munich residents have a modal split of 27% driving private cars, 10% riding personal vehicles, 21% public transit, 14% biking, and 28% walking. This share differs in the city's outskirts, where 17% drive a private car, 15% ride personal vehicles, 7% ride public transit, 11% cycle, and 20% walk. This study found that the city center has the lowest total emission, and the periphery area and the city are 18.5% and 33.5% higher than the city center. Analyzing operation costs of transportation shows that, on average have lower travel distance and CO_2e emissions. However, since Munich has a well-developed public transit system that covers almost the entire city, a transparent decreasing gradient for travel distance cannot be seen from the city center to the periphery. This situation again highlights the importance of public transit in realizing environmentally friendly goals. The road network has the lowest emissions from embodied (construction and materials) transportation impacts.

In contrast, public transit infrastructure has much higher embodied impacts because constructing tunnels and bridges significantly requires high amounts of materials and energy. However, private cars are the largest emitters of GHG emissions partly because of the considerably shorter life span of vehicles compared to public transit vehicles. Also, the high number of cars and long commutes increase the embodied costs of roads and the fossil fuels consumed in trips. Furthermore, the production of cars has significant embodied impacts, which increase the total share of GHG emissions associated with private cars (Anderson, Wulfhorst, & Lang, 2015). Overall, this section reveals the importance of comprehensively examining the impacts of transportation systems, from the extraction of materials to the construction and use of vehicles. Another essential element is the comparative analysis of how commuters in different locations within metropolitan areas and cities, urban locations versus suburban and peripheral zones, contribute to GHG emissions.

CONCLUSION

Overall, this chapter reveals the importance of a comprehensive examination of the impacts of transportation systems, from the extraction of materials to the construction and use of vehicles. Another essential element is the comparative analysis of commuters' contributions in different locations within metropolitan areas and cities, suburban and peripheral locations. Finally, the place of residential development within urban areas determines how residents use transportation energy for daily commutes. Those in the suburbs tend to contribute less because they travel longer distances in automobiles.

Glossary

- **Carbon footprint** is the volume of carbon dioxide and other carbon compounds released from a specific individual, organization, or other entity using fossil fuels (National Park Service, n.d.).
- **Climate change mitigation** implies preventing or limiting the amount of greenhouse gas emissions released into the atmosphere to stop the world from warming to more extreme levels (World Wildlife Fund, n.d.).
- **Environmental impact assessment** Before deciding to take the suggested action, a strategy, policy, program, or actual project is evaluated for its potential impact on the environment—the phase in this situation. (Climate Change Scavenger Hunt – National Park Service, https://www.nps.gov/teachers/classrooms/climate-change-scavenger-hunt.htm)

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CHAPTER 11.

ENVIRONMENTAL IMPACT ASSESSMENT: DATA, METHODOLOGICAL APPROACHES, AND EXAMPLES

INTRODUCTION

This chapter is divided into two sections. The first section describes environmental, economic, or social impact assessments to evaluate the implications of transportation for cities, people, and greenhouse gas emissions. This section describes quantitative, qualitative, and mixed-method approaches to inform environmental, economic, or social impact assessments. The second section focuses on environmental impact assessments of GHG emissions in transportation. The third section presents exercises and examples for estimating the greenhouse gas emissions associated with transportation systems, commuting patterns, and city planning factors. The first exercise calculates the carbon footprint of faculty, students, and staff related to their commutes from their residences to the University of Texas at Arlington. The second exercise uses a life-cycle assessment perspective to compare GHG emissions associated with transportation systems, including cars, carpooling, the subway system, and buses.

METHODOLOGICAL APPROACHES

Research approaches can be categorized according to how planners address research questions. They can use qualitative, quantitative, or mixed-method approaches in planning research to inform environmental, economic, or social impact assessments. In addition, literature reviews may help reveal methods that previous scholars used to address similar research questions and issues. The following section briefly describes the qualitative, quantitative, and mixed process approaches commonly used in planning research.

Qualitative approaches

Qualitative approaches help researchers understand how and why communities and cities are impacted or benefited by planning. For example, researchers may use ethnographic methods to reveal people's stories, perceptions, and everyday experiences (Creswell, 2003b). The following section discusses case studies and interviews as two methodological approaches of qualitative research that can inform environmental, economic, and social impact assessment in residential land use and transportation.

