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Clean Bus in LAC
Lessons from Chile’s Experience with E-mobility

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Lessons from Chile's Experience with E-mobility:

The Integration of E-Buses in Santiago

NDC Support Facility

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Content

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Abbreviations

3CV	Centre for Vehicle Control and Certification
AC	alternating current
AFT	Transantiago financial manager
CAPEX	capital expenditure
Ch$	Chilean pesos
CH_4	methane
CNE	National Energy Commission (Comisión Nacional de Energía)
CO	carbon monoxide
CO_2	carbon dioxide
CO_{2eq}	carbon dioxide equivalent
COP25	25th United Nations Climate Change Conference
DC	direct current
DTPM	Metropolitan Public Transport Board (Directorio de Transporte Público Metropolitano)
e-bus	electric bus
e-depot	electric depot
e-fleet	electric fleet
e-mobility	electromobility
ESTRAUS	Strategic Model of Santiago
EV	electric vehicle
GDP	gross domestic product
GHG	greenhouse gas
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation model
HC	hydrocarbon
IEA	International Energy Agency
km	kilometer
km^2	square kilometer
kWh	kilowatt hour
MAC	marginal abatement cost
MMA	Ministry of Environment (Ministerio del Medio Ambiente)
Mt	megatonne
MTT	Ministry of Transport and Telecommunication (Ministerio de Transportes y Telecomunicaciones)
MW	megawatt
MWh	megawatt hour
N_2O	nitrous oxide
NDCs	Nationally Determined Contributions
NH_3	ammonia
NO_x	nitrogen oxide
OPEX	operating expenditure
PM	particulate matter
PPDA	Pollution Prevention and Decontamination Plan for the Metropolitan Region
PPP	public-private partnership
Red	Red Metropolitana de Movilidad (previously Transantiago)
SEC	Superintendence of Electricity and Fuel (Superintendencia de Electricidad y Combustibles)
SECTRA	Secretary of Transport Planning (Secretaría de Planificación de Transporte)
SEREMITT	Region Secretary of the MTT (Secretaría Regional Ministerial de Transportes y Telecomunicaciones)
SO_x	sulfur oxide
SPV	special purpose vehicle
TCO	total cost of ownership
TPES	total primary energy supply
UITP	International Association of Public Transport
VAT	value added tax
WHO	World Health Organization

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Executive summary

This report aims to increase awareness of effective ways to reduce emissions in the transport sector by outlining the planning, implementation, and management of electric buses (e-buses) in the fleet of Santiago's public transport system. The study considers the contribution of e-buses to sustainable mobility and the methods used to measure associated reductions in emissions, in addition to the importance of these new technologies in raising public transport standards and complying with climate change commitments.

Currently, the public transport system in Santiago is going through a transition to green technology with the introduction of electric and diesel Euro VI buses, and toward a new bidding process that aims to separate the operation of bus services and provision. This change brings new regulatory challenges, but also opportunities for the introduction of new technologies. This report looks into some of the main challenges and opportunities Santiago and other cities face as they move toward a cleaner fleet.

Sustainable mobility context

Chile is composed of 16 regions, one of them being the Metropolitan Region. Almost 40 percent of Chile's population is concentrated in Santiago, making it Chile's most densely populated urban area with a population of 6.8 million in 2019. This is the area covered by the city's integrated public transport system (Red Metropolitana de Movilidad, previously Transantiago).

Chile has become a regional leader in financial matters in Latin America, based on a market-oriented economy, with a democratic political system and a solidly open market that for many years has offered an attractive business environment, showing the best financial risk ratings in Latin America. Chile has 26 trade agreements covering 60 countries. Specifically, its trade agreement with China is considered a tariff liberalization program, facilitating product exchange. Despite the benefits of economic and political stability, underlying social problems related to inequality recently sparked protests in October 2019. Attempts to find political solutions to the crisis include proposals to produce a new constitution over the next two to three years.

In environmental terms, **Chile is highly vulnerable to the impacts of climate change** because of its geography and variety of climatic zones. The transport sector is currently responsible for nearly 25 percent of Chile's carbon dioxide equivalent (CO_{2eq}) emissions. While this impact is directly related to a high motorization rate and the use of private cars, conventional buses also have an impact on the emission of particulate matter (PM) and nitrogen oxide (NO_x). Over the past 30 years, several **mitigation measures** have been adopted, such as cleaner fuels and emissions standards for new vehicles, both private and public. These include the recent addition of e-buses into the city's fleets, and have achieved significant reductions in emissions, especially in $PM_{2.5}$ and PM_{10}.

Oil is the largest primary energy source, accounting for 41.5 percent of the total primary energy supply in 2018; renewable energy represented 27.6 percent. While the **renewable energy sector, in particular solar, has been growing for many decades,** electricity demand is increasing rapidly, along with economic growth. Under a business-as-usual scenario modeled by the Ministry of Energy, **electricity demand would more than double by 2050**.

