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BARRIERS TO ADOPTING ELECTRIC BUSES

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ACKNOWLEDGMENTS

This report was developed under the project "Transitioning to a zero-emission transport world through bus electrification" along with its sister report, *How to Enable Electric Bus Adoption in Cities Worldwide.* We are grateful for the financial support of Germany's Federal Ministry for Economic Cooperation and Development for this project.

We would like to express our gratitude to the many people whose ideas and contributions were invaluable to the structure and content of this report. Several staff contributed to its creation. Emma Stewart was instrumental in helping to structure and initiate the report. Our internal reviewers at WRI helped guide the direction of the report: Anne Maassen, Anusha Chitturi, Celina Bonugli, Eric Mackres, Jone Orbea, Sergio Avelleda, Su Song, and Tolga Imamoglu. We would particularly like to acknowledge Renata Marson, Laura Malaguzzi Valeri, Maria Hart, and Emilia Suarez for their dedication and support in the research and review process. We also thank Emily Matthews and Sarah DeLucia for timely and crucial editorial support. We would like to thank the communications team—Romain Warnault, Jenna Park, Schuyler Null, and Billie Kanfer —who provided support in editing, graphic design, and outreach.

We would like to thank the following external reviewers, whose expertise in transport electrification were invaluable to the report: Adalberto Maluf (BYD Latin America), Bianca Bianchi (World Bank), Daniel Moser (GIZ), Gail Jennings (independent researcher), and Rebecca Collins (SEPTA). We are also grateful to the local stakeholders who participated in the case studies research and helped improve the credibility of this report.

The research underpinning this publication also received support from the "Climate Technology Transfer Mechanisms and Networks in Latin America and the Caribbean" project. The project, implemented by the Inter-American Development Bank (IDB) and financed with resources from the Global Environment Facility (GEF), promotes the development and transfer of technologies to contribute to the reduction of greenhouse gas emissions and vulnerability to climate change in Latin America and the Caribbean. The project prioritizes the topics of mitigation and adaptation to climate change in the sectors of energy efficiency and renewable energy, transport, forest monitoring, and resilient agriculture. WRI is the project executing agency for the transport component of the project.

We are pleased to acknowledge our institutional strategic partners, which provide core funding to WRI: Netherlands Ministry of Foreign Affairs, Royal Danish Ministry of Foreign Affairs, and Swedish International Development Cooperation Agency. We are also pleased to acknowledge the Stephen M. Ross Philanthropies for its support of WRI's Ross Center for Sustainable Cities program.

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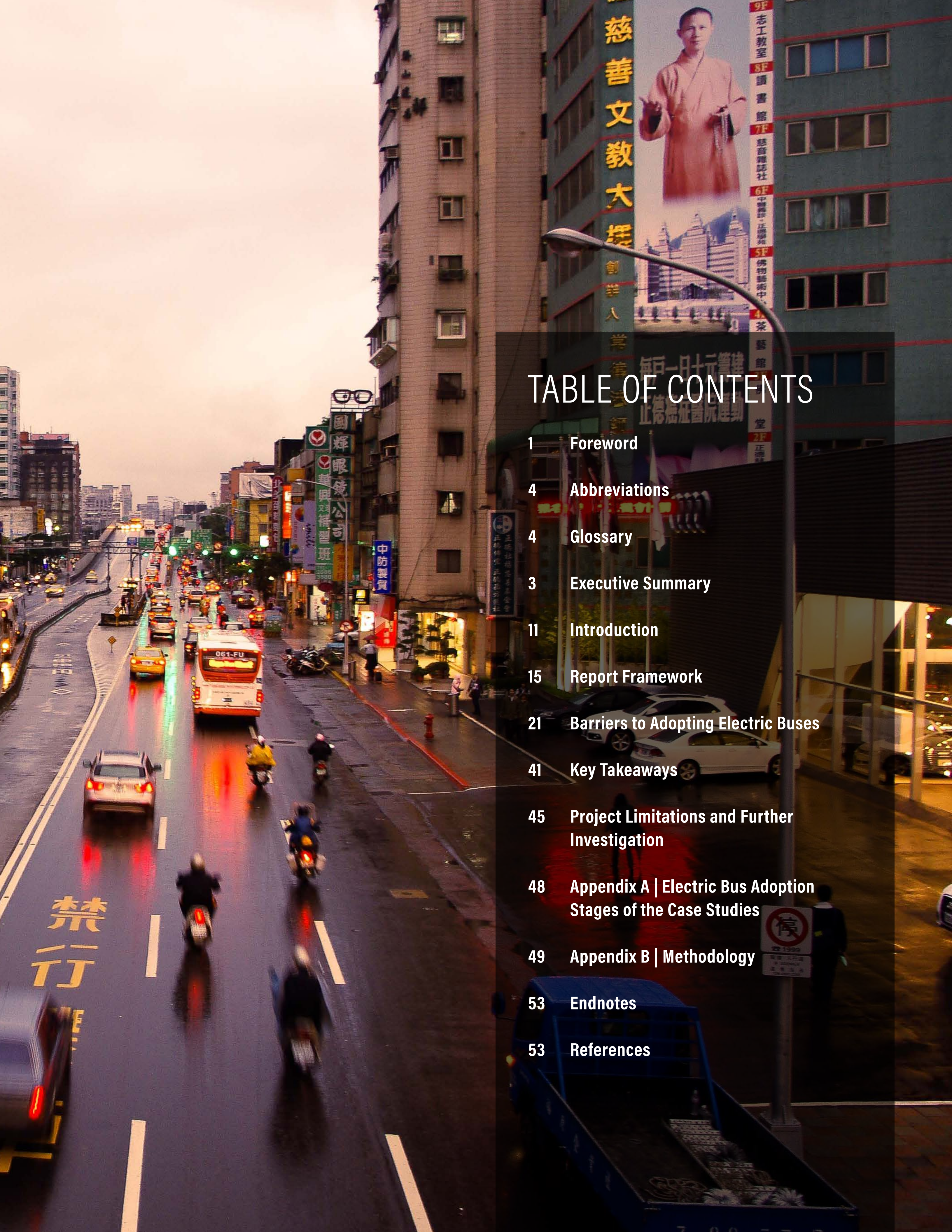

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FOREWORD

You're the mayor of a big city. It's time to invest in new buses for your over-crowded public transport system. Should you buy traditional diesel-burning buses that account for a significant share of the air pollution, ill health, and carbon emissions in the city? Or, invest in the future: clean, non-polluting, energy-efficient, affordable electric buses?

An easy answer, surely?

But it's a harder decision than many realize. Electric buses have huge advantages, and over the coming decade will need to replace traditional fleets on a massive scale if we are to address climate change and enjoy healthy air. However, despite their huge promise, their adoption has been uneven and, except in China, limited in scale. Most cities that have pursued electric bus adoption have struggled at some point. Some cities have even abandoned their electric aspirations and returned to the fossil-fuel status quo. This is unfortunate and typically unnecessary.

This report, *Barriers to Adopting Electric Buses*, and its sister report, *How to Enable Electric Bus Adoption in Cities Worldwide*, identify the barriers and offer practical solutions. We present the key conclusions from research analyzing 16 case studies on six continents, with a wide range of urban development patterns, from emerging cities in India to sprawling metropolises in Latin America and megaregions in China.

Common obstacles identified in this report include lack of operational knowledge on electric bus systems; unfamiliar procurement and financing schemes; and institutional deficiencies in terms of authority, funding, and land for the changes needed. The barriers outlined are cautionary tales that can guide high-level planners safely along the road to electric bus adoption. *How to Enable Electric Bus Adoption in Cities Worldwide* offers a framework to overcome these barriers and is addressed to transit practitioners and on-the-ground technical staff.

The lessons from these 16 early adopters can help cities avoid past mistakes and make the complex transition to electric buses faster and more successful. This first-of-its-kind collection of in-depth case studies is an invaluable guide to what can go wrong, and what to do next.

The good news is that a growing number of cities are demonstrating that success is possible through collaboration and persistence. Our hope is that these successes be replicated at great scale.

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EXECUTIVE SUMMARY

Electric buses (e-buses) can help cities address air quality issues and reduce greenhouse gas emissions (along with a clean grid). The transition to e-buses, however, has been subject to growing pains as industries and governments alike struggle to nurture the nascent e-bus marketplace into maturity. This report identifies some of the largest and most common barriers to e-bus adoption. Cities must fully understand the barriers to electric bus adoption to act swiftly and decisively to surmount these obstacles.

HIGHLIGHTS

- WRI conducted 16 comprehensive case studies, predominantly of cities in the global South, to identify a variety of technological, financial, and institutional barriers that policymakers face during different stages of electric bus (e-bus) adoption.
- Key technological barriers are created by (1) the lack of relevant information for decision-making and (2) the current operational limitations of e-buses and charging infrastructure.
- Key financial barriers emerge from (1) the difficulties agencies face in making the necessary changes to rigid procurement structures and (2) the lack of long-term, sustainable financing options.
- Key institutional barriers stem from (1) the lack of political leadership and pragmatic public policy and (2) the lack of institutional authority, funding, and physical real estate.
- By mapping key technological, financial, and institutional barriers from 16 case studies worldwide, the report provides cautionary tales to help officials anticipate the challenges they will face and plan accordingly to avoid costly mistakes.

LIST OF ACRONYMS AND ABBREVIATIONS

BYD	Build Your Dreams (electric bus manufacturer)
CNG	compressed natural gas
CO_2	carbon dioxide
e-bus	electric bus
GHG	greenhouse gas
SEPTA	Southeastern Pennsylvania Transportation Authority
TCO	total cost of ownership
TDA	Transport and Urban Development Authority (Cape Town, South Africa)

Glossary

- **Action**: An act taken toward reaching a particular goal. In this report, the terms *step* and *action* are used interchangeably.
- **Barrier**: An obstacle or circumstance that can prevent transit agencies and/or governments from initiating, continuing, or expanding their fleet of e-buses.
- **Development stage**: The advancement of an e-bus program in a particular city. This report adopts five different development stages, as shown in Table 3.
- **Electric bus (e-bus)**: A bus with a propulsion system that runs entirely on electricity, which is housed inside the bus in a battery (typically a lithium-ion battery). For this report, e-buses do not include buses powered by parallel electric infrastructure, such as the overhead electric wires typically used to power trolley buses.
- **E-bus lifecycle**: The overall processes required for e-bus adoption, including initial preparation, planning, e-bus procurement, operation and maintenance (O&M), and processes after buses reach the end of their useable life span.

- **E-bus pilot program**: A project to explore e-bus technology, usually initiated and organized by a transit agency or government entity. E-bus pilot programs involve the procurement, testing, and operation of e-buses, typically with a limited number of e-buses, and sometimes for a limited duration of time.
- **E-bus tradespace**: The entire industry and supply chain surrounding e-buses. This includes the manufacturing, procurement, management, and disposal of e-buses and their associated infrastructure. This report divides the e-bus tradespace into three main elements: (1) vehicles and batteries, (2) agencies and operators, and (3) grid and charging infrastructure.
- **Emissions**: All substances that are discharged in the air. For this report, this term usually refers to tailpipe emissions from buses.
- **Enabler**: An element (such as a policy or an action) that can help transit agencies and governments initiate, continue, or expand their fleet of e-buses.
- **Global North**: A general term for countries with established and relatively mature economies. The global North is sometimes referred to as the “developed world,” and typically includes Europe, Oceania, and the developed countries in Asia and North America.
- **Global South**: A general term for countries with emerging economies. The global South is sometimes referred to as the “developing world,” and typically includes Latin America, Africa, and the developing countries in Asia.
- **E-bus project**: A term used generically to describe the entirety of a city’s efforts to adopt e-buses.
- **Step**: An act taken toward reaching a particular goal. In this report, the terms *step* and *action* are used interchangeably.

Context

Electric buses (e-buses) have the potential to provide many benefits. Since e-buses have zero tailpipe emissions and are increasingly becoming commercially viable, they are emerging as a pragmatic option for reducing transit emissions. E-buses can help reduce CO_2 emissions globally (if the electricity is generated from a clean grid) while also reducing local pollutants. E-buses can also be a tool to improve energy efficiency (when strategically integrated and utilized as a grid resource), increase energy security due to reduced fossil fuel dependency, improve passenger comfort by reducing vibration and noise, and lower operating costs. Electrifying municipal bus fleets presents a unique opportunity to reduce emissions in the transportation sector while also bringing cobenefits to the cities making the transition.

The adoption of e-buses has accelerated in recent years, but the e-bus movement is still in its early stages. Globally, e-bus sales increased over 80-fold between 2011 and 2017 (Bloomberg New Energy Finance 2018). Nevertheless, e-buses still represent a new technology, which, compared to conventional diesel buses, is relatively untested and uncertain.

The adoption of e-buses has accelerated in recent years, but it is not happening fast enough to contribute toward reaching long-term global climate objectives. Leading sources on climate change indicate that investment in e-buses and other low-carbon technologies needs to double over the next two decades to maintain global warming well below a relatively safe threshold of 2 degrees Celsius (°C) (GEF 2017; IPCC 2018). Thus, the transition to e-buses and other energy efficient technologies needs to be accelerated.

Growth in the use of e-buses has been concentrated in China (where 99 percent of all e-buses are operating) and the global North (OECD/IEA 2018; Bloomberg New Energy Finance 2018). Since the basic technology behind e-buses is equivalent worldwide, this geographic divergence in adoption suggests that the barriers to adoption are not solely technical but also specific to local characteristics of cities in the global South. To effectively and equitably adopt e-buses worldwide, more research is needed to understand not only the universal barriers to e-bus adoption but also the particular barriers facing cities in the global South.

About This Report

This report identifies and presents the main barriers that cities face when implementing e-buses, especially in the global South. The barriers outlined in this report are meant to serve as cautionary tales to help guide high-level planners (such as city and state elected officials and transit agency administrators) safely along the road to e-bus adoption.

Analysis for this report is framed by a literature review and based predominately on 16 WRI-conducted case studies. Research for this report was initiated by a review of relevant current literature. Publications were reviewed that covered the emerging findings and discussions on the topic of e-buses and on the broader topic of barriers to implementing clean energy technologies. Given the nascency of the market and the lack of current research on e-buses, WRI conducted 16 case studies to take the current pulse of e-bus adoption and inform the barriers stated in this report. These 16 case studies covered cities around the world (with a particular focus on the global South) and provided the foundation for the findings in this report.

This report may be read in conjunction with a parallel publication, *How to Enable Electric Bus Adoption in Cities Worldwide*. This additional report, based on the same 16 case-study cities, identifies and elaborates on the pathways that different cities have taken toward electric bus adoption and highlights the enabling conditions for electric bus adoption under different circumstances. Together, these two reports can help officials anticipate the challenges they will face and plan accordingly to successfully implement e-bus fleets.

This report was written by the electromobility team at WRI. WRI is a global research organization that spans more than 60 countries, with more than 700 experts and staff. The overall mission of WRI is to turn big ideas into action at the nexus of environment, economic opportunity, and human well-being. The goal of the WRI team working on electric vehicles is to shine a light on the barriers and enablers regarding electric vehicle adoption, to promote greater understanding of the opportunities and risks. This report has been published in partnership with the German Federal Ministry for Economic Cooperation and Development.