Researchers use case studies to explore a well-delimited community, city, or a set of communities over time through detailed and in-depth data collection processes involving multiple information sources (Creswell, 2003b). Researchers should strategically select case studies to make more generalized conclusions from the data collected (Francis et al., 2010). Also, interviewing is part of qualitative research that allows interaction between researchers and participants (Denzin & Lincoln, 2008). Interviews require more careful consideration of how to access the study context and an understanding of the language and culture of respondents. Participants could become partners who guide researchers in research design (Sletto, 2012).

Quantitative approaches

Quantitative research is based on empirical and statistical analyses conducted to understand the relationships among the variables that explain situations and phenomena (Shadish et al., 2002). For example, in transportation planning, scholars often use urban form variables, such as population density and interconnectivity and people's income and ethnicity, to understand how transportation systems support mobility. One standard method that planners use to examine quantitative data is surveys. A survey or a questionnaire is a research tool, the primary function of which is to enable the measurement of data (Oppenheim, 1992). Some surveys inform databases that planners use, such as the American Community Survey, the origin-destination survey, or a survey that the researchers designed to explore commuting practices in a selected community. Databases may be publicly available or require empirical research and intensive fieldwork.

Mixed-method approaches

Mixed-method approaches include both qualitative and quantitative methods (Creswell, 2003a). Mixed-method approaches combine the advantages of both quantitative and qualitative methodologies to strengthen the validity and reliability of data. John Gaber highlights the benefits of *mixed-method design,* in which a researcher triangulates and corroborates outcomes from both quantitative and qualitative methods and increases the validity of results. A mixed-method research design complements the products obtained by qualitative and quantitative approaches. It enriches the understanding of the phenomenon being studied, allows comparisons and revisions, and improves the quality of questions and results from one research approach to others.

ENVIRONMENTAL JUSTICE ASSESSMENT IN TRANSPORTATION

Bullard (1997) argues that low-income communities of color disproportionately endure the highest transportation burdens. They usually live in communities that lack easy access to efficient and affordable systems and have less access to reliable private vehicles to get to places. Also, historically, low-income African American communities were disproportionately affected by the construction of highways (Bullard & Johnson, 1997). Despite the progress in transportation justice policies in the last five decades, low-income communities of color continue to live far from employment centers located in suburban locations. Low-income commuters often have unreliable cars and thus depend on public transit or affordable alternative car-sharing programs. On the other hand, wealthier communities benefit from transportation improvements, investments, policies, and subsidies, while others remain neglected (Bullard & Johnson, 1997).

To support transportation justice for vulnerable communities, planners should conduct empirical environmental justice assessments to reveal how transportation infrastructure supports or undermines community economic and social development. More importantly, ecological justice assessments should focus on low-income communities and have a comprehensive approach that includes housing and transportation. The evaluation should identify the obstacles that undermine mobility. This approach may also help reveal opportunities to increase affordable housing developments with access to transportation systems.

The National Environmental Policy Act (NEPA) provides a helpful guide to community-based environmental justice assessments[1]. According to NEPA, these assessments should use a comprehensive and dynamic approach that includes the following concepts:

- Meaningful engagement of vulnerable communities

- A careful understanding of the affected area or environment
- Identification of minority and low-income populations
- Impact Analysis of Communities
- Identification of disproportionately high and adverse impacts on vulnerable communities and ecosystems,
- Alternatives to mitigate the social and environmental harms
- Mitigation and monitoring.

Planners play a significant role in encouraging the meaningful involvement of vulnerable communities in environmental justice assessments. However, engagement may overlook and severely affect identified minority and low-income populations. Although the ecological justice assessment promoted by NEPA and the U.S. Department of Transportation represents a significant step toward supporting environmental justice issues, these assessments lack a comprehensive socio-ecological approach. Thus, the scope of the NEPA analysis should be expanded to understand better how transportation projects influence the living conditions and environmental quality of communities and the built environment. This comprehensive approach may help envision effective mitigation solutions (NEPA, 2019).