Chile aims to derive a **growing share of electricity from renewable sources**. The country has vast resources of solar energy and abundant unexploited potential for wind, hydro, and geothermal (IEA, 2018). In its National Energy Policy 2050, which was adopted in 2015, the government set targets for a **60 percent share of renewable power by 2035 and 70 percent by 2050**. The share is currently around 50 percent.

Over the past decade, Chile has implemented several domestic policies related to sustainable mobility. Particularly, in its commitments to the Paris Agreement, Chile's unconditional target is to reach a **30 percent reduction in CO_2 emissions** per gross domestic product (GDP) unit below 2007 levels by the year 2030 (and a conditional target of 35–45 percent), besides other measures related to black carbon mitigation in urban areas.

The National Electromobility Strategy seeks to contribute to the mitigation of greenhouse gases by improving the mobility and quality of life of Chileans. It outlines the actions that Chile must take in the short and medium term to ensure that **60 percent of private vehicles and 100 percent of urban public transport buses will be electric by 2050**.

The Nationally Determined Contributions in the context of the Paris Agreement, the National Electromobility Strategy, and other programs such as the Pollution Prevention and Decontamination Plan for the Metropolitan Region of Santiago, the National Climate Change Plan 2017–22, and the Energy Route 2018–22, aim to reduce Chile's level of emissions and mitigate the impacts of climate change. They have produced considerable impacts, particularly in the transport and energy sectors.

The effects of these policies in terms of reduced emissions can be measured using various methodologies, software, and tools (such as the MAC, Greet, and MODEM models). The emissions model used in Chile is MODEM, an application that allows atmospheric emissions from mobile sources to be estimated using information on vehicle flows from transport modeling outputs, vehicle flow profiles, and emission factors.

Implementation of e-mobility in Santiago

The public transport system in Santiago is based on the operation of six bus companies: Metbus, Buses Vule, STP, RedBus, Subus, and Express. Each is assigned a group of bus services (business units), integrated with a seamless electronic payment system that uses a smart card (bip!). Revenues are collected and managed by the regulator. The original length of the concessions' contracts was 10 years, with the first operations starting in 2007, but most of them were extended. The life cycle of a bus fleet is defined as at least 1,000,000 kilometers and/or 12 years of operation; once this has been reached, there is an imminent need to renew the fleet.

The remuneration scheme for bus operators is based on a payment per transported passenger (approximately 70 percent of bus operator revenues) and a payment per kilometer traveled (equivalent to the other 30 percent). An operator may see its payment reduced because of noncompliance with operational standards.

The business model used for the implementation of e-buses in Santiago consists of a public-private partnership (PPP) between the state and private companies. As with any PPP, each party had different motivations and responsibilities governing its initial involvement and further participation in the process. The Ministry of Transport and Telecommunications (MTT) and the participating private companies have so far introduced almost 400 e-buses together with the renewal of a large part of the bus fleet to the Euro VI diesel standard.

The state has played a supporting role from the beginning. As the system was going through a brand transformation led by the government, from Transantiago to Red Metropolitana de Movilidad ("Red"), there was an opportunity to renew the fleet and introduce better and cleaner technologies. Government actions to facilitate the process, reduce approval and authorization times, and support the planning and regulation of these buses, were critical to the success of the transition.

The energy companies Enel and Engie, in order to boost their core business (centering on energy sales and the installation of charging infrastructure), have financed the provision of buses and electric charging infrastructure using leasing contracts with the private bus operator companies. The leasing contracts involve monthly payments to cover three elements: fleet provision, charging infrastructure, and energy supply.

Following several e-bus pilots in Santiago's streets and the development of associated studies on e-mobility in the city, the bus operator Metbus was the first to include e-buses in its fleet (285 BYD vehicles), operating the first e-corridor in Latin America, followed by Buses Vule (76 Yutong vehicles) and STP (25 Yutong vehicles), and finally by RedBus (25 King Long e-buses expected in 2020). **These buses represent approximately 6 percent of the fleet** (411 e-buses in a total fleet of 6,849 in 2019).

The first e-buses implemented as pilots (BYD buses) in Santiago cost around $450,000, more than twice the diesel Euro VI cost. This changed significantly with the incorporation of a bigger e-bus fleet; the prices negotiated were much lower, as bus manufacturers BYD and Yutong saw an opportunity to introduce e-bus technology in the Latin American market. This time, the **e-bus price was around $300,000**, making it much more competitive relative to diesel Euro VI buses.

The current contracts allow the operators' quotes for fleet provision to be paid directly to the bus provider (and investor). The AFT (a financial entity in charge of collecting revenue and managing operators' payments) deducts, from each operator's payment, the amount corresponding to the leasing contract that operator has with the energy company. This has reduced the risk for investors. The providers and the operators sign provision contracts, approved by the state, that specify that, no matter what company is operating the e-buses, the state guarantees that the buses will remain in the system until the debt is paid. This also minimizes the risk to the financing entity, as the loan is secured by the state.