Key Barriers to Adopting Electric Buses

Based on analysis from 16 case studies and the literature, this report provides a matrix of barriers facing e-bus adoption. Barriers are categorized by (1) three major elements of the e-bus tradespace and (2) three general barriers to clean energy innovation. Table ES-1 presents this barriers matrix.

From this matrix, this report distills six key barriers facing transit agencies trying to adopt e-buses. These six key barriers are organized into the three general categories identified in this report (technological, financial, and institutional) and represent issues that transcend different elements within the e-bus tradespace. The case studies and literature suggest that these barriers will likely be faced by many transit agencies and are potentially debilitating issues that must be resolved for e-bus endeavors to move forward. These six key barriers are listed below:

Table ES-1 | Barriers Matrix

		GENERAL BARRIERS		
		Technological	**Financial**	**Institutional**
E-BUS TRADESPACE ELEMENTS	**Vehicles and batteries**	Lack of information on the advantages and disadvantages of e-buses Range and power limitations of e-buses Design flaws in e-buses Disjointed or limited e-bus marketplace	High up-front capital costs of e-buses Lack of financing options	Difficulties for manufacturers in engaging with cities Lack of a plan to remove current bus stock
	Agencies and operators	Lack of information on how to start Lack of operational data	Rigid financial management and business models Scaling investment past initial pilot programs	No enabling policies supporting adoption of e-buses Negative public perception Coordinating maintenance duties Weak governmental coordination Informal transit
	Grid and charging infrastructure	Lack of understanding of the requirements to upgrade infrastructure Limitations of the charging ports and stations Grid instability Lack of standards and regulations on charging infrastructure	Large capital expenses for grid infrastructure Difficult to determine grid infrastructure responsibilities	Lack of space and land to install infrastructure Limited planning for long-term implications

Source: Authors.

Key Technological Barriers

- **LACK OF KNOWLEDGE:** In general, cities lack the information needed to make informed decisions at almost all stages, from establishing an initial discussion to scaling up e-buses en masse. Cities lack both general knowledge on the barriers and enablers to implementing their e-bus fleet and city-specific data on the operational viability of their e-buses. Specifically, there is a lack of relevant information and data for cities to determine several key considerations:
    - The proper inputs required for an initial cost-benefit analysis of the e-buses and infrastructure
    - Strategies and techniques to optimize the design and implementation of an e-bus project
    - The operational characteristics, limitations, and maintenance requirements of e-buses available on the market
    - Infrastructure planning needs to be completed prior to adoption
- **TECHNICAL LIMITATIONS OF THE E-BUSES AND CHARGING INFRASTRUCTURE:** Technological limitations exist in all three components of the e-bus tradespace:
    - *Vehicles and batteries* produce limited range and power relative to conventional buses. The battery manufacturing industry, nascent and immature, faces a learning curve in its effort to produce reliable, road-tested products.
    - *Agencies and operators* lack the knowledge needed to adopt new operation models to accommodate for the range and power limitations of e-buses.
    - *Grid and charging infrastructure* are also new and evolving technologies that face limitations and stability challenges.

Key Financial Barriers

- **DIFFICULTIES FOR AGENCIES IN CHANGING PROCUREMENT PRACTICES:** Transit agencies and government institutions typically use rigid financial management models, which incentivize low-cost, low-risk procurement. Most procurement models do not consider the unique cost structure (more expensive up front but cheaper to operate than conventional buses) and uncertain risks inherent in e-buses and their corresponding infrastructure. Traditional procurement practices also do not allocate responsibilities for the new tasks associated with e-bus operations, such as maintaining the batteries and grid infrastructure. Although the total lifetime cost of owning e-buses is often lower than that of conventional buses, and agencies may recognize that a new approach toward procurement is needed, traditional models often prove difficult to change.

- **LACK OF LONG-TERM, SCALABLE FINANCING OPTIONS:** Given the risk, uncertainty, and nascency surrounding the e-bus industry, financing is a tremendous barrier that must be overcome if e-buses are to be implemented on a large scale. This is particularly true for municipalities that have not demonstrated strong credit worthiness with past investments. Scaling e-bus projects requires a large, risk-tolerant capital investment, both to procure the vehicles and to supply the necessary charging infrastructure and grid upgrades. Often no financial institutions are willing to make this investment, outside of small-scale pilot projects. Thus, the e-bus fleets in many cities are currently operating as nonscalable demonstrations.

Key Institutional Barriers

- **LACK OF LEADERSHIP AND PRAGMATIC PUBLIC POLICY:** One of the most frequently cited institutional barriers was the lack of enabling public policies and/or a specific implementation plan to guide e-bus adoption. In many cities, there are either (1) no laws or roadmaps to provide a strategy plan or financial backing for implementing e-buses, or (2) ineffective plans in place that lack clear goals and financial incentives. One main reason that guidelines and policies are not created and/or implemented is the lack of genuine interest from politicians and key stakeholders. When there are limited incentives and lackluster political support, it can be difficult for some cities to issue appropriate tenders to procure e-buses.

- **LACK OF INSTITUTIONAL AUTHORITY, FUNDING, AND LAND:** In many cases, a major barrier to initiating or furthering e-bus projects was the lack of institutional capacity. Some cities lack the resources or jurisdictional authority to coordinate an e-bus project. Informal transit posed a noteworthy barrier for many cities, since the owners and operators of informal transit vehicles are typically not accountable to transit agencies or other government bodies.

  The lack of government access to land and property also presented a substantial barrier to upgrading and installing the charging and grid infrastructure that e-bus projects require. Charging infrastructure requires land with permanent space to house it, which is often very difficult to find for transit agencies and municipalities. While property ownership issues are not conventionally thought of as barriers to e-bus adoption, owning and/or having permanent contracts over land to install and manage charging infrastructure is often crucial, especially as e-bus fleets are scaled up.


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INTRODUCTION

The transport sector accounts for approximately one-quarter of all GHG emissions worldwide. Public transport alone can be responsible for over a quarter of CO_2, hazardous particulate, and/or nitrogen oxide emissions in some cities in the global South. E-buses are emerging as an effective and pragmatic option for reducing emissions and providing other benefits; however, the e-bus movement is currently still in its early stages and experiencing growing pains. To date, e-bus adoption has been uneven and varied in scale, and implementation has not accelerated fast enough for the world to meet transport-related climate objectives.

The transport sector accounts for approximately 8 billion tons of annual greenhouse gas (GHG) emissions, which constitutes roughly one-quarter of all GHG emissions worldwide (UN Environment 2017; IEA 2018). Furthermore, transportation is the fastest-growing source of carbon dioxide (CO_2) emissions and fossil fuel demand worldwide (IEA 2018). In general, transportation is responsible for a significant and growing portion of global greenhouse gases.

Within the transportation sector, public transport fleets are of special interest because of their significant emissions impact. Although public transport fleets are relatively small in number compared to private vehicle fleets, they account for a disproportionately large number of externalities, especially in the global South. In Bogotá, Colombia, for example, the pre-TransMilenio bus fleet represented less than 5 percent of the total vehicles in the city but was responsible for 23 percent of CO_2, 55 percent of particulate matter 10 (PM_{10}), and 40 percent of nitrogen oxide (NO_x) vehicle emissions (Amaya 2006). Before Shenzhen, China, electrified its fleet, buses comprised 0.5 percent of the vehicles in the city but were responsible for 25 percent of the city's transportation-associated energy and 20 percent of the CO_2 emissions associated with vehicles (Ding Mei Ying 2017; NIUA-CIDCO Smart City Lab 2018). Similar figures are seen in cities around the world (Solís and Sheinbaum 2013; Song et al. 2014; Alam and Hatzopoulou 2014). Therefore, measures taken to increase the sustainability of municipal bus fleets can noticeably reduce emission levels and provide environmental benefits to urban residents.

Within the suite of sustainable bus transportation technologies, electric vehicles are emerging as an effective and pragmatic option for reducing emissions (Bloomberg New Energy Finance 2018). Electric buses (e-buses) utilize lithium-ion batteries to store an electric charge that is used to power an engine. Since this propulsion system does not require the burning of fuel, the vehicles emit no exhaust. E-buses can help reduce CO_2 emissions globally (if the electricity is generated from a modestly clean grid) while also reducing local pollutants.

In addition to these environmental benefits, e-buses can also help cities improve energy efficiency, increase energy security by reducing fossil fuel dependency, improve passenger comfort by reducing vibration and noise, and lower operating costs. Electrifying municipal bus fleets presents a unique opportunity to reduce greenhouse gas emissions in the transportation sector while also bringing cobenefits to the cities making the transition.

The e-bus movement is currently in its early stages, with numerous manufacturers emerging in several different countries. Most of the existing e-bus

Table 1 | Top 10 Manufacturers of E-Buses Based on Estimated Total Number of E-Buses Produced

MANUFACTURER	ESTIMATED UNITS SOLD	PRIMARY MARKET(S)
Yutong	35,000	China and international
BYD	20,631	China and international
Zhongtong	20,000	China
Solaris	103	Europe
Proterra	100	North America
Optare	82	Europe
VDL Bus and Coach	67	Europe
Volvo Bus	50	Europe
Van Hool	40	Europe
Bolloré Group	23	Europe

Source: Bloomberg New Energy Finance (2018).

manufacturers produce small quantities of e-buses and operate only on a regional scale. Even the largest manufacturers of e-buses arguably have not yet fully developed supply chains and maximized the benefits of economies-of-scale production (Steinhilber et al. 2013; NRC 2015). Table 1 lists the top 10 manufacturers of e-buses by estimated units sold and their primary market(s).

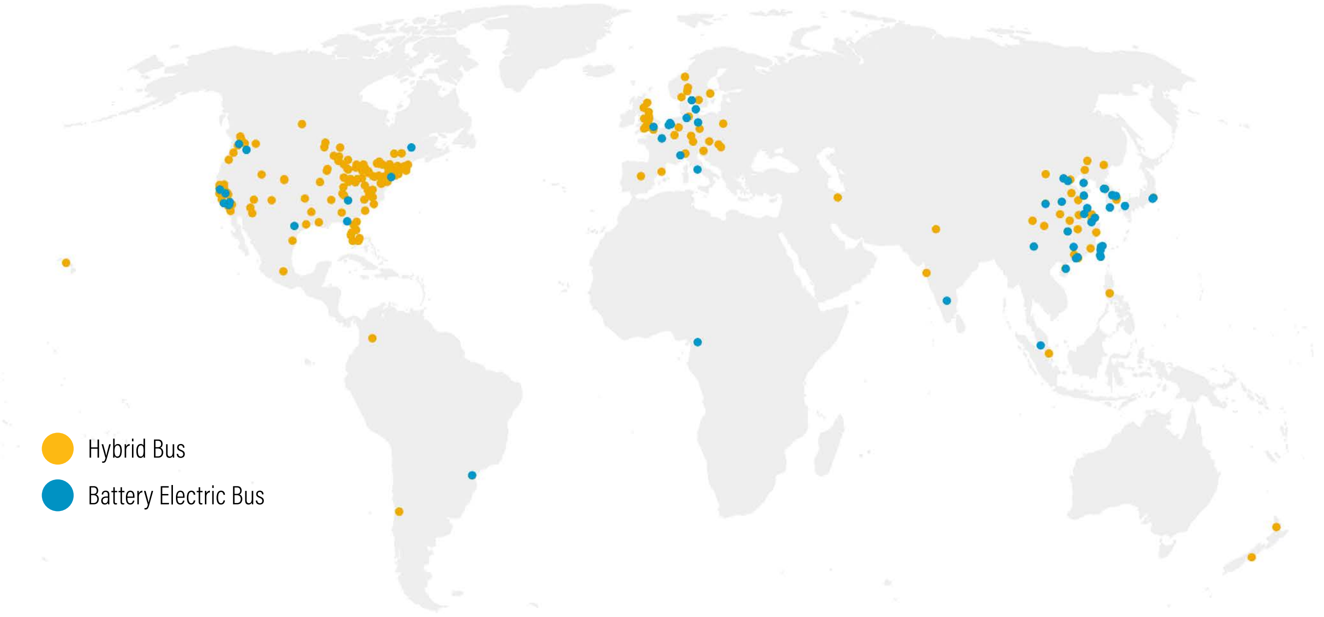
Alongside the emerging e-bus manufacturing market, the adoption of e-buses has been accelerating (IEA 2017; Castellanos and Maassen 2017), albeit at a relatively uneven pace. Globally, e-bus sales increased more than 80-fold between 2011 and 2017 (Bloomberg New Energy Finance 2018). The majority of this growth has been concentrated in China (where 99 percent of all e-buses are operating) and the global North (OECD/IEA 2018; Bloomberg New Energy Finance 2018), as illustrated in Figure 1 below.

Nevertheless, the investment in e-buses and other low-carbon technologies needs to double over the next two decades to help maintain global warming well below a relatively safe threshold of 2 degrees Celsius (°C) (GEF 2017). Investment must grow even faster to sustain warming under the 1.5°C threshold, which is increasingly being advised by the scientific community (IPCC 2018). Thus, the transition to energy-efficient technologies, including e-buses, is not happening fast enough to reach long-term global climate objectives.

To help understand and address the insufficient rate of e-bus adoption, the analysis in this report considers the geographic asymmetry of e-bus implementation (shown in Figure 1). Since the basic technology behind e-buses is equivalent worldwide, the geographic divergence in adoption patterns suggests that the barriers to adoption are not just technical but also specific to local characteristics of cities in the global South. Therefore, to promote effective adoption of e-buses worldwide, this report shines particular light on the barriers to e-bus adoption in the global South.

This report identifies and presents new research on the main barriers that cities face in implementing e-buses, especially in the global South. Research for this report is based on 16 comprehensive case studies that were conducted by WRI in cities around the world at varying levels of e-bus adoption, as well as on an extensive review of the current literature on the topic. This report's main objective is to inform policymakers of the barriers to e-bus implementation, with the hope that identifying the most commonly experienced barriers will enable policymakers to address them early and directly.

Figure 1 | Electric Bus Adoption



Source: WRI 2016.

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REPORT FRAMEWORK

The aim of this report is to present the barriers facing the adoption of e-buses, so that policymakers can consider and act on these barriers early in the implementation process. Primarily addressed to city and state elected officials and transit agency administrators, this report adopted a scope and methodological approach to guide the research. This section outlines the framework that was followed to focus this report.

Defining an Electric Bus

While many types of electric public transportation vehicles are currently commercially available, this report focuses specifically on battery electric buses (referred to in this report as "e-buses"). The e-buses discussed in this report have the following characteristics:

- **Pure electric propulsion system**: E-buses run exclusively on electricity. Hybrid technologies are not defined as e-buses.
- **Electricity storage capacity**: E-buses use onboard batteries to store electricity.
- **Limited dependence on charging infrastructure**: E-buses do not need to be in continuous contact with charging infrastructure (such as "third rails" or overhanging wires).

Some electric propulsion technologies, such as electric trolley buses (powered by overhead electric cables), have been in service with few technological changes for several decades. These technologies, however, have never become widely adopted because they typically require extensive on-street infrastructure that is expensive and does not offer flexible route planning. This report focuses exclusively on battery electric buses, because these buses represent an adaptable and increasingly cost-competitive technology that is currently emerging but still has been the subject of limited literature sources or published case studies.