Cost-benefit analysis

Cost-benefit analysis may also serve as a practical methodology to understand and balance investment and operational costs of transportation and their potential benefits and impacts on cities, communities, and the environment. For instance, public transit may improve communities' and cities' access to transit and provide efficient and affordable alternatives to private vehicles. The potential benefits of transit include reducing car driving and traffic and, thus, improving air pollution since some drivers may switch to transit or drive less. Another potential impact is improving the household economies of low-income commuters who may have better access to transit services. Those using cost-benefit analysis should carefully determine the scope of their research to understand how city investments in transportation provide economic development, environmental quality, and social justice benefits. (Chapter 7 provides insights into the cost-benefit analysis of railroad and **high-speed rail systems**.)

ENVIRONMENTAL IMPACT ASSESSMENTS IN TRANSPORTATION: THE EXERCISES

The third section presents exercises and examples for estimating the greenhouse gas emissions associated with transportation systems, commuting patterns, and city planning factors. One of the most essential methodological considerations is to explain the scope of the analysis and determine the units of study. Next, researchers may proceed to identify data that may inform their assessments. The exercises presented in this section solely use quantitative research approaches and publicly available data. These assessments may use the Census Bureau on transportation statistics or the American Community Survey. Finally, researchers can develop their calculations or use calculation sheets to help them elaborate on environmental impact assessments.

The Carbon Footprint of Daily Commutes to Work or School

The first exercise calculates the carbon footprint of students from the University of Texas at Arlington (UTA). This exercise seeks to show the necessary data that needs to be collected to address the problem. Data includes the average distance from students' homes in the Dallas-Fort

Worth Metroplex to UTA. Another essential element in determining the transportation mode these commuters use to get to school is their vehicles' fuel-efficiency characteristics. Table 11.1 shows some GHG emission factors to estimate the carbon dioxide emissions per passenger mile developed by EIU (2008).

The following equation helps estimate carbon dioxide emissions (one-way) trips from a student's residence to UTA. This equation uses the daily one-way distance between home and work in (km) and then multiplies this distance by two for a round-trip estimate. Then, researchers can use Table 11.1 to identify vehicle-specific emission factors (kg CO2/vehicle-km or kg CO2 / passenger-km).

Carbon footprint in a trip:

$$(''\ Distance\ traveled\ ''\ (km)''\ by\ vehicle\ type\ ''*''\ Emission\ factor\ by\ vehicle\ type\ ''\ (kgCO2''\ per\ passenger\ ''-km))/''\ number\ of\ passengers\ ''\$$$

Table 11.1 GHG Emissions for Various Vehicles with various passenger load assumptions

Vehicle Type	Grams of CO2 per passenger mile	Grams of CO2 per passenger kilometer
SUV	416	258
Average U.S. car	366	227
Light rail	179	111
Toyota Prius	118	73
Metro	94	58

Sources: Demographia, 2005; EIU, 2008; O'Toole, 2008.

Table 11.2 shows the carbon footprint of a typical trip conducted by a former student in a class titled "Green Cities and Transportation." The student usually commutes 29 miles from his Dallas, Texas, home to UTA. On average, his one-way trip's carbon footprint is 10.61 kg CO2. Table 11.2 also shows scenarios considering carpooling and using alternative, fuel-efficient vehicles. Overall, carpooling in a Toyota Prius would reduce the carbon footprint from 10.61 to 0.86 kg CO2 for a daily, one-way trip. This, in turn, means that carpooling an efficient vehicle is nearly 12 times more efficient than driving solo in an average car. Highly occupied vehicles incentivizing sustainable and perhaps more equitable commuting practices may also significantly reduce GHG emissions.

Table 11.2 Carbon dioxide emissions associated with a one-way trip from a student from Dallas to UTA.