The payment that operators receive from the system is adjusted if any of the concession's conditions that affect the financial equilibrium of the contract change significantly. Where new buses correspond to a fleet increase, the state covers the difference between the cost of the new technology and the old buses, through an update of the monthly payment to the bus operator company. Thus, for the first 200 e-buses, the state assumed the increase in capital costs associated with the new technology.

Importantly, **operators project that e-buses will have lower operational costs** than diesel buses. The difference in capital expenditure between electric and diesel technology is compensated by the reduction in operating expenditure (approximately 66 percent), so the business is expected to break even within 10 to 14 years of payment, with an operation of 6,000 kilometers/month. This has encouraged various operators to start renewing their old fleets to become electric without any state financial support, not only because of the savings in operating expenditure, but also because **forecasts indicate that the prices of electric technology are expected to decrease over time**.

Maintenance costs are also approximately 66 percent lower for e-buses than diesel buses. There are two main approaches to the maintenance of e-buses. In the case of bus operator Metbus, the bus manufacturer BYD oversees preventive, corrective, and predictive maintenance of the e-buses, in addition to the management of spare parts, and suffers a reduction in monthly lease payments when the buses are not charged and available to be used when needed. On the other hand, both bus operators STP and Buses Vule oversee maintenance issues themselves, so that the bus manufacturer Yutong has no responsibility other than providing spare parts.

The implementation of an e-fleet introduces new challenges related to the capabilities and performance of e-buses. Elements such as the charging of batteries, custom modifications for urban operations in Santiago, guarantee schemes, availability of and alternatives to spare parts, plans for the disposal of batteries, and approval type processes, among others, are crucial to consider when selecting the bus technology and designing the service.

Chile's Centre for Vehicle Control and Certification (3CV) has a technical laboratory to certify the characteristics of different types of vehicles operating in Chile, and recently conducted analyses of the emissions and energy efficiency of buses in the public transport system, including both electric and diesel buses. The characteristics considered in the certification process of e-buses include safety, dimensions, type of engine, and energy efficiency. These are tested in a controlled laboratory environment that aims to represent the street conditions the e-buses will face.

There are also relevant elements to consider in the design, construction, and installation of depots, such as the approval times needed for the construction of infrastructure, the existence of electric infrastructure and the capacity of the electric grid, the power and number of chargers needed for the operation of buses, the charging management mechanism (smart or other), the technology of the buses and the chargers, the maintenance of the infrastructure, and the possibility of energy storage, among others.

The planning of electric services, meanwhile, requires considering the performance of a bus in real-life situations and how this might affect the design and implementation of operational plans, mainly in terms of capacity and autonomy. The **training of workers in the use of this new technology is essential to achieve savings in operation and maintenance,** especially for bus drivers and personnel in charge of maintenance and charging processes. Technical teams in charge of defining the operation must also be prepared for the transition to e-buses.

The **new tender process for the public transport system in Santiago** is challenging the current business model by **separating fleet provision and depot ownership from the operation** of buses in the street. This modification changes the basis of the current business model of Santiago's public transport system, as the state will have two different contracts with independent companies that will respond to different incentives and penalties. It is expected that this new proposed design will set a good base for the further growth of the e-mobility market within the public transport system in Santiago.

Standard improvement of electric buses

The implementation of e-mobility in public transport, together with the new standards of Red Movilidad, offer several benefits. The new buses in Santiago feature **air conditioning, Wi-Fi, USB chargers, padded seats, and low-floor entrances**, in addition to the benefits associated with using electricity instead of fossil fuel. The results obtained from a user experience survey, conducted as part of this study, highlight passengers' very positive evaluations of the e-buses. The attributes most mentioned in the survey were that they **generate less environmental pollution** (83 percent), **have good air conditioning** (72 percent), offer a **smooth ride** (67 percent), and are **less noisy** than diesel buses (59 percent).

When asked to rate the different characteristics of the e-buses on a scale of 1 to 7, respondents **gave the best ratings to environmental sustainability (6.7), comfort (6.2), and design (6.2)**. In an overall evaluation of the different technologies, the diesel buses of the Transantiago standard received an average rating of 3.4; diesel buses of the Red standard, a 4.3; and e-buses a 6.4.

A small choice exercise between two trip alternatives was included in the survey: 89 percent of respondents were willing to wait one extra minute to board an e-bus instead of an old diesel bus (Transantiago standard), 66 percent an extra 3 minutes, and **39 percent would wait extra 5 minutes**. Finally, the survey included open-ended questions regarding what people liked, resulting in positive evaluations regarding the use of clean technology, the reduction of noise, and the comfort of the buses. For e-buses operating on the Grecia corridor, suggestions included increasing the frequency of service.

Forecasted emissions reductions

As part of this study, estimations of reduced emissions for two scenarios were modeled with MODEM, to consider the impacts of fleet renewal in different proportions and years. MODEM simulations were conducted, projecting a theoretical scenario of 50 percent diesel Euro VI and 50 percent of e-buses for 2030, as follows:

- **2019:** Current situation with 409 diesel Euro VI and 411 e-buses (including the already confirmed arrival of buses expected for the end of 2020).