The Research and the Case Studies

This research endeavor began with a review of relevant current literature. Publications were reviewed that covered the emerging findings and discussions on the topic of e-buses. Since e-buses are a new and evolving topic with little existing literature, research was also conducted on the broader topic of barriers to implementing clean energy technologies in general. This literature search provided a foundation of knowledge that was used to guide and frame the report.

Given the nascency of the market and the lack of current research on e-buses, 16 case studies were conducted to take the current pulse of e-buses and inform the barriers stated in this report. These 16 case studies were all completed using a standard protocol (Appendix B), which utilized three main approaches to gathering data and information:

- Desk research
- Interviews
- Primary sources

The locations of these case studies are listed in Table 2 and were strategically selected based on the following criteria:

- *Geographic diversity*: The selected studies represent cities geographically dispersed around the world, with particular emphasis on cities in Latin America, Asia, Africa, and other regions in the global South. Select case studies were also included from the global North, because these locations had developed programs with e-bus insights that were applicable globally.
- *Research capability*: These case studies were also carefully chosen to represent cities where WRI has extensive staff, resources, and contacts.
- *Development stage diversity*: These case studies represent a wide variety of stages in the process of adopting e-buses. (See the subsection below and Table 3 for more information on the development stages.

Table 2 | Locations of Case Studies

REGION	COUNTRY	CITY
Africa	Ethiopia	Addis Ababa
	South Africa	Cape Town
Asia	China	Shenzhen
		Zhengzhou
	India	Ahmedabad
		Bangalore
		Manali
Europe	Spain	Madrid
	Turkey	Izmir
North America	Mexico	Mexico City
	United States	Philadelphia
South America	Brazil	Belo Horizonte
		Campinas
	Chile	Santiago
	Colombia	Bogotá
	Ecuador	Quito

Source: Authors.

The Development Stages

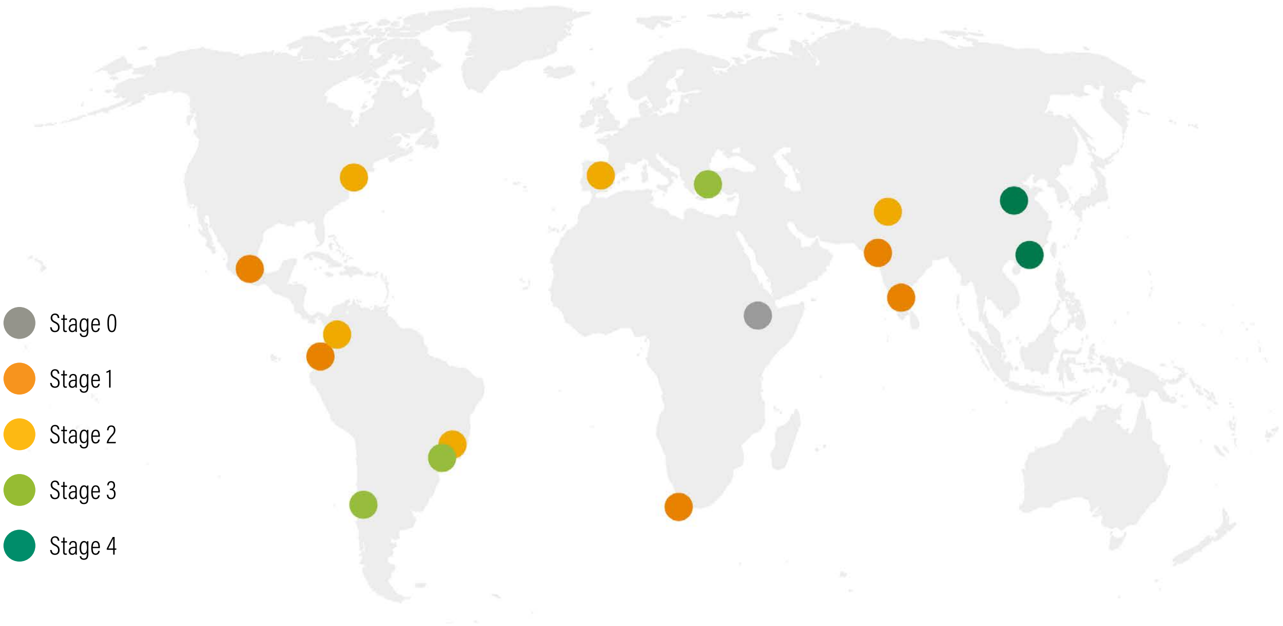
Based on observations through local engagement, expert interviews, and literature reviews, this report adopts five different stages of development, representing the full spectrum, from cities in the very initial stages of e-bus inquiry to cities approaching (or at) maximum bus fleet electrification. Table 3 provides the definitions used to describe each development stage in this report. These definitions are also adopted in WRI's parallel report, *How to Enable Electric Bus Adoption in CIties Worldwide* (hereafter the "enablers report"). Figure 2 maps the 16 case studies categorized by their development stage. More information on how each case study qualifies for each development stage is provided in Appendix A.

Table 3 | Development Stages

STAGE	DEFINITION	CASE STUDY CITIES
0	**No substantial planning.** ■ There have been no substantial official talks or discussions on e-buses. ■ No official research has been conducted. ■ No private parties have been formally contacted regarding providing capital or services for an e-bus program. ■ There is no actual implementation of an e-bus program.	Addis Ababa, Ethiopia
1	**Talks and plans, but no pilot tests.** ■ There have been formal discussions about e-buses. ■ Initial research has been conducted. ■ Initial policies, targets, and/or tenders may have been released. ■ No e-buses have been tested by the transit agency/operator.	Ahmedabad, India; Bangalore, India; Cape Town, South Africa; Mexico City, Mexico; Quito, Ecuador
2	**The city is running an initial pilot program.** ■ E-buses have been procured. ■ E-buses have been tested (with or without passengers) by the transit agency/operator. ■ Tests have offered some information on the operational performance of the e-buses (although these data may have severe limitations). ■ A pilot program is under way, but further expansion has not been planned.	Belo Horizonte, Brazil; Bogotá, Colombia; Madrid, Spain; Manali, India; Philadelphia, United States
3	**The city has gone past an initial pilot program.** ■ The city is expanding the number of e-buses and/or starting a second e-bus procurement. ■ There are plans in place to substantially grow the number of e-buses in the near future.	Campinas, Brazil; Izmir, Turkey; Santiago, Chile
4	**Mass adoption.** ■ E-buses account for a substantial portion of the municipal bus fleet. ■ The city is at or approaching its long-term e-bus target.	Shenzhen, China; Zhengzhou, China

Source: Authors.

Figure 2 | Map of Case Studies by Stage



Source: Authors.

BARRIERS TO ADOPTING ELECTRIC BUSES

This section provides details on the barriers identified in this report. Each barrier is accompanied by the stage (or range of stages) that are most applicable to that barrier. The barriers are intended not to dissuade policymakers from e-bus endeavors but to provide caution on the potential pitfalls and risks that should be considered.

The barriers described in this report are generally provided through the context of a transit agency's perspective. Transit agencies (along with other local and national government entities with stakes in the transportation sector) are usually the main organizations charged with leading the implementation of e-buses. Therefore, public agencies are typically the most critical and influential stakeholder, and it is most important to understand barriers from their perspective. As mentioned previously, the barriers outlined through this report are intended not to dissuade policymakers from e-bus endeavors but to provide caution on the potential pitfalls and risks that should be considered. The categorization of barriers in this report is based on a review of the current literature on the topic and the 16 case studies. From the literature and case studies, barriers were commonly divided into three major elements of the e-bus tradespace:

- Vehicles and batteries
- Agencies and operators
- Grid and charging infrastructure

Within each of these three sections, the barriers are further divided into three subcategories:

- Technological
- Financial
- Institutional

These three subcategories were derived from Suzuki (2015), a frequently cited article that categorizes the universal barriers to new sustainable technology. These subcategorizations create a matrix (see Table 4), with barriers categorized by the e-bus-specific element they affect and by which broader barrier to clean energy innovation they fall under. Table 4 displays the matrix framework with the major identified barriers. These barriers are explained in detail in the subsections below.

Each section heading is accompanied by the stage (or range of stages) that are most applicable to that barrier. The literature and case study findings suggested that some barriers are persistent throughout all stages of development, while others are particularly acute challenges at specific stages. For example, e-bus range limitations affected case studies across every development stage, while challenges to finding information and data on e-buses are typically greater for cities in the earlier stages of e-bus development. These stages are included to illustrate which barriers are most prevalent at each stage of e-bus adoption and to provide context for which barriers are persistent among several different stages. The stages designated below are based on both (1) a literature review and (2) the findings from the 16 case studies conducted. These stage notations are only intended to provide general information on which stages face certain challenges most acutely; just because a certain stage is not indicated for a certain barrier does not mean that no cities under that stage will experience that barrier. The barriers below are ordered roughly by their applicable stages, with barriers affecting early stages listed first, followed by barriers most relevant to latter stages.

Table 4 | Barriers Matrix

		GENERAL BARRIERS		
		Technological	**Financial**	**Institutional**
E-BUS TRADESPACE ELEMENTS	**Vehicles and batteries**	Lack of information on the advantages and disadvantages of e-buses Range and power limitations of e-buses Design flaws in e-buses Disjointed or limited e-bus marketplace	High up-front capital costs of e-buses Lack of financing options	Difficulties for manufacturers in engaging with cities Lack of plan to remove current bus stock
	Agencies and operators	Lack of information on how to start Lack of operational data	Rigid financial management and business models Scaling investment past initial pilot programs	No enabling policies supporting adoption of e-buses Negative public perception Coordinating maintenance duties Weak governmental coordination Informal transit
	Grid and charging infrastructure	Lack of understanding of the requirements to upgrade infrastructure Limitations of the charging ports and stations Grid instability Lack of standards and regulations on charging infrastructure	Large capital expenses for grid infrastructure Difficult to determine grid infrastructure responsibilities	Lack of space and land to install infrastructure Limited planning for long-term implications

Source: Authors.

Barriers to Procuring Vehicles and Batteries

For most policymakers, vehicles and their corresponding batteries are the obvious elements to consider when planning an e-bus project. While many important, often overlooked, barriers also exist related to other elements of operating e-buses, some critical barriers directly related to vehicles and batteries. This section contains barriers specific to the actual characteristics of the e-buses, their batteries, and other components.

Technological Barriers

Lack of information on the advantages and disadvantages of e-buses (Stages 0, 1)

For cities early in the development process that are still considering the advantages and disadvantages of e-buses, one of the most fundamental barriers to procuring e-buses is a lack of information on the technology. In some cities, public transit decision-makers may have never considered electrifying their bus fleet. In other cities, policymakers may have developed a rudimentary understanding of e-bus technology (such as the average ranges, typical prices, and basic infrastructure needs of e-buses) but lack additional knowledge on the environmental, health, and economic benefits and disadvantages of adopting the technology (NRC and TRB 2015). Also, given the emerging nature of e-buses and the nascent stage of the market, some cities have had difficulty finding reliable, up-to-date sources of information to produce an accurate cost-benefit analysis of the efficacy of adopting e-buses. Simply put, cities lacking basic performance and financial information on e-buses are unlikely to adopt e-buses.

For cities that have successfully researched e-buses, general uncertainties remain regarding the battery lifecycle and the residual value of the e-buses at their point of retirement. Almost no e-buses have been operating long enough to reach their estimated decommission date, so there is currently very little information on how long e-buses will actually last and how these old e-buses will perform. Many cities noted that these uncertainties make it difficult to properly evaluate whether it is worthwhile to acquire e-buses in pilots or en masse. In addition to performance longevity issues, there are also concerns about how to properly dispose of the batteries. While battery disposal is an issue for a future date, many cities have prudently identified as an issue the lack of knowledge surrounding the safe mass disposal of batteries.

Range and power limitations of e-buses (Stages 2, 3, and 4)

Despite gains in the range and ability of e-buses over the past several years, e-buses still have performance limitations. The specifications of the e-buses currently available on the market vary widely, depending on the manufacturer and the model. In general, however, the case studies have indicated that e-bus performance has improved over the past several years. In Shenzhen, for example, early performance issues required two e-buses to replace the work of one diesel bus in 2011. By 2016, the rate of replacement from diesel to e-buses was almost equal, with 1.03 e-buses needed on average to replace each diesel bus. Despite these advances, the case studies revealed that many cities still face limitations with the range and power of their e-buses.

Range, the maximum distance traveled on a full charge, was cited as a barrier to increasing e-bus fleets in many cities. Many cities stated that, while some bus routes (usually routes with limited mileage, such as feeder bus routes and downtown circulators) are compatible with the range of e-buses, the current range of their e-buses was insufficient to cover other routes. The limited range of the e-buses often reduced their daily use. This was seen in Bogotá, where it was noted that e-buses averaged 235 kilometers per day, while diesel buses averaged 440 kilometers per day. Despite e-bus technological advancements, range remains a critical limitation of e-buses for transit operators.

Part of the reason range has persisted as an issue for e-buses is the reported variability of battery performance. Batteries lose effectiveness in cold weather, since low temperatures decrease the rate in which chemicals can react, which reduces how much current is produced (Jaguemont et al. 2016). Cold temperatures also require extensive use of heating systems, which further drain the mileage capacity of the batteries. Thus, cold temperatures can exacerbate e-bus range limitations (Bloomberg New Energy Finance 2018). In Zhengzhou, for example, e-buses are charged for an extra hour during the winter, yet they still have unavoidably less range than they do in more moderate temperatures. Hot temperatures can also tax battery range, since running air conditioning and other ancillary cooling services takes a significant amount of battery capacity. In Izmir, for example, manufacturers originally struggled to produce a bus that could meet the transit agency's requirement to maintain 13 hours of air conditioning while traveling over 150 kilometers. Battery functionality can also vary for other reasons; Shenzhen noted that battery charge dropped during heavy summer rains, and Campinas noted that some of the batteries lost charge for a number of different, often unknown, reasons. The variability of battery performance can create unexpected e-bus range limitations and intensify range anxiety among operators.

In addition to range limitations, many cities also state power limitations as a key barrier. Many e-buses still face difficulties navigating steep topography (Banister 2004). Topography was noted as a barrier to e-bus performance in many case studies, especially in South American cities with hilly terrain. This was illustrated in Campinas, where e-buses ascended hills slowly, resulting in schedule delays. Overcrowding was also a noted issue that revealed the power limitations of e-buses. In Bangalore, for example, the transit agency often runs buses over the manufacturer-recommended passenger limits, a task that can be managed by diesel buses but likely not by most currently available e-buses.

Power issues have also led to limitations in the types of e-buses that can be produced. In Bogotá, biarticulated buses comprise 67 percent of the city's latest TransMilenio bus fleet procurement tender, but no biarticulated e-buses are commercially available for purchase in bulk (BYD introduced the first biarticulated e-bus in April 2019, but this type of e-bus is not yet widely available). Until power limitations are resolved, e-bus adoption will remain relegated to a constrained set of routes and features.

Design flaws in e-buses (all stages)

In addition to issues with range and power, many design defects have also been noted as problems with e-buses. The battery banks and technological components of e-buses often require different designs than the engine components of conventional buses, and these designs have not fully been standardized and real-world-tested for global use. For example, operators in Bogotá and Campinas both reported that the e-buses they received were still prototypes and not adequately prepared for the rough roadway conditions in their cities (Box 1). E-buses in these cities were subject to ruptured air suspension valves, broken doors, and even serious structural damage to the frame. In Philadelphia, a new e-bus model (with no economies-of-scale production and limited testing) was delivered to the transit agency heavier than anticipated due to battery weight. Modifications to the bus were required before the bus could be put into revenue service and carry a full passenger load. In some cases, these defects have either caused, or been the product of, a manufacturing backlog. While many of these defects are being addressed, manufacturers appear to still be experiencing a learning curve when it comes to creating quality e-buses for market consumption.