Person	**Vehicle type**	**Passengers**	**Emission Factor**	**Distance**	**kg CO2 per trip**
g of CO2 per passenger per mile	**Vehicles Miles Travelled**				
Driving solo	Average U.S. car	1	366	29	10.61
Sharing with another person	Average U.S. car	2	366	29	5.31
Driving solo in an efficient car	Toyota Prius	1	118	29	3.42
Driving an efficient car and carpooling	Toyota Prius	4	118	29	0.86
Riding a mildly occupied bus	Motor bus	15	221	29	0.43
Riding a highly occupied bus	Motor bus	30	221	29	0.21

The Carbon Footprint of Commutes to UTA (Using the GHG Protocol Initiative)

The GHG Protocol Initiative offers calculation sheets and methodologies to help cities, communities, industries, and companies develop inventories of greenhouse gas (GHG) emissions associated with the energy-use practices of people in buildings and vehicles. Assessment of GHG emissions in transportation considers three categories of related GHG emissions. Scope 1 includes vehicles owned/controlled by organizations, companies, or institutions. For instance, at UTA, the MAV Movers are governed by the university and may be considered vehicles in Scope 1. Scope 2 emissions include GHG emissions associated with the organization's electricity consumption, although emissions are produced elsewhere. Scope 3 refers to the trips conducted by the people who work in an organization. For example, students and staff who commute from their homes to UTA may be considered Scope 3 because they are associated with the university and thus indirectly impact GHG emissions.

The GHG Protocol uses two approaches to estimate GHG emissions: 1) the average distance of trips and 2) fuel consumption. The first approach uses the same methodology already explained in the previous exercise. The latter requires a careful understanding of vehicles' characteristics and fuel economies. In this section, we explain methods to estimate vehicles' fuel consumption.

Vehicles' Fuel Consumption

The U.S. Department of Energy, Office of Energy, and **Renewable Energy** offer calculation sheets to compare the fuel usage associated with vehicles according to their make, year, and characteristics. For example, the MPG estimates for a 2017 Ford F150 pickup range from 22 to 23 MPG, whereas those for a 2017 Toyota Prius range from 49 – 64 MPG. This, in turn, suggests that the Toyota Prius is twice as fuel-efficient as the 2017 Ford. As a result, this fuel-efficient vehicle would allow commuters to use less gasoline than the pickup.

Table 11.3 A comparative assessment of vehicles' fuel economies. Source: Author using DOE (2022) estimates of fuel consumption in miles per gallon units.

To address this exercise, researchers can use the average estimate of fuel efficiency: 22.6 MPG for the 2017 Ford F150 and 56.3 MPG for the 2017 Prius. Then, we estimate the gasoline consumption of these two vehicles using a daily commuting distance of 29 miles for a trip from Dallas to the UTA campus.

1. Link to download the Transportation Calculation Sheets developed by the GHG Protocol: https://ghgprotocol.org/calculation-tools#sector_specific_tools_id

2. https://www.fueleconomy.gov/
3. https://www.fueleconomy.gov/feg/browseList.jsp?src=feg

To estimate fuel consumption associated with the one-way trip, we can use the following equation: Fuel consumption = distance in miles/fuel efficiency (miles per gallon). For example, the fuel consumption of the 2017 Ford F150 is 1.31 gallons, whereas the 2017 Toyota Prius is 0.51 gallons.

Table 11.4 illustrates the GHG estimate associated with a one-way trip (29 miles) from Dallas to UT Arlington using different methods. The first approach uses the distance method, considering a gasoline car (2005-present model) and a 29-mile trip. The second approach uses the fuel consumption approach. It considers the estimates of gasoline consumption for the 2017 Ford F150 and Toyota Prius, while the third approach considers both distance and fuel consumption. Table 11.4 shows that the assessment of GHG emissions associated with the trip resembles the third approach, which carefully considers the distance traveled and the specific fuel consumption associated with the vehicle. Using the GHG Protocol calculation tool for mobile sources, we estimate a carbon footprint of 11 kg CO2eq associated with a journey to UTA. The GHG Protocol tool provides a disaggregated estimate for CO2 emissions and other greenhouse gases, including CH4 and N2O. This tool can help us develop scenarios that compare the implications of a vehicle's MPG and distance traveled. For instance, the contribution to GHG emissions of a 2017 Toyota Prius (4 kg CO2e) is only a third of the assistance of a 2017 Ford F150 (12kg CO2e). This, in turn, reveals the GHG mitigation potential of fuel-efficient vehicles. Planners can use this calculation tool to estimate GHG emissions related to transportation. However, fine-grained data on distance and fuel consumption could inform a more accurate and specific analysis, but it requires additional research.