- **2030:** 50 percent of the fleet Euro VI diesel and 50 percent electric.

Under these assumptions, the current scenario produces a slight reduction in emissions, while the 2030 scenario would produce a much more significant reduction in emissions. The modeled technological change significantly reduces CO_2, NO_x, hydrocarbon (HC), and carbon monoxide (CO) emissions. When comparing the different 2030 scenarios, the most notable decreases are of NO_x and HC emissions, both by approximately 90 percent, compared with a 2030 scenario with no fleet renewal; CO_2 would be reduced by 15 percent. The model predicts that for the 2030 scenario with the Red standard (electric and Euro VI) buses, $PM_{2.5}$ and PM_{10} emissions would be reduced by 70 percent and 56 percent, respectively, compared to the 2030 scenario with the current fleet composition.

These estimations confirm that, in conjunction with coordinated actions to boost the e-mobility market, the first stage of introducing e-fleets in the public transport system has set a good basis for achieving national environmental goals and international compromises in terms of sustainability and emissions reductions. To meet the Nationally Determined Contributions' targets for CO2 emissions, this process of bus renewal in Santiago needs to be combined with measures to increase public transport's share of the entire system, encourage low-emission technologies in private vehicles and taxis , as well as extend the implementation of e-mobility to other Chilean cities' public transport systems.

The study offers valuable lessons and knowledge from Chile's experience introducing e-buses in Santiago and its impacts on green development. It is hoped that this information will be useful for the planning, implementation, and management of e-buses, as a way to further low-carbon growth and sustainable development in other cities around the world.


Red Metropolitana de Movilidad

02

Introduction

Context of the report

The global use of electric vehicles has increased significantly in recent years. In 2018 alone, the stock of electric passenger cars grew by around 63 percent, reaching 5 million in total (IEA, 2019a). This trend has had, and will continue to have, an impact on energy markets, prompting stakeholders throughout the world to take actions to adjust. In 2017 there were 385,000 electric buses (e-buses) globally, 99 percent of them in China, where they composed about 18 percent of the bus fleet in 2017 (Bloomberg New Energy Finance, 2018).

The responsibilities Chile assumed under the Paris Agreement, such as its commitment to achieve carbon neutrality by 2050, and its creation of a National Electromobility Strategy, Energy Route 2018–22, and Pollution Prevention and Decontamination Plan for the Metropolitan Region of Santiago, have driven the modernization of Santiago's public transport system to include a growing number of e-buses. In addition, the Chilean government recently approved a Decarbonization Plan in the context of the 25th United Nations Climate Change Conference (COP25) (CCAP, 2019).

Santiago's public transport system (formerly known as Transantiago and now as Red Metropolitana de Movilidad, or "Red") uses a concession model for the operation of its buses, which complement 140 kilometers (km) of urban subway and a relatively new suburban rail service, Metrotren Nos. On an average day, transactions within the public transport system reach 5.5 million, within an integrated fare system that uses smart cards for fare collection. It is important to mention that in the current concession, the firms in charge of bus operations own the fleets they operate.

At present, the system is going through a transition to green technology with the introduction of electric and diesel Euro VI buses. The entry of new actors and business models around the provision and financing of the fleet also present new challenges in the implementation and regulation of these new technologies from an energy and transport perspective.

Nowadays, Chile has the second-biggest e-bus fleet in the world, after China. As of November 2019, Red's 386 e-buses, in addition to the recently arrived 490 Euro VI buses, represented nearly 15 percent of the bus fleet operating on Santiago's streets.

Objectives of the report

The main objective of this report is to raise awareness regarding pathways to reduce emissions in the transport sector, by highlighting Chile's transition toward sustainable mobility in Santiago. Three topics are covered:

- The contribution of e-buses to sustainable mobility, and the methods used to measure reductions in emissions.
- Experiences related to planning, preparation, and management, including contextual elements that have facilitated the introduction of e-buses in Santiago.
- The importance of technology in the raising of public transport standards, and their relation to climate change commitments.

Structure of the report

As described in the methodology (Appendix A), the report is based on desk research as well as interviews and passenger surveys. It is organized into seven chapters.

3 After an executive summary and introduction, various aspects of Chile's context are described in chapter 3. Santiago's sociopolitical, economic, environmental, energy, and transport profiles are outlined, followed by an analysis of national commitments to sustainable mobility and the impact that e-mobility and specifically electric buses may have on them. Additionally, an exercise in modeling the emissions of various scenarios of fleet renewal is conducted.

4 Against that backdrop, chapter 4 explains the new business model for the adoption of e-mobility, starting with a timeline that considers public-private coordination and the main changes to e-mobility to be expected with the introduction of e-buses. Next, a description and analysis of the public-private partnership (PPP) are conducted, reviewing the new actors involved, the enablers of the adoption of e-buses, and the main risks associated with different fleet provision models. In addition, the key elements of e-buses' implementation, e-depots' construction, planning and operations of e-mobility, and changes in the requirements of human resources are analyzed. Finally, next steps for Chile are discussed, such as the implementation of e-mobility in other cities and future bidding processes for Santiago's public transport system.