BOX 1 | BOGOTÁ AND E-BUS DESIGN FLAWS

Bogotá was one city that experienced noteworthy problems with e-bus design. When the city's bus rapid transit system, TransMilenio, decided to pilot e-bus technology, one of the biggest issues it faced was with not just the new electronic propulsion technology but the basic, conventional components of the e-bus. The bus model had to be specialized to meet the requirements of the transit system (an articulated bus with high floors), which meant the manufacturer, BYD, had to create a new prototype. As with many new models, this e-bus features several design issues. These problems were exacerbated by a rushed request from the agency to have the buses rolled out for use. To accommodate weight and space for the batteries, BYD used low-grade material for the frame and for other fundamental elements of the bus. This e-bus design was adequate for roadway and driving conditions in most cities in BYD's domestic market in China, but it proved inadequate to deal with the aggressive driving, constant overcrowding, and rough pavement conditions found in Bogotá.

Bogotá's roadway conditions led to many problems with e-bus maintenance. Drivers reported issues with rigidity of the suspension, charred residue in the control panels, problems with (and failures of) the pneumatic system, and frame alignment issues. The majority of these maintenance problems were completely unexpected, both by TransMilenio staff (who were used to more robust buses) and by BYD (which had not experienced these issues in China). Many of the parts that needed to be replaced were not readily accessible, because BYD was not anticipating these parts would require replacement. Therefore, many components had to be specially ordered from China, which required time for shipping and for navigating cumbersome international trade regulations. This ordeal lengthened maintenance times and dramatically reduced the e-bus availability rate. While this experience did lead BYD to adopt stronger materials for its future e-buses in Bogotá, these design issues have implanted concerns among local stakeholders about the feasibility of adopting e-buses at scale.

Disjointed or limited e-bus marketplace (all stages)

The nascent e-bus marketplace includes large numbers of manufacturers, most of whom sell only in limited geographic regions and without firmly established credibility or track records. Only a few have become well-known and widely trusted e-bus manufacturers. As a result, many transit agencies perceive that their choices are limited (NRC and TRB 2015; Bloomberg New Energy Finance 2018). For example, during the initial procurement processes in Belo Horizonte, Campinas, and Philadelphia, stakeholders said there were at the most a handful of viable manufacturers in their regions. In other regions, the competition is between domestic manufacturers in the very early stages of producing e-buses. In Izmir, for example, the procurement process required three rounds of tenders because it was difficult to find an adequate manufacturer. While there is a diversity of e-bus options, the market often seems dominated by a few companies, because most manufacturers produce very small quantities and are geographically limited.

Financial Barriers

High up-front capital costs of e-buses (all stages)

The high up-front cost associated with e-buses is often cited as the primary challenge to e-bus procurement around the world (C40 Cities 2013; Lajunen 2014; ARB 2015; Marchán and Viscidi 2015; Lajunen and Lipman 2016; Bi et al. 2017; Li et al. 2018; Bianchi et al. 2019). In line with the literature, almost all case studies in this report identified the capital cost of e-buses as a *large* barrier to mass producing the technology, and some case studies identified capital costs as the *largest* barrier. Examples from the case studies conducted and from the general literature reveal that e-buses typically cost two or three times more than conventional diesel buses, although these numbers can vary (C40 Cities 2013; Bloomberg New Energy Finance 2018). E-buses have a high initial cost for several reasons, mostly related to their status as a new technology with (1) unknown risks (such as uncertainties concerning long-term battery performance, maintenance requirements, and the residual value of e-buses) and (2) an emerging marketplace (which has not yet achieved efficient economies of scale in its production of batteries and other elements related to the electric propulsion system) (Steinhilber et al. 2013; NRC 2015). As a result, e-buses have a much higher price tag than conventional diesel buses, which can make their procurement difficult to justify in economic terms.

Although there is general agreement throughout the transport industry that e-buses will become more price-competitive with conventional buses over time, it is unclear when, if ever, they will reach capital cost price parity with conventional buses. The single-largest contributor to the cost of an e-bus is the price of its battery (around 20 percent of the total vehicle price in 2018) (Bloomberg New Energy Finance 2018). Battery prices have fallen 79 percent since 2010 (Bloomberg New Energy Finance 2018), and many cities (e.g., Campinas, Shenzhen, and Zhengzhou) are reporting that their new e-buses have improved horsepower and range compared to their older counterparts. Nevertheless, it remains difficult to discern the price trends in the industry over the past few years. Prices for e-buses vary dramatically based on the manufacturer, the specifications of the e-bus, and the location of the transit agency (Bianchi et al. 2019). For example, e-bus prices quoted (but not authenticated) through the case studies ranged from roughly US$300,000 in Santiago, Belo Horizonte, and Shenzhen; to $475,000 in Izmir; to $600,000 in Cape Town; to $900,000 in Philadelphia. Due to this price variability, most global e-bus price-trend analyses use estimates and assumptions (based on the prices for different bus components). Data collected from the 16 case studies from this report are not sufficient to provide conclusive information on global e-bus price trends; however, the case study findings indicate that over the past few years e-bus prices may have dropped in some locations and remained stagnant in many others. Regardless, it is certain that the industry has yet to witness a radical reduction in the capital cost of e-buses, and it remains unclear when this may occur.

Lack of financing options (all stages)

Because of these high up-front capital costs, many transit agencies must secure financing for e-buses, which can be difficult. Financing constructs for e-buses had historically fallen into two primary categories: capital leases and operating leases. However, recent changes in accounting standards for operating leases have rendered this construct generally nonviable. In a capital lease, the operator or transit agency buys (and owns) the e-bus up front but pays for it over time (similar to buying a house with a mortgage). Under the prior construct for an operating lease, the operator or transit agency never buys the e-bus but pays a certain price each month for the rights to use it (similar to renting a house). This allowed for the possibility of an off-balance sheet accounting for government agencies and bus operators. The updated accounting standards generally place the balance sheet burden on the entity that directly operates the vehicles, which makes such an arrangement difficult to execute. Since a capital lease typically also requires an operator or transit agency to report the entire value of an e-bus as a liability on its balance sheet, capital lease structures limit not only the financial risk to the manufacturer but also the benefit to the operators or transit agencies. Thus, depending on a transit agency's budgeting rules, capital leasing may offer no benefit over a direct purchase.

While some e-bus manufacturers do offer leasing options (which eliminates residual value risk for the transit agency and/or bus operators), the terms of these leases can vary dramatically depending on the city, and these leases are typically only available for pilot programs or small order sizes. In some cases, manufacturers provided favorable leasing to cities near one of their manufacturing plants. Cities have also experienced difficulty getting reliable information on how a lease would function and the overall impacts it would have on costs. For example, Philadelphia and Belo Horizonte had trouble receiving concrete information on what terms a leasing arrangement could offer, since leasing programs were still in their infancy and had not been fully established. In general, it is difficult to determine whether existing leasing schemes are offered as loss-leader promotions to certain cities or are financially sustainable procurement options for the global e-bus marketplace.

All forms of leases require tremendous capital when seeking to procure large numbers of e-buses, which, when combined with the uncertainty and risk surrounding the future of e-buses, intrinsically limits the extent to which any e-bus financing model can be replicated globally. Novel forms of financing, such as "pay-as-you-save" and separate battery leasing (both suggested by Proterra and other e-bus manufacturers), may be useful but are essentially variants on capital- and operating-lease arrangements. Each form of financing carries value and risk to the e-bus industry and to transit agencies seeking to decarbonize their fleets. Given the risk, uncertainty, and nascency surrounding the e-bus industry, financing is a tremendous barrier that must be overcome if e-buses are to be implemented on a large scale.

BOX 2 | BELO HORIZONTE AND CONTRACTS IMPEDING E-BUSES

The current operator contracts are one of the main barriers to the e-bus pilot program in Belo Horizonte. Contracts to operate bus service in Belo Horizonte currently run on 20-year terms. Since the last round of contracts was signed in 2008, operators are bound by the current terms until 2028. Under the existing contracts, none of the bus operators are obligated or incentivized to adopt clean bus technology. In fact, some aspects of these contracts, such as the incentives to procure buses with long ranges and proven life spans, discourage adoption of new bus technology. While many operators have expressed interest in the e-bus pilot program, none has volunteered to actually operate e-buses on a permanent basis. The terms of operators' contracts provide no incentives or requirements to deal with the high costs, learning curves, and elevated risks associated with adopting e-buses.

City officials in Belo Horizonte have attempted to circumnavigate the issues that have stemmed from existing contractual agreements, but, so far, no progress has been achieved. Due to the operator contracts, the initial e-bus pilot program was run without operator involvement. One of the main intents of the current pilot testing was to showcase the technology and thereby interest operators in voluntarily adopting e-buses. However, to date, no operators have expressed interest in investing in what is seen as an expensive and risky endeavor. To address these concerns, local officials also proposed leasing the batteries to operators (from either the transit agency or the utility company) to lessen the financing burden and risk involved in adopting e-buses. This proposal, however, has still not generated any interest from operators. In general, operators indicate that they are content to maintain their diesel buses, since these conventional buses are established, low-risk, and adequately fulfill contractual obligations. The case of Belo Horizonte demonstrates that any shortcomings in a contract can hinder progress for years to come.

Institutional Barriers

Difficulties for manufacturers in engaging with cities (Stages 0, 1, and 2)

For some cities, e-buses have proved hard to implement due to barriers between the manufacturer and the transit agency. Cities that are physically or economically isolated from their e-bus manufacturers can incur extra expenses and delays in procuring and maintaining their e-bus fleets. Several cities, especially in Latin America, noted that having e-buses shipped from overseas required paying tariffs and dealing with the bureaucracy associated with international trade. When e-buses needed spare parts for maintenance, these often had to be shipped overseas from the manufacturer as well, which led to more costs and delays, limiting the operational availability of the e-buses.

To avoid the economic and bureaucratic barriers between manufacturers and transit operators, some manufacturers have started to build factories in different countries. However, due to the emerging nature of the technology and issues surrounding economies of scale, sometimes it is still easier for parts to be made and shipped from overseas. Even in Campinas, which houses one of the largest Latin American factories for its Chinese e-bus manufacturer, it was often easier and cheaper to manufacture and assemble key components in China. In many cities, manufacturers still face a logistical barrier to providing economical and efficient service.

Lack of a plan to remove current bus stock (Stages 2, 3, and 4)

Almost all cities limit the number of e-buses they can procure based on their current stock of buses that are still in operation. Most cities do not consider replacing their conventional buses with e-buses until their current buses have reached the end of their life span. In cities that have recently procured diesel buses or have standing long-term contracts with manufacturers, e-buses may be kept from entering service for a long time. For example, Belo Horizonte has 20-year contracts with its operators, which means that operators in this city have no obligation or motivation to electrify their bus fleet before their 2008 contracts are up for renegotiation in 2028 (Box 2). This contractual lock-in for the current operators has been identified as the major reason that operators are currently not very engaged in Belo Horizonte's e-bus pilot program. Similarly, in Philadelphia, one of the major drivers of the transit agency's ability to commit to procuring e-buses is the retirement schedule for its existing bus fleet (as well as the nonelectric buses already procured but not yet delivered by manufacturers). If current contractual agreements and commitments to retire buses after their total life span are kept, then mass adoption of e-bus technology is unlikely to occur for many years.

Barriers to Agencies and Operators

This section highlights barriers related to transit agencies, bus operators, and other stakeholders with responsibility in procuring, operating, and/or maintaining e-buses. Many barriers in this section stem from the fact that agencies and operators are unfamiliar with the necessary actions needed to adopt e-buses and/or are unwilling or unable to change the status quo.

Technological Barriers

Lack of information on how to start (Stages 0 and 1)

A fundamental technical barrier facing agencies and operators is simply a lack of information on how to start an e-bus project. Officials in many cities admitted that they previously had been completely unaware of e-buses. For most cities, no planner has ever procured an e-bus, no operator has ever driven an e-bus, no technician has ever serviced an e-bus, and no electrician has ever installed charging infrastructure for an e-bus. In some cases, such as in Izmir, even the manufacturers knew relatively little about e-buses at the beginning of the process. Historically, it has been very difficult to find information on the barriers facing e-bus adoption and the key steps to enable successful e-bus implementation. Without experienced personnel or guidebooks on the topic, it can be extremely challenging for cities to create an informed roadmap on how to navigate e-bus adoption.

Lack of operational data (Stages 0, 1, and 2)

In addition to the lack of general information on the procurement of e-buses, cities also lack needed data on the operational abilities of e-buses. The range and charging limitations of e-buses need to be understood by agencies so they can adjust operations accordingly. From an operational perspective, overcoming these mileage constraints requires expensive and/or unproven methods, such as (1) intermediate charging locations, (2) battery swapping, or (3) reorganizing routes to reduce distances. Each of these options has proved incredibly difficult for operators to implement. For example, e-bus charging infrastructure in many cities has been located in only one or two locations, to take advantage of economy-of-scale reductions in installation and maintenance costs. Therefore, the e-buses must return to select locations to recharge, which diminishes their ability to run on long assignments that would take them far from the charging points. In Philadelphia, the range limitations of e-buses required those buses to be assigned to specific routes, which provided less operational flexibility than the transit agency's conventional practice of using the buses on dynamic and shifting blocks of work (which often include several different routes). Transit agencies still struggle to adjust operations to account for the limited range of e-buses.

In addition to the impact of e-bus range on operations, some e-bus operators also struggle to deal with charging time requirements. Conventional diesel buses not only have longer range per fuel-up, but they also can refuel much faster than e-buses. While long charging times may not affect route operations if the e-buses are charged overnight, routes that require midday fueling between blocks of work can present a barrier to e-bus adoption. Also, bus assignments often may not plan for a midday refueling, but buses need the flexibility to refuel if last-minute schedule changes make this necessary. In Philadelphia, for instance, this flexibility was noted as being of critical importance in maintaining operational efficiency. Even if e-buses can complete their scheduled assignment without taking time to recharge, they may lack the flexibility to reroute as may be necessary to maintain system-wide service reliability.

BOX 3 | MADRID AND DIFFICULTIES ADVANCING PAST PILOT PROJECTS

Madrid offers an example of a city that has faced difficulty scaling its e-bus fleets past pilot projects. An early adopter of the technology, the Spanish capital has since diminished its role as a forerunner in e-bus adoption. In an impressive feat for the time, Madrid adopted 18 5.2-meter electric minibuses to transport people around the historic center of the city in 2007. Despite this ambitious start, Madrid failed to increase the size of its e-bus fleet for over a decade. When new e-buses were finally introduced in 2018, they were implemented as new (and separate) pilot experiments; they did not represent an effort to scale the original e-bus project. Madrid has crafted ambitious goals for future e-bus procurements, but, despite 11 years of pilot testing, transit officials have not yet meaningfully scaled up their e-bus fleet.