Table 11.4. GHG emissions associated with a one-way trip from Dallas to UTA considering approaches of distance, fuel consumption

Source Description	Region	Mode o	Scope	Activity Data	GHG Emissions						
Vehicle Type	**Distance Travelled**	**Units**	**Fuel**	**Fuel Amount**	**Unit of Fuel**	**Fossil Fuel CO2 (metric tons)**	**CH4 (kilograms)**	**N2O (kilograms)**	**Total GHG Emissions, (metric tons CO2e)**		
Distance: U.S. average car	The U.S.	Road	Scope 3	Vehicle Distance (e.g., Road Transport)	Passenger Car – Gasoline – Year 2005-present	29	Mile		0.011	4.263E-04	2.291E-04	0.011
Fuel: Ford F150	US	Road	Fuel Use			Gasoline/ Petrol	1.31	US Gallon	0.012	4.333E-04	2.329E-04	0.012
Fuel: Toyota Prius	The U.S.	Road	Fuel Use			Gasoline/ Petrol	0.5	US Gallon	0.004	1.654E-04	8.888E-05	0.004
Fuel and Distance: Ford F150	US	Road	Fuel Use and Vehicle Distance	29	Mile	Gasoline/ Petrol	1.31	US Gallon	0.012	4.263E-04	2.291E-04	0.012
Fuel and Distance: Toyota Prius	The U.S.	Road	Fuel Use and Vehicle Distance	29	Mile	Gasoline/ Petrol	0.5	US Gallon	0.004	4.263E-04	2.291E-04	0.004

Source: Author (2022) using the GHG Protocol Calculator, Mobile Combustion

Second Exercise: The Journey to Work in U.S. Cities Journey to Work in U.S. Cities

The second exercise compares commuting patterns associated with workers across various U.S. cities, including Dallas, Minneapolis-Saint Paul, and Philadelphia. This exercise contrasts the journey to work, the means of transportation they use, and the distance traveled while controlling for the socioeconomic characteristics of commuters. This exercise seeks to teach researchers to gather and explore transportation and commuting data on transportation.

Planners can use various databases on transportation and commuting practices to understand how commuters get to places in the U.S. For this exercise, we explore the U.S. Census Data's American Community Survey: Journey to Work.[4]

To address this exercise, you may use some of the questions that participants respond to in the ACS, which include S0802 Means of transportation to work by selected characteristics. Then, the metropolitan statistical area will be used as a geography of analysis. Table 11.5 summarizes the means of transportation workers older than 16 who were used to get to places in three urban statistical areas used by race. This table reveals significant differences in the share of private vehicles used by white workers and their Hispanic, African American, and Asian counterparts.

Table 11.5 Means of transportation used by workers in Dallas-Fort Worth Metroplex, Minneapolis-St. Paul, and Philadelphia-Camden Wilmington, Metro Area.

	Dallas-Fort Worth-Arlington, TX Metro Area	***Minneapolis-St. Paul-Bloomington, MN-WI Metro Area***	***Philadelphia-Camden-Wilmington, PA-NJ-DE-MD Metro Area***									
	Total	**Car, truck, or van — drove alone**	**Car, truck, or van — carpooled**	**Public transportation (excluding taxicab)**	**Total**	**Car, truck, or van — drove alone**	**Car, truck, or van — carpooled**	**Public transportation (excluding taxicab)**	**Total**	**Car, truck, or van — drove alone**	**Car, truck, or van — carpooled**	**Public transportation (excluding taxicab)**
Label	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**
Workers 16 years and over	3,709,605	2,898,827	361,337	43,633	1,923,174	1,442,759	149,765	80,962	2,956,445	2,081,996	221,705	258,778
One race	94.9%	95.3%	93.3%	96.6%	97.0%	97.3%	96.1%	95.3%	97.0%	97.3%	96.3%	96.7%
White	65.8%	66.7%	59.4%	44.1%	80.8%	83.0%	66.7%	64.8%	69.5%	73.6%	58.9%	42.1%
Black or African American	15.6%	15.8%	14.3%	38.1%	7.1%	6.4%	9.6%	18.9%	18.2%	15.6%	20.0%	43.3%
American Indian and Alaska Native	0.5%	0.5%	0.6%	0.6%	0.4%	0.4%	0.6%	1.1%	0.2%	0.1%	0.3%	0.3%
Asian	7.2%	6.8%	8.1%	8.8%	6.4%	5.6%	13.3%	7.5%	6.1%	5.2%	10.6%	7.2%