5 Chapter 5 addresses how technology is leveraged in the field of public transport to improve service and standards. Passengers' experiences gathered from surveys are presented.

6 In chapter 6, lessons learned and recommendations are presented, to extract knowledge from Santiago's experience that might be relevant to other cities.


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Sustainable mobility context

The city of Santiago

Santiago's experience with e-buses is influenced by the city's political, social, and demographic context as well as the setup of its transport and energy system. These factors also determine the barriers and enablers for the integration of e-mobility in the city's public transport system.

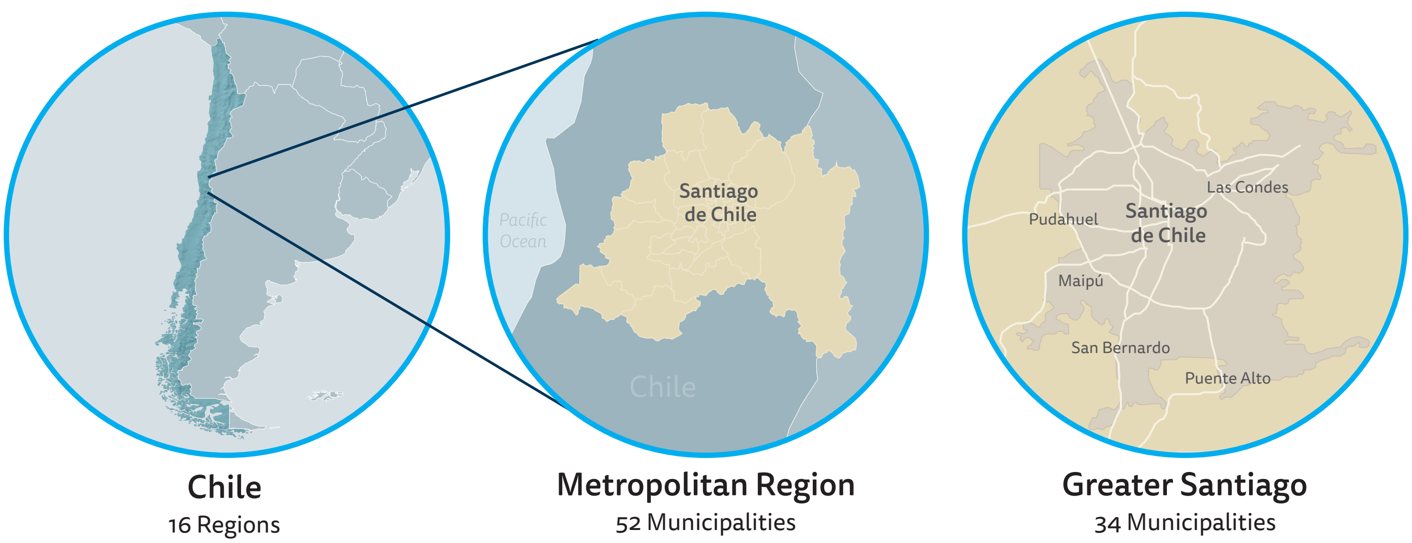
Political, social and demographic context

Chile is composed of 16 regions, one of them being the Metropolitan Region. This is divided into 6 provinces and 52 municipalities; almost 40 percent of Chile's population, or 7.2 million of an estimated 18.8 million, was concentrated in this region as of 2019 (Instituto Nacional de Estadísticas, 2019a).

Santiago, known as Greater Santiago (Gran Santiago), is the capital of Chile and part of the Metropolitan Region. It is the most densely populated urban area in the country, holding about 6.8 million inhabitants of the Metropolitan Region's 7.2 million in 2019.[1] Santiago is not a proper administrative division but a territorial extension defined by its urban continuity, which includes 34 municipalities. One of them is the Municipality of Santiago, commonly known as "downtown."

For this report, Greater Santiago will be referred to as Santiago, since it is the area covered by the integrated public transport system (Red Metropolitana de Movilidad, or "Red," previously Transantiago).