There are two main reasons why Madrid has failed to progress past e-bus pilot projects. First, the high up-front cost of the e-buses was covered by one-time grants, which do not provide a scalable financing option for future procurements. Financial aid programs, notably the Institute for Diversification and Saving of Energy, funneled critical investment from the national government and the European Union into the e-bus programs. These subsidies were so essential to the pilot programs that officials in Madrid said cost was not a real barrier to adopting e-buses, since the city received large amounts of seed investment. While these funding sources proved critical in introducing e-buses to Madrid, a scalable, long-term financing scheme is needed to introduce e-buses en masse.

The second reason for Madrid's difficulties in advancing its e-bus program is its conservative, risk-averse approach toward decision-making. The transit agency has expressed an interest in increasing the number of e-buses in its fleet, but it is determined to do so in an incremental manner, to prevent drastic adoption of charging infrastructure. While this strategy may prove prudent from a financial and planning perspective, it has thus far impeded expansion past pilot fleets. Additionally, the transit agency is determined to wait for newer, next-generation technology with better range and performance. For this reason, transit officials have recommended against buying e-buses in bulk at this time (often favoring the adoption of other propulsion technologies, notably compressed natural gas [CNG]).

Financial Barriers

Rigid financial management and business models (Stages 1, 2, 3, and 4)

The high up-front costs associated with e-buses are often cited as the primary challenge to e-bus procurement (C40 Cities 2013; Lajunen 2014; ARB 2015; Marchán and Viscidi 2015; Lajunen and Lipman 2016; Bi et al. 2017; Li et al. 2018). In addition to the issues caused by the need for more initial capital investment (explored above), these high up-front capital costs often are incompatible with conventional procurement processes. Procurement models typically focus on up-front cost and lack the flexibility to consider the total cost of ownership (TCO) over the life span of the e-bus (Bloomberg New Energy Finance 2018). Since e-buses have a high up-front capital cost but are typically cheaper to operate than conventional buses, cost models that rely solely on purchase prices make it hard for e-buses to compete against conventional buses, even if e-buses have a lower TCO. Competitive tendering, an open-bidding process to ensure that items are purchased at the lowest market price, is commonly used in adopting new technologies, since competition can incentivize innovation by the private sector. However, when e-buses are competing against conventional diesel buses in a tendering process, diesel buses will be able to provide a much lower bid and preclude the adoption of the more capital-intensive e-buses (Estache and Gómez-Lobo 2004; Castellanos and Maassen 2017). Procurement processes often impede e-bus adoption when they are not updated to account for the total costs and benefits of e-buses.

Adopting new business models to facilitate e-bus procurement can be difficult. In some cases, cities have partnered directly with an e-bus manufacturer and avoided a bidding process, but these single-source procurement strategies can expose transit agencies to scrutiny and claims (justified or not) of procurement corruption. This issue has become central in the e-bus efforts in Cape Town (discussed in detail below). Adopting new procurement techniques for e-buses is challenging because it is often very speculative to predict the future operational expenses associated with e-buses. For example, the instability of electricity prices was noted in Izmir as a major barrier to evaluating e-bus TCO over the mid- and long-term. Additionally, Shenzhen, despite benefiting from heavy government subsidies (upward of 50 percent of the capital cost), initially struggled to change its strict net-cost procurement model to account for the true costs associated with e-buses. It is often difficult for cities to adopt procurement models that account for the up-front costs and risks associated with e-buses.

Scaling investment past initial pilot programs (Stages 2 and 3)

In response to the high up-front capital costs and the financial and institutional barriers to adopting e-buses, e-bus fleets in many cities are currently operating as nonscalable pilot programs. These programs are often started with seed investment from either (1) a national or regional one-time grant (such as in India or the United States) or (2) a promotional leasing scheme provided for a limited time by an e-bus manufacturer (such as in some cities in Latin America). While these pilot programs are critical for advancing the knowledge base and technical expertise surrounding e-buses, they often do not provide a roadmap for scaling e-bus implementation to achieve mass adoption.

Institutional Barriers

No enabling policies supporting adoption of e-buses (Stages 0, 1, and 2)

One of the most frequently cited institutional barriers to operators was the lack of national and local governmental incentives and/or directives at the agency level to guide e-bus adoption. In many cities, no laws or roadmap documents currently provide a plan or financial backing for implementing e-buses. For example, Izmir found it difficult to expand its fleet of e-buses due to a lack of tax incentives. Similarly, in Campinas, the expansion of the e-bus fleets was hindered by the lack of incentives and sources of favorable financing. Many other cities (including Cape Town, Addis Ababa, and Quito) stated that the lack of an electromobility strategy made it difficult for transit agencies to solidify their plans to roll out and/or expand their e-bus fleets. Some cities even mentioned established disincentives (such as diesel and natural gas subsidies) that discouraged e-bus adoption. Outside literature has also noted the role of such disincentives. Bianchi et al. (2019), for example, state that diesel subsidies in some cities give conventional buses a 20 percent price advantage in their total cost of ownership over e-buses. Even when guiding documents were available, the absence of specific targets and funding options often rendered these documents ineffective. Many cities had difficulty structuring their e-bus program due to a lack of concrete planning and solid commitments.

One of the reasons that guidelines and policies are not implemented is the lack of interest or awareness among politicians and key stakeholders. In some cities, very few actors are actually involved in and supportive of a push to receive e-buses. In Belo Horizonte, for instance, a small e-bus pilot has failed to gain momentum because no bus operators and few politicians have shown any interest in testing the technology. Furthermore, e-bus projects are sometimes championed by one political administration but then deprioritized by its successor. In Santiago, for example, an incoming government disengaged the proposed e-bus tender and decided to focus first on completing a new metro project. While this change of plan ultimately pivoted toward a more aggressive e-bus policy (Santiago now has more e-buses than any city in Latin America), it also delayed progress for several months as the government transitioned with the new administration. Likewise, e-bus plans in Mexico City may be in jeopardy as a change in political leadership has shifted focus away from e-buses and toward enhanced trolley bus service (Box 4). There are many reasons that politicians and stakeholders may not champion e-bus projects (including a general lack of knowledge, political pressure, or financial concerns). Regardless of the reason, however, a city without a base of e-bus supporters will be very unlikely to start and maintain an e-bus program.

BOX 4 | POLITICAL TURNOVER IN MEXICO CITY

The e-bus efforts in Mexico City demonstrate the barriers that political turnover can create. As with many other projects in Mexico City, the current city and federal administrations have a lot of influence over the fate of the e-bus project. Changes in political administrations add an extra layer of uncertainty for e-bus implementation, on top of the inherent uncertainties associated with adopting a new technology. For example, the governance for much of the city's bus network is highly dependent on the current administration, and plans often change when new administrations take office. More generally, changing political administrations can impact the direction of working groups, partnerships, plans, and strategies.

Given the influence that a change in administration can have on enacting an e-bus project, many stakeholders in Mexico City have argued for an expedited project timeline to fit within a six-year mayoral and/or presidential term. According to some stakeholders, planning for e-buses must start at the beginning of a political administration to maximize its chances of implementation. If the planning, development, authorization, and implementation of the e-bus project extend past six years, the benefits of the project may not be realized by the public before a new administration takes charge, and it may be politically advantageous for new leaders to curtail the project. In Mexico City (as in many other cities), political turnover can be a major impediment to e-bus adoption.

When there are limited incentives and lackluster political support for an e-bus project, it can be difficult for some cities to issue appropriate tenders to procure e-buses. As discussed above, e-buses cannot compete in a bidding process against conventional bus technologies if tenders are not drafted to encourage new technology. In Bogotá, for example, the latest bus tender originally included no enticements for e-buses and ultimately (after pressure from various stakeholders) included only a modest (negligible, according to some e-bus advocates) advantage for e-buses over conventional buses and no advantage to e-buses over Euro VI and CNG buses.[1] Tenders that are not based on policy and political will favorable to e-buses can stunt efforts to procure electric fleets.

Negative public perception (all stages)

Even when political will is amenable to implementing e-buses, cities sometimes face barriers when politicians' actions in favor of e-buses are called into question by constituents. As a new technology, e-buses can attract more public attention than conventional buses. This public curiosity sometimes translates into political support for e-buses, but it can also bring increased public scrutiny. Any missteps in the implementation of an e-bus project may receive more publicity than the regular business of a transit agency. This increased spotlight can sour the public perception of the project (and more generally of the agency). This barrier was highlighted by officials in Santiago, who had seen the public perception of their transit agency damaged as a result of their last high-profile project, Transantiago, a massive transit reorganization effort. Transit agencies can expose themselves to accusations of incompetence if they are unable to successfully implement highly publicized e-bus programs.

In addition to being placed under the microscope for potential incompetence, transit agencies may also face increased scrutiny for perceived contractual irregularities. In many of the examined cities, some dissenters called the morality of the business practices of the transit agency and/or operator into question. In some cases, these accusations gained enough political momentum to hinder the implementation of e-buses. Cape Town may offer the most acute example, as described in Box 5. High-profile e-bus projects can draw attention to the proceedings of a transit agency and create large political (and even legal) barriers to procuring e-buses.

Coordinating maintenance duties (Stages 2 and 3)

The operational restructuring required to address the different maintenance duties of e-buses is often uncoordinated. If e-bus maintenance will be the duty of the transit agency or operator, then measures need to be taken to ensure the manufacturer (or other qualified group) provides training and continued guidance. If maintenance will be partially or fully contracted to a third party, then the duties and responsibilities of each stakeholder need to be well defined. In either scenario, a lack of coordination can lead to low e-bus availability rates. In Shenzhen, for example, at the outset of the e-bus program, disorganization and a lack of maintenance preparation led to e-buses costing much more than anticipated to maintain and requiring more time out of service.

Weak governmental coordination (Stages 0 and 1)

Transit agencies can often face difficulty implementing e-buses due to weak levels of coordination and authority. In many cities, different government stakeholders in the e-bus planning and implementation processes are siloed. In Campinas, it was noted that city planners often do not communicate with the public transit agency, which is not always aligned with the transit operators, who do not often listen to local research institutions. In many cities, different stakeholders often hold overlapping responsibilities without a clear plan for how to divide tasks. For example, in Belo Horizonte, vehicle purchasing, operation, and maintenance were identified as joint responsibilities shared by several stakeholders, without specifically divided assignments. Fragmented intragovernmental planning between local and national government entities was also identified as an issue in several cities, including Cape Town, Addis Ababa, and Quito.

BOX 5 | CAPE TOWN AND SCRUTINY OF PROCUREMENT

In Cape Town, the e-bus project has been heavily scrutinized following reports of improprieties in the procurement process. Initially, some officials in the city's transit agency, the Transport and Urban Development Authority (TDA), proposed pursuing a single-source procurement for a pilot project including 11 e-buses with manufacturer BYD. While this first procurement scheme was rejected by supply chain officials because it failed to respect key financing laws, the subsequent public tender was awarded to BYD. However, certain bidders claimed that the public tender had favored BYD by including very specific requirements that only BYD would have been able to meet. Further, allegations of irregularity around the tender, and accusations of maladministration and corruption in the city government, led an appointed law firm to recommend that the tender be canceled (although the city has taken delivery of all 11 buses). The elected officials seen as having been involved in the alleged corruption have since resigned, and the TDA commissioner remains on suspension. The matter remains unresolved (as of publication of this report), and the pilot program has been unable to advance.

Cape Town illustrates that the perception of misconduct can have significant consequences. Regardless of whether wrongdoing actually took place or not, the perception of fraud has created a major barrier for the e-bus project in Cape Town.

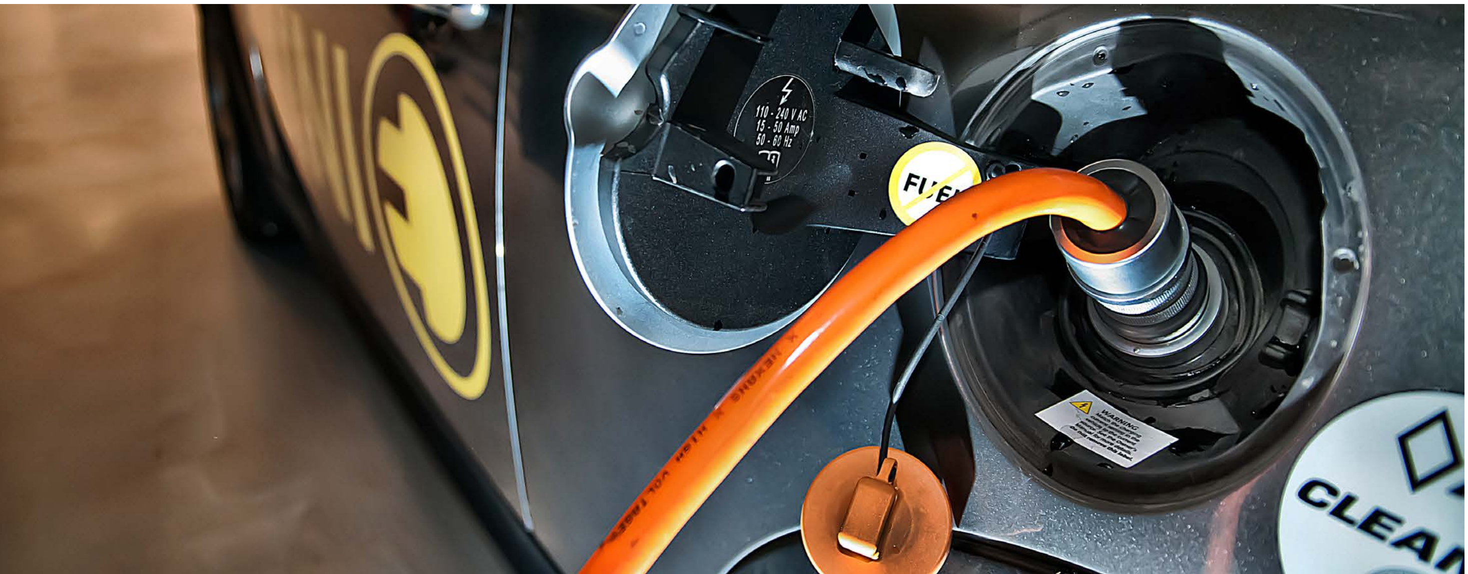
BOX 6 | ADDIS ABABA AND THE BARRIER OF INFORMAL TRANSIT

In Addis Ababa, informal transit dominates public transportation. Informal services started roughly 50 years ago, when entrepreneurs saw an economic opportunity to provide transit services in areas served inadequately by the city's bus system. Informal operators have since grown to dominate the public transit landscape, operating minibuses, informal taxis, auto-rickshaws, and horse carts that collectively carry 79 percent of all public transit trips in Addis Ababa.

The prominent role that informal transit plays in the city's transportation sector has made it difficult for Addis Ababa officials to formalize the public transit system. Informal transit presents a barrier to adopting e-buses, since informal operators lack systems to coordinate and finance such transit enhancements. While the government does provide formal transit services, these are often difficult to expand since the transit agency is typically underfunded. In light of this, most of the recent formalized transit projects (such as express bus service and the light rail system) have (1) required outside investment from either a private partnership or a foreign entity and (2) provided a premium, more expensive service aimed at attracting new middle-class riders, not at diverting (less affluent) riders from the current informal transit system. Initial talks for implementing an e-bus project indicate that these e-buses will likely be part of a premium bus service. While this plan will suffice for establishing a pilot fleet, true mass adoption of e-buses is made arduous by large-scale informal transit.