	Dallas-Fort Worth-Arlington, TX Metro Area	***Minneapolis-St. Paul-Bloomington, MN-WI Metro Area***	***Philadelphia-Camden-Wilmington, PA-NJ-DE-MD Metro Area***									
	Total	**Car, truck, or van — drove alone**	**Car, truck, or van — carpooled**	**Public transportation (excluding taxicab)**	**Total**	**Car, truck, or van — drove alone**	**Car, truck, or van — carpooled**	**Public transportation (excluding taxicab)**	**Total**	**Car, truck, or van — drove alone**	**Car, truck, or van — carpooled**	**Public transportation (excluding taxicab)**
Label	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**
Native Hawaiian and Other Pacific Islander	0.1%	0.1%	0.2%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.2%	0.1%
Some other race	5.7%	5.4%	10.7%	4.8%	2.2%	1.9%	5.9%	3.0%	3.0%	2.6%	6.3%	3.8%
Two or more races	5.1%	4.7%	6.7%	3.4%	3.0%	2.7%	3.9%	4.7%	3.0%	2.7%	3.7%	3.3%
Hispanic or Latino origin (of any race)	27.1%	26.5%	43.8%	21.2%	5.3%	4.6%	11.9%	7.5%	8.3%	7.5%	15.5%	9.1%
White alone, not Hispanic or Latino	47.8%	48.7%	31.8%	29.4%	78.4%	80.8%	61.7%	61.8%	65.6%	70.0%	51.6%	38.9%

Source: Link to the National Household Travel Survey developed by the U.S. Department of Transportation database. https://nhts.ornl.gov/od/vis/chord.

Glossary

- **Environmental justice** is the equitable treatment and meaningful participation of all people in creating, implementing, and enforcing environmental laws, rules, and policies, regardless of race, color, country of origin, or income level. ("Ethical Management," n.d.)
- **Renewable energy** is generated from a non-depleted source, such as wind or solar power.

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Figure 1.2 United Nations (UN) Sustainable Development Goals (2015-2030). From "UN adopts new Global Goals, charting sustainable development for people and planet by 2030," by United Nations, 2015 (https://news.un.org/en/story/2015/09/509732). Copyrighted!

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GLOSSARY

1. **Biodiversity** is a top-notch bus-based transportation system that offers metro-level capabilities for quick, pleasant, and economical services. (“Essay on Biodiversity,” n.d.)
2. **The bus rapid transit (BRT) system** is a top-notch bus-based transportation system that offers metro-level capabilities for quick, pleasant, and economical services. (Institute for Transportation and Development Policy, n.d.)
3. **Carbon footprint** is the volume of carbon dioxide and other carbon compounds released from a specific individual, organization, or other entity using fossil fuels. (National Park Service, n.d.)
4. **Climate change** is a change in regional or worldwide climate patterns since the middle to late 20th century. It is primarily attributable to the increasing atmospheric carbon dioxide caused by burning fossil fuels. (Society of Exploration Geophysicists, n.d.)
5. **Climate change mitigation** implies preventing or limiting the amount of greenhouse gas emissions released into the atmosphere to stop the world from warming to more extreme levels. (World Wildlife Fund, n.d.)
6. **Congestion pricing** entails restricting or blocking the release of greenhouse gas emissions into the atmosphere to prevent the earth from warming to more extreme levels. (Investopedia, 2012)
7. **Discretionary Travel** is optional, including excursions to places of pleasure or shopping.
8. **Environmental impact assessment** Before deciding to take the suggested action, a strategy, policy, program, or actual project is evaluated for its potential impact on the environment—the phase in this situation.(Climate Change Scavenger Hunt – National Park Service. https://www.nps.gov/teachers/classrooms/climate-change-scavenger-hunt.htm)
9. **Environmental justice** is the equitable treatment and meaningful participation of all people in creating, implementing, and enforcing environmental laws, rules, and policies, regardless of race, color, country of origin, or income level. (“Ethical Management,” n.d.)
10. **Environmental racism,** sometimes also known as ecological racism or apartheid, is a form of racism that can be observed through the adverse environmental outcomes disproportionately impacting communities of color (“Environmental racism,” 2024).
11. **Global South** is the regions of Latin America, Asia, Africa, and Oceania.
12. **Global warming** is a slow-moving rise in the planet’s average temperature typically linked to the greenhouse effect of higher amounts of carbon dioxide, chlorofluorocarbons, and other pollutants.
13. **Greenhouse gas emissions** are the gases released into the planet’s atmosphere, particularly carbon dioxide, contributing to the greenhouse effect.
14. **High occupancy toll (HOT)** Vehicles with many people enter lanes. For use, there is a cost (particularly during rush hours), which promotes carpooling and provides cars with a less