Figure 3-1: Santiago's administrative definition



Source: Original compilation

Table 3-1: Summary of administrative – sociodemographic divisions

City/ Region	Population (2019)	Municipalities	Area (Km²)	Density (inhab/km²)
Greater Santiago	6.8 million	34	≈ 650 km²	9,821/ km²
Metropolitan Region	7.2 million	52	15,403.2 km²	460/km²
Chile	18.8 million	346	756,102 km²	25.07/km²

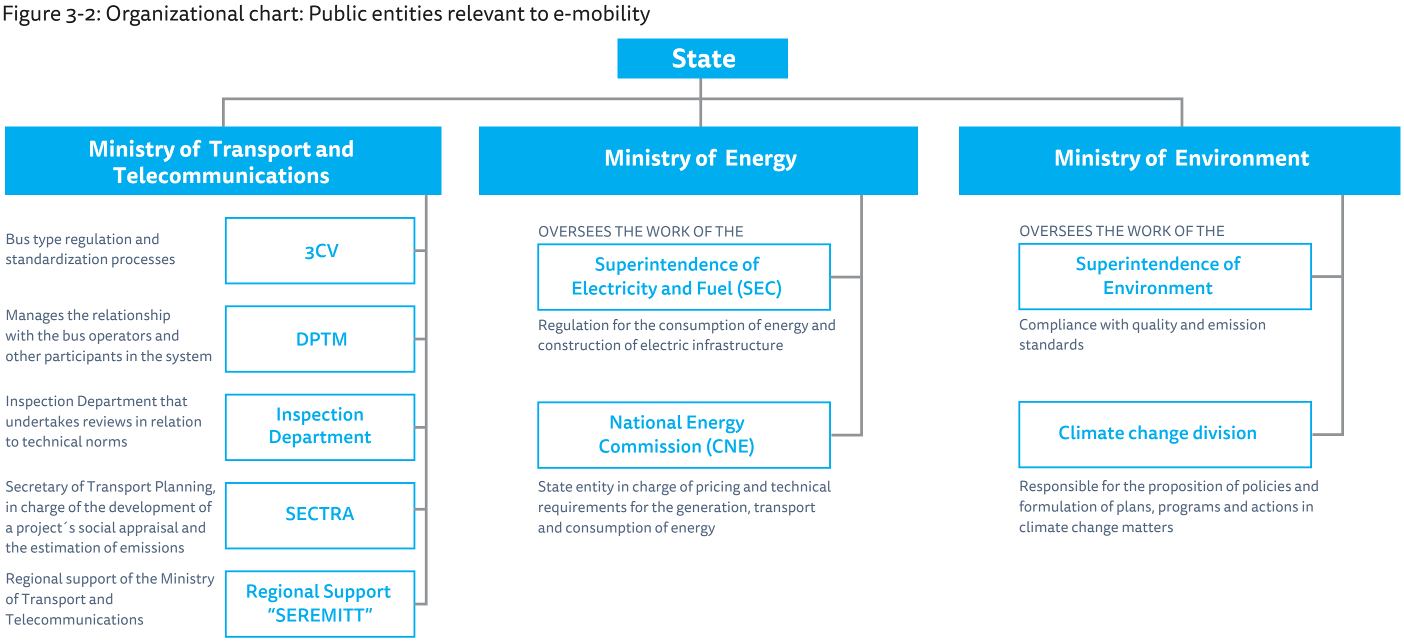
Source: Fieldwork conducted for the present study in 2019

[1] The last census of 2017 indicates that 7.1 million inhabitants live in the Santiago Metropolitan Region

The main public organizations in Chile that oversee issues related to e-mobility are the Ministry of Transport and Telecommunications (Ministerio de Transportes y Telecomunicaciones, MTT) and the Ministry of Energy. Although Chile's Ministry of Environment (Ministerio del Medio Ambiente, MMA), through its Climate Change Division, is responsible for the proposition of policies and formulation of plans, programs, and actions in climate change matters, it is not a direct participant in current e-mobility initiatives.

- **Ministry of Transport and Telecommunications (MTT):** Created in 1974, the organization oversees national transport and telecommunication matters and is responsible for the direction and control of its implementation. The MTT supervises public and private companies that operate the means of transportation and communications in the country, coordinates and promotes the development of these activities, and monitors compliance with relevant laws, regulations, and standards.
- **Ministry of Energy:** Created in 2010, the agency prepares and coordinates plans, policies, and standards for the adequate functioning and development of the energy sector; ensures compliance; and advises the government in all energy-related matters. The energy sector includes all the activities of study, exploration, exploitation, generation, distribution, transmission, consumption, efficient use, import and export, and any other matter that concerns electricity, coal, gas, oil and its derivatives, nuclear energy, geothermal and solar energy, or any other energy source. The Ministry of Energy has played a fundamental role in the boost Chile has given to e-mobility through initiatives such as the National Electromobility Strategy (2016) and the Energy Route 2018–22, detailed later in this report.
- **Ministry of Environment (MMA):** Created in 2010, this state organization is in charge of coordinating the design of policies and regulatory frameworks, plans, and programs of environmental matters such as the adoption or creation of decontamination plans and emissions standards for vehicles, as well as air quality monitoring. The MMA also oversees the protection and conservation of biological diversity and renewable natural resources and water, promotes sustainable development, and ensures the integrity of environmental policy and its regulation. The ministry, through its Climate Change Division, is responsible for the proposition of policies and the formulation of plans, programs, and actions that aim to mitigate climate change.