Informal transit (Stages 3 and 4)

Systemic weaknesses in national and local governmental coordination have led to informalized transit systems in many cities, and these informal systems are not able to take on the task of adopting e-buses (Hidalgo and Graftieaux 2008; Flores Dewey 2013). When governmental institutions cannot or do not govern adequate transit service, bus services are often provided by numerous private owners and operators with little or no government oversight. Under this scheme, bus service is often considered to be "informal," since the government does not play a significant role in the provision of bus transit (Hidalgo et al. 2010; Flores Dewey 2013; Paget-Seekins 2015). In many cities, informal transit accounts for a sizable share of the total public transit system. In Addis Ababa, for example, 79 percent of public transit trips are taken on informal transit minibuses and shared taxis (Box 6). Informal transit makes up a large portion of the total transit trips in numerous cities across the world, including many cities studied for this report. These small, informal operators typically do not have the financial capital, external motivation, or assistance needed to procure e-buses (Paget-Seekins 2015). Additionally, government efforts to adopt e-buses are difficult to assign to informal operators, since the latter's operations have very limited governmental involvement. While early e-bus efforts may be able to circumnavigate this issue by focusing small pilots on the existing formalized transit service, informal transit systems constitute a barrier to large-scale introduction of e-buses in many cities around the world.



Barriers to Grid and Charging Infrastructure

Grid and charging infrastructure are critical elements of e-bus projects, which are typically not given the attention they deserve by policymakers. Infrastructure barriers are also often understudied by literature on e-buses. This section discusses the main barriers to e-bus adoption related to grid and charging infrastructure.

Technological Barriers

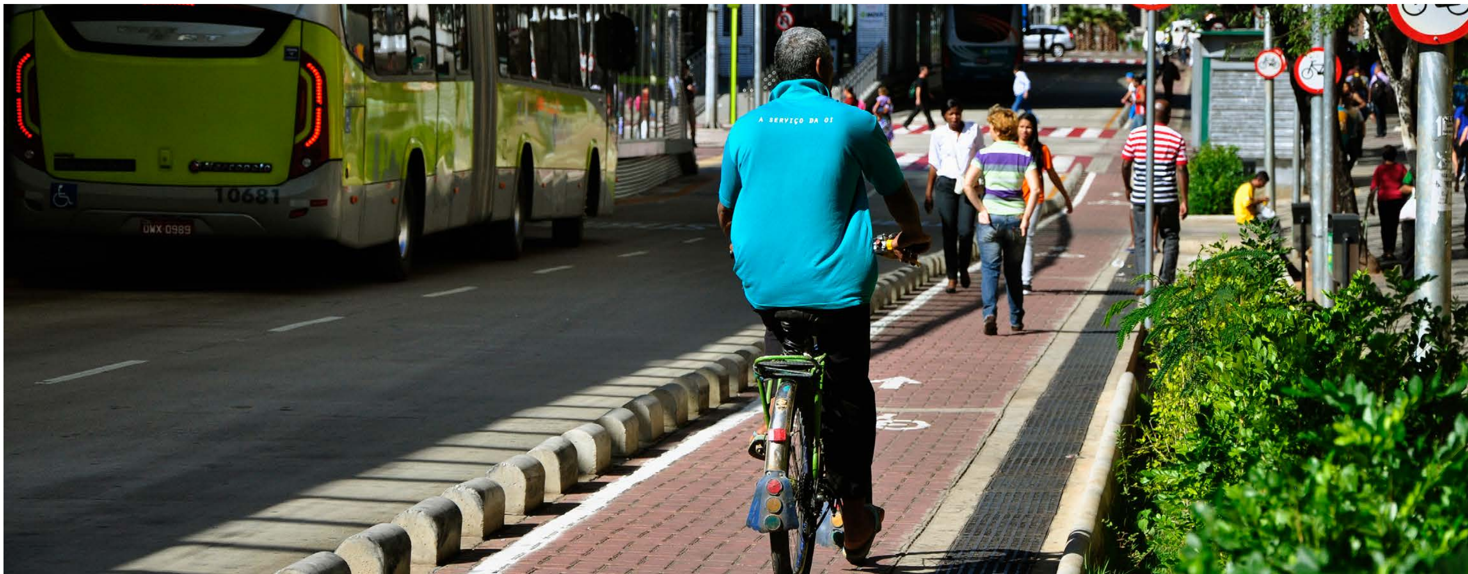
Lack of understanding of the requirements to upgrade infrastructure (all stages)

City officials (including both transit and utility providers) often lack an understanding of the essential infrastructure upgrades needed to implement an e-bus project. Transit agencies and bus operators usually do not have deep technical expertise in electricity infrastructure and often struggle to fully grasp what electrical upgrades are needed to facilitate e-buses. In Philadelphia, for example, the transit agency did not initially create a detailed analysis of the costs to install e-bus infrastructure, because it originally decided on an e-bus that would charge en route and not have a major impact on its facilities. Only after deciding to update its e-bus specifications to a depot-charging bus did the agency fully explore all of its new infrastructure challenges (Box 7). Even for cities that identify the importance of infrastructure, it can be very difficult for the local utility to obtain detailed information about how charging stations are installed and what kind of grid upgrades will be required.

In addition to the physical infrastructure requirements, city officials often also do not understand the importance of and requirements for smart charging. *Smart charging* is the generic name for an electricity pricing and distribution scheme that uses computer algorithms to ensure efficient, flexible, and economical charging. Smart charging schemes have been identified in some cities as a fundamental requirement for charging e-buses en masse. While enabling smart charging is a relatively small expense compared to other infrastructure requirements, it does require forward thinking to ensure that appropriate communication infrastructure is in place (such as ethernet connections and hardware to protect security). In most cities, officials have not yet developed a full understanding of the benefits of and requirements for smart charging, let alone created plans for adopting smart charging networks or their associated infrastructure.

Limitations of the charging ports and stations (Stages 2, 3, and 4)

While a lack of smart charging will likely complicate mass adoption of e-buses, the more acute issue currently facing cities is simply the availability of charging ports. Charging ports (the lead cable connections that are plugged into an e-bus for charging), and more generally charging stations (the entire charging entity, including the housing box and the charging ports), are typically expensive, require the permanent reallocation of space



BOX 7 | PHILADELPHIA AND CHARGING INFRASTRUCTURE CHALLENGES

Philadelphia's transit agency, the Southeastern Pennsylvania Transportation Authority (SEPTA), faced many challenges in starting its e-bus project due to the rapidly evolving e-bus market, which brought with it new infrastructure choices and difficult decisions. The initial plan was for the e-buses to feature small battery ranges and receive intermediate pantograph charges under canopies at the end of their routes. However, SEPTA later determined that a newly introduced electric bus model (with a larger battery and no need for overhead charging canopies) would best fit its needs. Also contributing to this decision was the determination that overhead charging canopies could require challenging and expensive land acquisition and face space constraints and liability concerns. Therefore, SEPTA decided to change from en route charging to charging exclusively at depots. The identification of this critical revision relatively late in the procurement process required SEPTA to enter new contract negotiations with its e-bus manufacturer, which increased costs and extended the procurement process by roughly six months.

The extended-range-battery e-buses made the creation of adequate charging infrastructure more complicated. SEPTA calculated that the depot that was to house the 25 e-buses had limited electricity capacity. This required the installation of a new substation at the depot. As part of this work, SEPTA looked at current electricity capacity at all eight of its depots and found that charging capacity exists for only an additional 105 e-buses (or roughly 7 percent of SEPTA's total fleet of 1,454 buses).

Mitigating these capacity restraints on the large-scale adoption of e-buses will require new transformers, substations, and sources of electricity. In light of these infrastructure requirements, SEPTA and the local utility have identified the potential future need for major investment in the grid and/or in new power-generation sources. Future endeavors could be made complex and political by local environmental groups' threatened opposition to future e-bus procurement plans if these require increasing the amount of electricity generated from fossil fuels.

SEPTA also found it difficult to plan for the high costs associated with implementing the charging infrastructure. The charging stations, which were installed in a one-to-one ratio with the e-buses, cost $50,000 each, while the substation cost roughly $400,000. Labor costs to physically install these pieces of infrastructure was also substantial. The all-in cost to install this infrastructure was more than $1 million.

The infrastructure could have cost even more. SEPTA's preference is for e-bus charging to supply full redundancy, allowing operations to continue in the event of a power loss. The cost of redundancy, however, proved prohibitive. Creating redundancy for the electricity supplied to the 25 initial e-buses was estimated to cost an additional $750,000. The experience with infrastructure costs led SEPTA to reduce the size of its now-planned second deployment of e-buses from 25 to 10. While SEPTA has stated goals to expand its e-bus fleet, the required electricity needs, and the corresponding price of infrastructure, have been notable challenges.

to be installed, and need to be protected from the elements. For these reasons, it is often difficult to install large numbers of charging stations, and the availability of charging stations is often a key limiter on the number of e-buses that can be purchased. In some cities, such as Zhengzhou and Philadelphia, planners have made future e-bus procurement decisions explicitly contingent on the limited number of available charging stations. Additionally, cities often fail to consider that charging docks do not always function. Just like e-buses, charging docks are a new technology that faces operational limitations. These limitations increase when charging in cold temperatures and/or under adverse weather conditions. Charging stations are still an emerging technology with high costs, cumbersome physical requirements, and reliability issues.

Grid instability (Stages 2, 3, and 4)

Challenges with grid stability are another major barrier to implementing e-buses. In some Stage 0 and Stage 1 cities, mostly in India and Africa, one of the identified barriers was simply ensuring that the local utility company could provide a reliable flow of electricity for the e-buses, given those cities' current general difficulty supplying consistent electricity. While this issue does not apply to many cities at the moment, as e-bus fleets are established and expanded, grid instability at the local level will likely become increasingly important for all cities. Although most cities have interconnected systems in place to circumnavigate problems in the grid network, the charging docks, substations, and transformers that were installed for e-bus electrification in some cities lack these redundancies. This means that one malfunctioning substation can impede the ability to charge an entire fleet of e-buses. As e-bus fleets expand past pilots and start to comprise substantial portions of the total bus fleets, grid instability could paralyze an entire transit system. A lack of grid stability is presently a barrier to cities with currently inadequate electricity networks, preventing scalable e-bus implementation.

Lack of standards and regulations on charging infrastructure (all stages)

As is common with nascent technology, the e-bus charging industry currently lacks standards and regulations, and this is acting as a barrier to streamlining implementation. There are still variations in the types of available charge port design (i.e., the design of the charging outlet that connects to the e-bus). Multiple standards—notably the CHAdeMO[2] standard and the Society of Automotive Engineers standard—have been proposed for the plug-in cable connection to "fast" chargers (alternatively referred to as Stage 3 chargers). There are also additional standards being proposed in China, North America, and Europe. The inconsistency of these standards creates a further barrier to streamlining e-bus charging infrastructure.

Charging methods also lack standardization. While most e-buses are charged by being plugged in at a depot, several charging strategies and technologies currently on the market are vying to become the future standard. Some cities, such as Madrid and Zhengzhou, currently have e-bus fleets that operate using several different charging technologies, including overhead charging, wireless inductive charging, and battery swapping. Madrid and Zhengzhou have seen benefits from these nondepot charging schemes (mostly related to saving time and boosting range), but they are often considered prohibitively expensive to scale. While this mix of charging options provides pilot data on the efficacy of different charging technologies, it demonstrates the logistical challenges that accompany the lack of charging standards in the industry.

Financial Barriers

Large capital expenses for grid infrastructure (Stages 2, 3, and 4)

In addition to the ones surrounding the procurement of e-buses, immense financial challenges also complicate the establishment and maintenance of the required charging infrastructure. Large capital costs are associated not only with procuring charging stations but also with the required preparatory work (such as excavating concrete, enhancing or expanding underground utility connections, and upgrading electrical systems, including distribution transformers and substations). Additionally, it can be difficult to minimize the costs of installation (such as the amount of concrete that must be excavated) because flexibility is needed given the severe space limitations at many urban depot locations (a problem explored in more detail below). The high cost of upgrading grid infrastructure and renovating depots with charging points was identified as a barrier in many of the case studies.

Several cities (such as Philadelphia, Shenzhen, Cape Town, and Campinas) also noted that, although these infrastructure costs are substantial, this barrier was not adequately identified during the planning stages of the e-bus programs. For example, charging issues led to implementation delays in Philadelphia, where the cost of investment (estimated at roughly $750,000 per megawatt) led the transit agency to limit the size of its second e-bus pilot. In Campinas, charging placement changes made the capital costs so unexpectedly high that e-bus service commenced with buses charged by temporary, expensive, and highly polluting diesel generators. Planning for charging infrastructure costs can also be hampered by a lack of financing options. Financing charging infrastructure, like financing e-buses (see section above), can be difficult to achieve due to the nascency of the marketplace and the unknown risks. E-buses require large capital investments in grid and charging infrastructure that are often overlooked by city transit agencies.

Difficult to determine grid infrastructure responsibilities (all stages)

One reason why charging infrastructure is often overlooked is because it is sometimes difficult to determine who should be responsible for funding and maintaining it. Charging infrastructure represents a new expense, one without historic precedence on who should pay. For example, the provision of electricity traditionally falls outside the purview of public transit agencies, and these agencies may be unwilling to assume the entire cost of grid upgrades. Likewise, traditional bus manufacturers are typically not responsible for installing fueling infrastructure, and they may be hesitant to play an active role in funding charging points. It is often difficult for the many government agencies and private sector stakeholders to work together to fund the installation and maintenance of charging infrastructure.

Institutional Barriers

Lack of space and land to install infrastructure (Stages 2, 3, and 4)

Charging infrastructure requires permanent physical space to house it, which is often very difficult to find for transit agencies and municipalities. E-buses need to be parked near charging infrastructure, which often makes it harder to park the e-buses in a tandem or block formation. Planners in Cape Town estimated that the charging infrastructure and new parking schematics may require depots to be up to 30 percent to 40 percent larger to accommodate new e-buses and charging infrastructure. These space issues are critical, since many cities seemed to share the sentiment expressed by representatives of Philadelphia's transit agency: "Inches matter in our facilities." For example, the installation of a substation and charging docks at a depot in Philadelphia required the removal of a storage area and a change in the operations at the depot. Exacerbating these space issues is the nature of the charging stations, which are often difficult to tuck away on a roof above an e-bus and sometimes have maximum length allowances for their cable leads. Since space at depots is often very limited, and creating additional depots is prohibitively expensive in many urban areas, the lack of available land can often constitute a barrier to scaling e-bus fleets.

The space requirements for charging infrastructure are further complicated when such infrastructure needs to be placed on land not owned by a cooperative stakeholder. In Shenzhen, for example, bus companies had to buy most of their rented depot land in order to secure the right to install the charging infrastructure (Box 8). Federal property laws in Brazil required Belo Horizonte and Campinas to deal with land acquisition issues as well in their installation of the charging infrastructure. Property issues became such an obstacle in Philadelphia that the transit agency decided to scrap its plans to install overhead charging infrastructure at a terminal owned by a mall and instead purchase different e-buses with longer ranges. E-buses are often limited by the availability of charging infrastructure, and charging infrastructure is often limited by the availability of land.