crowded route while easing traffic on nearby roads. A method of managing the demand for transportation that uses dynamic tolling to lessen traffic.

15. **High-speed rail (HSR)** is a passenger rail transportation that travels much faster than other rail traffic. The European Union has established specific parameters, such as 200 km/h (120 mph) for modified tracks and 250 km/h (160 mph) or faster for new routes. (High-speed Rail. https://railsystem.net/high-speed-rail)
16. **Informal transportation** is often composed of tiny cars that a single person owns, operates, or leases.
17. **Life-cycle assessment (LCA)** is a methodology for assessing environmental impacts associated with all the life cycle stages of a commercial product, process, or service. (Khadour, 2011)
18. **Light rail transportation (LRT)** is a kind of urban rail public transit that, on average, has more capacity and speed than typical street-running tram systems but lesser capacity and speed than heavy rail and metro systems. The phrase is commonly used to describe rail systems with rapid transit-style features that employ electric rail cars and operate primarily in private rights that are isolated from other traffic but may occasionally be mixed with other traffic in city streets, depending on the situation. (Rail System, n.d.)
19. **Low-Income Commuters** work irregular schedules with no safe or affordable way to get to work.
20. **Mandatory trips** are required for performing activities with limitations in terms of time, such as work trips.
21. **Metropolitan transportation authority (MTA)** is a public benefit corporation responsible for public transportation in the New York City metro area of the U.S. state of New York. (Wikipedia, n.d.)
22. **Non-Motorized transportation,** walking, cycling, and other forms of small-wheeled, human-powered mobility are all considered non-motorized transportation. These forms of transportation, except for walking, use non-motorized vehicles such as bicycles, skateboards, push scooters, wheelchairs, and rickshaws. (Wikipedia, n.d.)
23. **Renewable energy** is generated from a non-depleted source, such as wind or solar power.
24. **Spatial accessibility,** the ease with which community inhabitants may physically access facilities, is referred to as spatial accessibility.
25. **Sustainable development** refers to economic development that does not deplete natural resources.
26. **Sustainable mobility** includes the critical notion of access to mobility, regardless of income or location. Also, equity in accessibility, with particular attention to more vulnerable groups of the population and geographical areas at risk of social exclusion. (Neste, n.d.).
27. **Sustainable transportation** refers to low- and zero-emission, energy-efficient, affordable modes of transport, including electric and alternative-fuel vehicles and domestic fuels. The benefits of sustainable transportation in the United States include Cost savings on energy and cars. (U.S. Department of Energy, n.d.)
28. **Traffic congestion** is a condition on road networks that occurs as use increases and is characterized by slower speeds, longer trip times, and increased vehicular queuing.

Congestion begins when traffic demand is great enough for vehicle interaction to slow the traffic rate. (Jung and Vu, 2016)

29. **Equity** No of their economic level, level of ability, or any other criteria, all community members must have access to and afford reasonable transportation choices. This guarantees that transportation resources, advantages, prices, programs, and services are distributed fairly.
30. **Traffic flow** comes from interactions between infrastructure and passengers. The components of traffic flow include flow, speed, and density.
31. **Transportation policy** focuses on creating a collection of ideas and theories to attain specific goals about the social, economic, and environmental situations as well as the operation and effectiveness of the transportation system. (Transport Geography, n.d.)