Figure 3-2: Organizational chart: Public entities relevant to e-mobility



Source: Original compilation

The MTT is responsible for granting concessions to operators in Transantiago; other tasks relevant to the transport system are undertaken by MTT-dependent entities such as the Metropolitan Public Transport Board (Directorio de Transporte Público Metropolitano, DTPM), the Inspection Department (Fiscalización Nacional de Transportes), the Secretary of Transport Planning (Secretaría de Planificación de Transporte, SECTRA), and the Regional Secretary of the MTT (Secretaría Regional Ministerial de Transportes y Telecomunicaciones, SEREMITT).

The DTPM is the executive office that manages relations with bus operators and other participants in the system, like Metro, Metrotren, and companies providing complementary services. The DTPM's structure features divisions with a focus on, for example, operations control, planning and development, infrastructure, users, regulation and system finance, technology, legal issues, communications, and administration.

The Inspection Department undertakes reviews compliance with technical and environmental norms. For instance, it ensures that buses comply with technical requirements, and also protects bus lanes from being used by private vehicles. The Centre for Vehicle Control and Certification (3CV) implements vehicle-type approvals and standardization processes, and SEREMITT maintains a bus registry and grants permits for buses to operate within the system. On its part, SECTRA oversees the development of transport projects' social appraisal and emissions estimates.

In the energy field, the Superintendence of Electricity and Fuel (Superintendencia de Electricidad y Combustibles, SEC) regulates the consumption of energy across uses (domestic and industrial) and regulates the construction of electrical infrastructure and its characteristics. The National Energy Commission (Comisión Nacional de Energía, CNE) is an entity within the Ministry of Energy that is in charge of pricing and technical requirements for the generation, transport, and consumption of energy.

The MMA oversees the competencies of other sectors through the Council of Ministers for Sustainability (CMS). This is a deliberative body focused on public policy and general regulation in environmental matters. It is composed of the minister of the environment, who leads it, and representatives of the agriculture, finance, health, economy, development and reconstruction, energy, public works, housing and urban planning, transport and telecommunications, mining, and social development departments. In 2014, this council initiated procedures to change its name to the Council of Ministers for Sustainability and Climate Change, which was to be joined by the Ministry of Foreign Affairs (MINREL) in its role in international negotiations.

The Superintendence of the Environment oversees compliance with quality and emissions standards.

Meanwhile, the Climate Change Division contributes to sustainable development resilient to the impacts of climate change, and helps the country in its transition to a low-carbon economy through the integration and promotion of better sectorial public policies that allow agencies at a local level to face climate change and implement mitigation actions that serve as an example at a global level.

In 2016, the Sustainability and Climate Change Agency was formed. Its main role is to promote the inclusion of climate change problems and sustainable development in the private sector through public-private agreements and the execution of programs and projects that contribute to the construction of a low-carbon economy and compliance with Chile's commitments in the Paris Agreement. Its areas of action are the promotion of entrepreneurship and innovation, the implementation of efforts to mitigate and adapt to climate change, the encouragement of technologies and financing required for these efforts, and the development of relevant capacities.

Economic, regulatory and financial context

Table 3-2 summarizes economic figures for Chile in comparison to Latin America and the Caribbean as a whole.

Table 3-2: Summary of the economic characteristics of Chile compared to averages for Latin America and the Caribbean (prices in USD$ as of October 2019), 2018

Index	Chile	Latin America
GDP	$ 298 Billion USD	-
GDP Growth	3.9%	1.2%
GDP per Capita	$15,000 USD	$ 8,500 USD
Unemployment	7.2%	9.3%
Inflation	2.9%	7.0%

Source: Central Bank of Chile, National Statistics Institute and World Bank, Latin America GDP per capita: https://datos.bancomundial.org/indicador/NY.GDP.PCAP.CD?locations=ZJ-CL, Chile and Latin America unemployment rate, inflation and GDP growth; https://repositorio.cepal.org/bitstream/handle/11362/44605/1/S1900308_en.pdf

Chile has a market-oriented economy characterized by a high level of foreign trade and a reputation for strong financial institutions and sound policy that have given it the strongest sovereign bond rating in South America. This market orientation is supported by a low level of economic protectionism, allowing Chile's trading partners to send and receive goods and products with remarkably few tariffs, quotas, or other constraints (Forbes, 2018; World Bank, 2019).

Chile's 26 trade agreements cover 60 countries and include agreements with the European Union (EU), the

South American trade bloc Mercosur, India, the Republic of Korea, Mexico, and China. The trade agreement between Chile and China is considered a tariff liberalization program. Since 2015 more than 97 percent of Chilean goods that enter the Chinese market do so without tariffs. Similarly, all about 2 percent of Chinese products enter duty-free into Chile (Undersecretary of International Economic Relations, 2017).

In general,[2] the only tax that falls on imported goods is the same value added tax (VAT)[3] applied to any product (internally produced or imported) that is marketed in Chile. Thus, the import tariffs that would likely be applied to the purchase of buses in other countries of the region are not present in Chile (World Bank, 2019).