Limited planning for long-term implications (Stages 3 and 4)

Perhaps the largest single barrier to the long-term, large-scale implementation of e-buses is the lack of thorough consideration and planning, by most cities and national governments, for the massive electricity grid upgrades needed to power mass-adopted e-bus fleets. The majority of local utility providers interviewed for the case studies said that small e-bus pilot programs will not unduly burden the electricity grid. However, very few officials had any information on what would need to be done to the electricity grid to accommodate large numbers of e-buses. Additionally, long-term grid requirements are typically outside of transit agencies' perceived jurisdiction. Regardless, mass e-bus fleets will likely become a significant percentage of the total electricity load. In Zhengzhou, for example, electric vehicles (including e-buses) are projected to require 36 percent of the total electricity load by 2020. In most cities, officials are focused simply on getting e-bus programs up and running successfully, and very few are considering the long-term grid investments that will be needed. Mass e-bus operations will require upgraded distribution transformers, new substations, new powerlines, and possibly new power plants, all of which will necessitate large coordination of stakeholders to organize and fund. In most cities, no consideration has been given to how to complete this massive infrastructure task.

BOX 8 | SHENZHEN AND PROBLEMS WITH LAND RIGHTS

Operating buses in Shenzhen had traditionally relied on renting land. While many of the major depots were owned by the bus operating companies, they were mostly located on the city periphery. Within the urban core of Shenzhen, buses conventionally used parking areas and layovers that were rented from private landlords. With conventional buses, renting areas for bus layovers was sensible, because it allowed layover locations to change as routes changed. Therefore, before the e-bus program started, approximately 80 percent of buses used rented land for layovers.

The infrastructure requirements for e-buses challenged the rental model that had been adopted by the bus operators. E-buses required installing charging infrastructure, not just at the periphery depots but also within the urban core. However, when officials attempted to install charging infrastructure at the rented layover stations, landlords often disapproved, out of fear that the bus companies would use the infrastructure as an excuse to use their land indefinitely. This required city officials to delay e-bus deployment as they searched for open plots that charging infrastructure could permanently occupy. Most of the major challenges that Shenzhen faced in scaling up its charging infrastructure were directly related to land acquisition issues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KEY TAKEAWAYS

WRI has distilled six key barriers representing the major themes of the individual barriers discussed in the section above. These six key barriers are grouped according to the three general categories of barriers identified in this report (technological, financial, and institutional) and represent issues that transcend the three identified elements of the e-bus tradespace (vehicles and batteries, agencies and operators, and grid and charging infrastructure).

The case studies revealed that many cities have dealt or are dealing with common barriers (especially those barriers that are present during early stages). While some barriers have not been identified by many cities, this may be the result of a lack of awareness (rather than overcoming that barrier). This may be particularly true for issues that are not as prevalent in early stages of e-bus adoption but become more acute as cities expand their fleets (depot space, grid instability, etc.). Although not every city will be subject to every barrier, many of the identified barriers appear to be general.

From the matrix of barriers described in Table 4, WRI has distilled six key barriers representing the major themes of the individual barriers discussed in the section above. There are six proposed key barriers because six is the smallest number of categories that can adequately encapsulate the identified barriers in the deep dive in the preceding section. These six key barriers are grouped according to the three general categories of barriers identified in this report (technological, financial, and institutional) and represent issues that transcend the three identified elements of the e-bus tradespace (vehicles and batteries, agencies and operators, and grid and charging infrastructure). Furthermore, the case studies and literature suggest that these barriers will likely be faced by many transit agencies and are potentially debilitating issues that must be resolved for e-bus endeavors to move forward.

Key Technological Barriers

E-buses are a new technology. As is true for most emerging technologies, the e-bus tradespace is inadequately understood by policymakers and is still evolving to maturity. Therefore, e-bus adoption must overcome two key technological barriers:

In general, cities lack the information needed to make informed decisions at almost all stages, from establishing an initial discussion to scaling up e-buses en masse. Cities lack general knowledge on the barriers to and enablers of e-bus implementation as well as city-specific data on the operational ability of their e-buses. Specifically, cities lack information and data needed to determine

- the proper inputs required for an initial cost-benefit analysis of the e-buses and infrastructure;
- how to best initiate and operate an e-bus project;
- the operational characteristics, limitations, and maintenance requirements of the e-buses available on the market; and
- infrastructure planning requirements to be completed prior to adoption.

TECHNICAL LIMITATIONS OF THE E-BUSES AND CHARGING INFRASTRUCTURE: Technological limitations exist in all three of the following components of the e-bus tradespace:

- *Vehicles and batteries* produce limited range and power relative to conventional buses. The battery manufacturing industry, nascent and immature, faces a learning curve in its effort to produce reliable, road-tested products.
- *Agencies and operators* lack the knowledge needed to adopt new operation models to accommodate for the range and power limitations of the e-buses.
- *Grid and charging infrastructure* are also new and evolving technologies that face limitations and stability challenges.

Key Financial Barriers

E-buses and the associated infrastructure require nonconventional financing and management mechanisms since they are expensive (up front) and relatively unproven. This causes problems with both the procurement models adopted by transit agencies and the financing plans provided by lenders. WRI has identified two key financial barriers:

DIFFICULTIES FOR AGENCIES IN CHANGING PROCUREMENT PRACTICES: Transit agencies and government institutions typically use rigid financial management models that incentivize low-cost, low-risk procurement. Most procurement models do not consider the unique cost structure (more expensive up front but cheaper to operate than conventional buses) and uncertain risks inherent in e-buses and their corresponding infrastructure. Traditional procurement practices also do not allocate responsibilities for the new tasks associated with e-buses, such as maintaining the batteries and grid infrastructure. Although the total lifetime cost of owning e-buses is often lower than that of conventional buses, and agencies may recognize that a new approach toward procurement is needed, traditional models often prove difficult to change.

LACK OF LONG-TERM, SCALABLE FINANCING OPTIONS: Given the risk, uncertainty, and nascency surrounding the e-bus industry, financing is a tremendous barrier that must be overcome if e-buses are to be implemented on a large scale. This is particularly true for municipalities that have not demonstrated strong creditworthiness with past investments. Scaling e-bus projects requires a large, risk-tolerant capital investment, both to procure the vehicles and to supply the necessary charging infrastructure and grid upgrades. Often no financial institutions are willing to make this investment, outside of a small-scale pilot. Thus, the e-bus fleets in many cities are currently operating as nonscalable pilot programs.

Key Institutional Barriers

E-bus projects are often hampered by a lack of institutional support. Simply put, e-bus implementation faces barriers when governments and institutions either will not or cannot foster the projects (due to lack of planning or lack of resources, respectively). WRI identified two key institutional barriers:

LACK OF LEADERSHIP AND PRAGMATIC PUBLIC POLICY: One of the most frequently cited institutional barriers was the lack of favorable public policies and/or a specific implementation plan to guide e-bus adoption. In many cities, there are either (1) no laws or roadmaps to provide a strategy plan or financial backing for implementing e-buses, or (2) ineffective plans in place that lack clear goals and financial incentives. One main reason that guidelines and policies are not created and/or implemented is the lack of genuine interest from politicians and key stakeholders. When there are limited incentives and lackluster political support for an e-bus project, it can be difficult for some cities to issue appropriate tenders to procure e-buses.

LACK OF INSTITUTIONAL AUTHORITY, FUNDING, AND LAND: In many cases, a major barrier to initiating or furthering e-bus projects was the lack of institutional capacity. Some cities lack the resources or jurisdictional authority to coordinate an e-bus project. Informal transit posed a noteworthy barrier for many cities, since the owners and operators of informal transit vehicles are typically not accountable to transit agencies or other government bodies.

The lack of government access to land and property also presented a substantial barrier to upgrading and installing the charging and grid infrastructure that e-bus projects require. Charging infrastructure requires land with permanent space to house it, which is often very difficult to find for transit agencies and municipalities. While property ownership issues are not conventionally thought of as barriers to e-bus adoption, owning and/or having permanent contracts over land to install and manage charging infrastructure is often crucial, especially as e-bus fleets are scaled up.


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PROJECT LIMITATIONS AND FURTHER INVESTIGATION

While the barriers outlined in this report provide a robust overview of the issues facing transit agencies seeking to develop e-bus fleets, the research has some limitations. Nevertheless, this report expands on existing research and, uniquely, places e-bus barriers within a global context. The report discusses many important barriers that have not been commonly addressed in previous research (such as space limitations at depots, public perception issues, and the hidden complexities in planning grid infrastructure) and provides a first-of-its-kind map of hazards to help guide high-level planning efforts safely along the road to e-bus adoption.

While this report's identification and analysis of barriers provides a robust overview of the issues facing transit agencies seeking to develop e-bus fleets, the research has some limitations. These constraints should be understood by decision-makers using this report's findings to guide policy. Here are some of the major limitations of this report, along with recommendations for further investigation that may help diminish these limitations.

The number of case studies was limited. WRI conducted 16 case studies for this report. While this represents an unprecedented data-collection effort given the nascency of e-bus research, this is not a large enough sample to produce quantitative results with statistical significance. Further research could include more case studies (especially now that more cases of e-bus procurement exist) and apply a more systematic, data-centric approach to producing statistically significant, quantitative findings.

E-bus research is a fast-moving target. E-bus programs are evolving rapidly throughout the world. Given the fast pace of technological changes and procurement decisions, it is hard to take a perfect snapshot of the status quo of the industry. Also, this rapidly changing industry makes it more difficult for report findings to stay relevant after publication. To combat this issue, case study follow-ups could be conducted. The findings of this report and any follow-up reports could be encapsulated in an application, providing an intuitive platform for policymakers to keep up to date on the latest developments related to e-bus barriers (and enablers, as mentioned in the parallel enablers report). Better connections between research institutions and policymakers can provide a virtuous two-way line of communication, with researchers providing industry-wide findings to city officials and city officials providing their local data and institutional models to researchers.

The progress of the case studies is not representative of typical cities. The choice of the 16 case studies intentionally overrepresents cities that are actively pursuing strategies to adopt e-buses. While this decision was necessary to properly capture worthwhile findings, it does not provide context for what the average city is doing. It is presumed that most cities globally are likely at Stage 0, having done no real investigation into pursuing e-buses. This assumption should be validated, however, and better contextualized with further investigation and research.

This report lists barriers but does not supply solutions. The barriers above are important for policymakers to understand the state of the e-bus market and the issues that persist as cities attempt to increase their e-bus fleets. Equally important, however, are strategies for transit

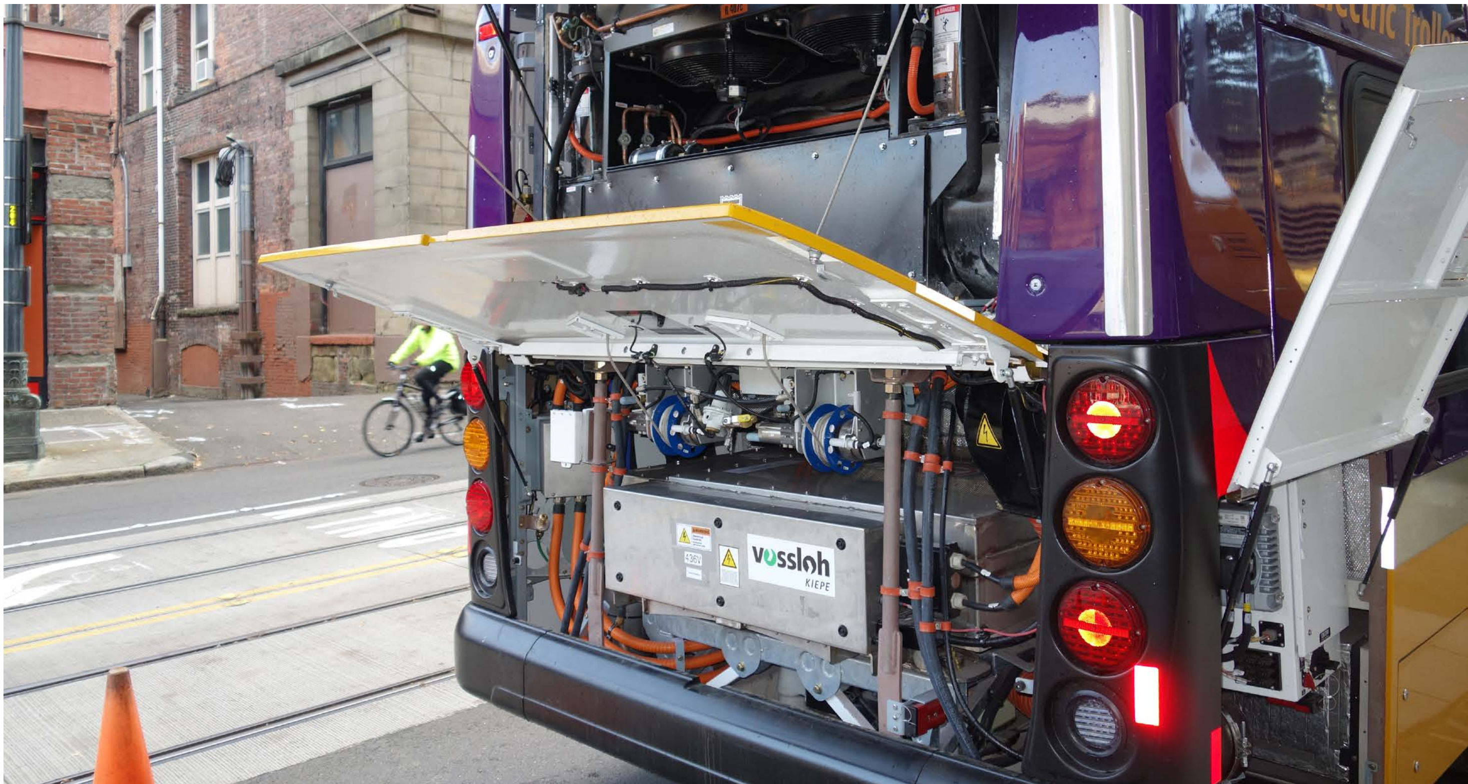
agencies to overcome these barriers. Recognizing this requirement for action, WRI has created the enablers report, which provides guidance for cities attempting to establish and expand e-bus fleets. The enablers report is published in parallel with this report, building upon many of the findings outlined in this document.

Conclusion

This report outlines the many barriers facing the adoption of e-buses. Some of these challenges (such as unavailable vehicle financing, rigid procurement models, and lack of stakeholder knowledge) have been identified in previous work by WRI staff and other researchers (Castellanos and Maassen 2017; Li et al. 2018; Bloomberg New Energy Finance 2018). This report, however, harnesses the unprecedented knowledge collected in a deep-dive analysis of e-bus projects in 16 cities, allowing this publication to expand upon those barriers and uniquely place them within a global context. This report also exposes many important barriers that have not been commonly addressed in previous research (such as space limitations at depots, the effects of public perception issues, and the hidden complexities in planning grid infrastructure). This report builds and expands upon the existing literature on the barriers to e-bus adoption.

One of the large themes that cut across many of the identified barriers was the issue of scalability. While many cities have been able to implement small-scale projects, many barriers (such as the limitations of e-bus technology, financing business models, and the current grid capacity) make it very difficult for pilot projects to be scaled. Cities often can devise a plan to create an initial e-bus project of modest size, but they have much more difficulty creating a plan that can lead to full-scale e-bus adoption. Scaling initial e-bus pilot programs to create sustained, growable e-bus fleets is a crucial but challenging task for many cities.

The barriers outlined in this report are meant to serve as cautionary tales. While this report focuses on many of the negative aspects of e-bus programs, the intent of this publication is not to discourage stakeholders but to provide a map of hazards to help guide high-level planning efforts safely along the road to e-bus adoption. For an in-depth, step-by-step guide on the measures that transit agency specialists and planning technicians should consider to facilitate a successful e-bus program, please refer to the enablers report.



APPENDIX A | ELECTRIC BUS ADOPTION STAGES OF THE CASE STUDIES

Based on city actions taken to date, WRI developed a categorization system to assess the relative progress made by each of the 16 cities toward mass e-bus adoption. The cities are predominantly from the global South, but two cities from the United States and Europe (Philadelphia and Madrid) are also included because their experiences in e-bus adoption can provide useful information for other cities. Specific city-level actions were also categorized as either policy- or implementation-based actions:

- **Policy actions:** The city has considered or is actively considering specific e-bus policies or adoption targets.
- **Implementation actions:** The city has procured and is operating e-buses either as a pilot or as part of its nominal public transit operations.

The extent to which each of the 16 cities has taken concrete policy and/or implementation actions was evaluated to place each city in one of five categories, called Stages 0 to 4 (Table A-1). Cities can use these actions as a guide to determine in which stage of electric bus adoption they fall.

Table A-1 | Actions toward Electric Bus Adoption Taken by the 16 Case Study Cities

STAGE	CITY	POLICY/TARGET			IMPLEMENTATION			
		Informal discussions	Formal discussions	Policy enacted	Preliminary test	Structured Pilot	Multi-route operations (plan)	Mass route operations (network)
0	Addis Ababa, Ethiopia	🟩	🟥	🟥	🟥	🟥	🟥	🟥
1	Ahmedabad, India	🟩	🟩	🟩	🟥	🟥	🟥	🟥
1	Quito, Ecuador[a]	🟩	🟨	🟨	🟥	🟥	🟥	🟥
1	Mexico City, Mexico[b]	🟩	🟩	🟨	🟨	🟥	🟥	🟥
1	Cape Town, South Africa[c]	🟩	🟨	🟥	🟨	🟨	🟥	🟥
1	Bangalore, India[d]	🟩	🟩	🟩	🟥	🟥	🟥	🟥
2	Belo Horizonte, Brazil[e]	🟩	🟩	🟩	🟨	🟥	🟥	🟥
2	Bogotá, Colombia	🟩	🟩	🟨	🟩	🟥	🟥	🟥
2	Madrid, Spain	🟩	🟩	🟨	🟩	🟨	🟥	🟥
2	Philadelphia, United States	🟩	🟩	🟩	🟩	🟩	🟥	🟥
2	Manali, India[f]	🟩	🟩	🟩	🟩	🟩	🟨	🟥
3	Izmir, Turkey	🟩	🟩	🟩	🟩	🟩	🟩	🟥
3	Campinas, Brazil	🟩	🟩	🟩	🟩	🟩	🟩	🟥
3	Santiago, Chile[g]	🟩	🟩	🟩	🟩	🟩	🟩	🟨
4	Zhengzhou, China	🟩	🟩	🟩	🟩	🟩	🟩	🟩
4	Shenzhen, China	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Notes: **GREEN:** implemented; **YELLOW:** ambiguous; **RED:** not implemented.

a. Quito has had an e-bus pilot test led by the manufacturer, but the government has not had any serious conversations about adopting e-buses or made any plans in this regard.
b. Mexico City is developing a long-term policy and is planning to pilot buses on certain routes when the research has been completed.
c. Before a structured pilot plan was developed, Cape Town procured a small fleet of electric buses, which are not yet in operation. However, the project was under investigation by local authorities when the case study was performed.
d. Bangalore had a three-month e-bus trial supported by a manufacturer, but the agency didn't further expand the project or procure the buses. Thus, WRI does not count the trial as a structured pilot.
e. Belo Horizonte is about to start the pilot testing process but had not officially launched the project as of report publication.
f. Manali has been operating a fleet of 25 electric buses. However, the buses operate only during a certain time of year, the plan to scale up the project is ambiguous, and the replicability of the project is hard to determine.
g. Santiago adopted 100 electric buses in late 2018 and another 100 in early 2019. However, whether these new buses qualify as "mass route operations" is still ambiguous.

Source: Authors.

APPENDIX B | METHODOLOGY

CASE STUDY PROTOCOL AND INTERVIEW GUIDELINES OF ELECTRIC BUS ADOPTION CASE STUDY (EXCERPT)

Overview of the case study

This project is trying to review the barriers cities are facing during the electric bus adoption process and to identify key actions urban leaders could take to fill knowledge gaps, tackle barriers, and accelerate adoption. The experience of cities in adopting electric buses is a relatively new topic with limited recorded knowledge, which is why WRI has chosen a case study as the best approach to fill the information gap. Both primary and secondary sources of data are needed to finish quality case studies with limited resources. While desktop research can collect secondary data and answer questions like "who," "what," and "where," interviews with stakeholders can help answer "how" and "why" questions regarding electric bus adoption.

The case studies will be conducted under a consistent analytical framework that is mainly based on lifecycle elements of electric bus adoption and allows for adjustment due to potential differences between cities. The case studies will be selected to include as many types of cities as possible and may include counterpart cases that are not as successful but which could help identify specific barriers that may have different impacts on cities in different stages of electric bus adoption. In addition to literature reviews and desktop research, detailed information will be collected through interviews with local stakeholders. These case studies serve as the major sources to facilitate a deep dive into cities of different situations, and to learn about the on-the-ground barriers they have encountered in their local contexts. This document provides a guide and general requirements for the case studies and interviews, to ensure cross-case comparability.

Case study questions and hypotheses

Through the case studies and interviews, we attempted to answer two key questions:

- What barriers does a city face when planning and implementing the adoption of electric buses?
- What actions can urban leaders take to address these barriers and accelerate the adoption process?

We hypothesized that multiple stages exist for electric bus adoption in different cities. Even though the adoption approaches could vary, similar categories of barriers and related actions may exist, such as institutional, technical, financial, social, and environmental ones.

The case studies attempted to understand "what," "how," and "why" certain steps are taken, or certain measures are carried out, for electric bus adoption in selected cities. The "what" questions were mainly addressed by literature reviews and desktop research and supplemented by interview questions, especially for the indirect aspects of adoption. The "how" and "why" questions we pursued mainly through interviews with related stakeholders, who could provide firsthand information on the case. When we identified applicable literature, we used additional literature reviews to strengthen our understanding of all components of the case studies.

This research does not focus on any specific electric bus technology. Instead, its aim is to determine how and why a technology was adopted, and key measures related to "technology adoption" and "technology diffusion," using electric buses as an example. When the results of the project are delivered to the target audiences, we suggest that rather than focus on which technology to choose, it could be more productive to focus on the local situation and base the choice on those circumstances. The choice of bus technology should be made by local officials based on local conditions.

Theoretical framework for the case studies

Technology diffusion normally can be divided into multiple stages, based on the level of technology maturity and market penetration. We hypothesize that electric buses, as an emerging clean technology, will go through the same development stages. Based on author preliminary analysis through research, case studies, local engagement, and literature reviews, we developed five stages for electric buses, according to the adoption conditions for cities around the world. The definitions will be improved once the research is done.

- **Stage zero (0)**: At this stage, there are no specific measures regarding electric buses in the city. Some thoughts may have been articulated, but no concrete actions have been taken yet.
- **Emerging stage (1)**: At this stage, the city is considering electric bus adoption, starting to conduct research and analysis on the applicability and feasibility of electric buses to the local context, preparing a related work plan or roadmap, or setting targets for adoption.
- **Breakthrough stage (2)**: At this stage, the city starts to test the technology with pilot projects, trying to collect operational data, investigating areas for improvement, and preparing for mass adoption of electric buses.
- **Growing stage (3)**: At this stage, the city is speeding up the adoption process by procuring more electric buses. Meanwhile, route-based or city-level planning has started to ensure quality service and improve operational efficiency.
- **Consolidated stage (4)**: to the maximum level of electrification defined by the city: At this stage, the city is heading for 100 percent electrification of its local bus system, or, based on local needs and conditions, it is reaching the maximum level of electrification it is willing to or could have, without sacrificing service quality. Meanwhile, city-level planning needs to happen, and backup plans need to be prepared before full electrification.

In order to conduct the comparative case study analysis and collect comparable information, we have used a predefined case study outline. Some flexibility can be exercised due to variance among cases. But the general categories are the same.

Case study outline

Instructions: Case study authors should refer to this framework first before starting the research process in order to generate a set of consistent and comparable case studies. Then, based on the information collected, authors can determine whether the city context requires anything outside of this framework, or whether any innovations in the system should be added to the list. The sample questions should be considered as a guide to information collection and may provide some idea of the content. They may be tailored and adjusted based on local context.

- General information on the city
  - Electric bus development
  - History of electric bus development
  - Identification of the stage of development
  - Next steps
- Barriers and benefits (if any recorded information exists)
  - Barriers: Potential categories include, but are not limited to, technology and infrastructure, cost and financing, and institutional, operational, environmental, and social aspects.
  - Benefits: Cost savings, emissions reductions, and so on.
- Stakeholder analysis
- Key components
  - What are the key components of this stage, and of previous stages, if any?
  - What other components or variables in this case are not reflected in this lifecycle component framework?
- Key takeaways (keep short but synthesized)

Data collection procedures

In this project, desktop research and interviews are the two primary research methods. Apart from published journal articles, which are limited in this case, the literature review should have a strong emphasis on gray literature, such as reports and other resources not publicized internationally, government policies, company reports, research institute publications, and unpublished research. For the interviews, the project will use a semistructured approach to collect primary information from local stakeholders. This type of interview contains predetermined questions but allows the flexibility to ask more customized questions based on the actual conversation. The targeted local stakeholders are ideally all sectors involved in the city's electric bus adoption project, to reduce potential bias and incorporate diverse voices.

This section will not go into literature review method, and will focus on interviews only. It covers the suggested steps for data collection (more focus on interviews), the type of evidence to be expected, specific information to be reviewed, and issues to be covered prior to fieldwork (interviews).

Expected preparation prior to interview

For each city, the status, policy, and process of electric bus adoption could be different. Thus, it is important to define key concepts ahead of time, and develop a general framework for information collection, in order to maintain the uniqueness and comparability of all cases.

- **Define the key terms below before the interview:**
  - The scope of the electric bus adoption project or effort.
    - Whether district, city, regional/provincial, or national level efforts are included. Be clear about different levels' efforts in the case. The actions, measures, stakeholders, and results could be different.
  - The technology the city will be, is, or has been implementing.
    - This project is mainly focused on battery electric buses, which could include different charging methods.
    - If the city does not distinguish among the categories of battery electric bus, plug-in hybrid electric bus, fuel cell bus, and conventional hybrid electric bus, it will be important to find out the intention and reason behind this and maintain a good record of the general policy or plan and other information.
  - The transport modes included in electrification targets, plans, or projects.
    - This project is mainly focusing on buses.
    - But it will be interesting to see the connections with other modes, such as private vehicles, two–three wheelers, taxis, and freight if the city's electrification focus is not solely or mainly on electric buses.
  - The development stage (see case study outline) of the city.
    - If multiple stages exist, try to separate the information for each stage and record the trends, if any.
- **Create a stakeholder map and identify the right person to perform the interview.**
  - If this task is hard to initiate at the beginning with desktop research, find the focal contact person, or people who issued a certain target, for example, and ask them for more information. The more stakeholders involved, the less informant bias exists.

Potential stakeholders

A list of potential stakeholders is shown below. It varies by city and should be a list of reference. Each case will also have key stakeholders and tertiary stakeholders, who play different roles and have different impact on the project. This could be analyzed later in the case study and report. At the current stage, it is important to capture as many stakeholders as possible.

- **City level**
  - Bus operators (public, private, etc.)
  - City officials who are in charge of the related project
    - Public planning
    - Related public work or infrastructure
    - Transport
    - Energy and/or environment
    - Treasury (for budget purpose, fuel vs. electricity), or who pays the bills
    - Other
  - Utility companies (public, private, etc.)
  - Charging service providers
    - Utilities (if they are in charge)
    - Manufacturer
    - Installer
  - Local transport research institute
  - Manufacturers (local)
  - Passengers/public (if involved in decision-making process)
  - Financial institute
- **Regional level**
  - Transit authorities
  - Planning committee
  - Governance or regulatory authorities (transport, energy, environment, etc.)
- **Higher level**
  - National-level officials
- Transport, energy, industry and technology, treasury, environment, etc.
  - Utility companies (national, regional)
  - Manufacturers (national, international)
  - National research institute, academia
  - Financial institute
  - Bank, leasing company, international development organization, etc.
- **Other local specific stakeholders**
  - E.g., a certain committee organized specifically for a certain electric bus project in a city, or a group of specialists for the project, or a local carbon market (if connected with electric buses)

Interview questions

Institutional	Institutional setting Specific arrangement
Governance	Policies and targets Key initiatives and mechanisms, for electric buses, if any International agenda and climate actions (SDG, NDP, etc.)
Technology	Upstream, manufacturing Downstream, operation
Operation	Procurement, contracting, and commissioning process Bus operation and maintenance Bus and battery recycling and scrapping Impacts evaluation
Cost and finance	Cost Finance
Societal	Societal—including users/passengers Economic Political
Environmental	Environmental impact analysis Results
Barrier	Barriers and opportunities Local and universal

Not all of these questions need to be asked in interviews; some may be answered through desk research. Some categories are applicable to specific stakeholders.

Results of the Case Studies and Interviews

The results of the case studies are reflected in this report. A brief summary of interviews conducted is listed in the table below.

Table B-1 | A Summary of Stakeholders Interviewed in 16 Case Studies

CITY	STAKEHOLDERS INTERVIEWED					
	CITY OFFICIALS, GOVERNMENT	TRANSIT AGENCY/ AUTHORITY	BUS OPERATOR	VEHICLE/ BATTERY MANUFACTURER	UTILITY/ CHARGING	RESEARCH INSTITUTE
Addis Ababa, Ethiopia	X	X	X	X	X	
Ahmedabad, India	X	X				
Quito, Ecuador	X					X
Mexico City, Mexico	X	X				X
Belo Horizonte, Brazil		X	X	X	X	
Cape Town, South Africa	X	X	X		X	X
Bogotá, Colombia	X	X	X	X	X	X
Bangalore, India	X	X			X	
Madrid, Spain	X	X	X	X		X
Philadelphia, USA	X	X	X	X		X
Manali, India		X				
Izmir, Turkey	X		X			
Campinas, Brazil		X	X	X	X	X
Santiago, Chile	X	X	X			X
Zhengzhou, China			X	X		
Shenzhen, China		X	X	X		X

Source: Authors.

ENDNOTES

1. WRI is currently working with stakeholders in Bogotá to retool the tender requirements set for bus procurements.

2. This acronym for this standard, proposed by major Japanese automakers, stands for "charge de move," a pun on the Japanese expression *O cha demo ikaga desuka* (Shall we have a cup of tea while charging?), which refers to the quick charge time. https://www.chademo.com/faq/.

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ABOUT WRI

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Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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ISBN 978-1-56973-960-0