Regarding financial risk, Chile shows the best ratings in Latin America (Diario Financiero, 2019). According to Fitch, the risk rating for Chile remains an A. [4] All this is based on the country's credible policy framework focused on a regime of inflation targets, flexible exchange rates, and a relatively strong sovereign balance (San Juan, 2019).

Fitch's rating is consistent with the evaluations made by Moody's and S&P, which grant Chile A1 and A+ rankings, respectively (Diario Financiero, 2019; S&P Global Ratings, 2019), demonstrating that Chile's ability to meet its financial commitments is strong.

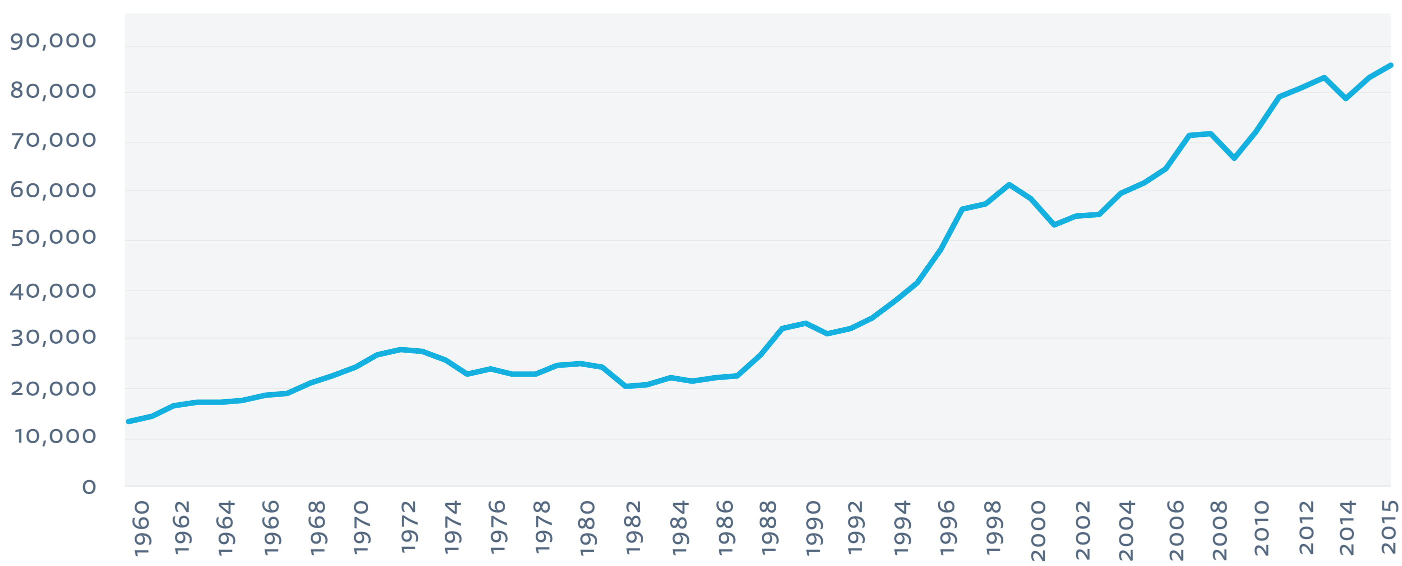
Chile has become a regional leader in financial matters due to a stable democratic system and a solid open market that guarantees a safe business environment (Ministry of Foreign Affairs, 2017; Badenhausen, 2018). Among the best countries to do business in 2019, Chile ranks 33rd—the first in Latin America (Forbes, 2018).

Environmental context

Some of the greatest challenges facing cities today are related to climate change and air quality, especially in developing countries. Climate change and deteriorating air quality threaten to have serious consequences for public health and tend to increase social vulnerability in a scenario of scarce public resources. Chile is highly vulnerable to the impacts of climate change due to its diverse geography, several features of which are considered risk factors associated with the negative impacts of climate change. Its length and diverse topography provide for a varied climate with different challenges in different areas. Chile's geography includes an extremely long coastline, the world's driest desert—the Atacama Desert—in the north, a Mediterranean climate in the central region, and a snow-prone Alpine climate in the south, with glaciers, fjords, and lakes.

Given its position as an emitter of greenhouse gases (GHGs) and other pollutants, the transport sector plays an important role in the country's climate change policies. In 2013, the transport sector accounted for 23 percent of all fossil-fuel-related carbon dioxide (CO_2) emissions worldwide (IEA, 2019b). Despite technological developments leading to significant reductions in GHG and other pollutant emissions per vehicle and the implementation of reduction targets, transportation in and around cities remains a major source of emissions that have detrimental impacts on human health, ecosystems, and the climate.

Figure 3-3: Carbon dioxide emissions in Chile, 1960–2016 (kt)



Source: World Bank: https://datos.bancomundial.org/indicador/EN.ATM.CO2E.KT?locations=CL

[2] Chile has, in its economic regulations, specific taxes for different types of products due to the negative externalities that they produce: for example carbon, green taxes, the alcohol tax, and the cigarette taxes. There is no such tax that affects the import of buses.

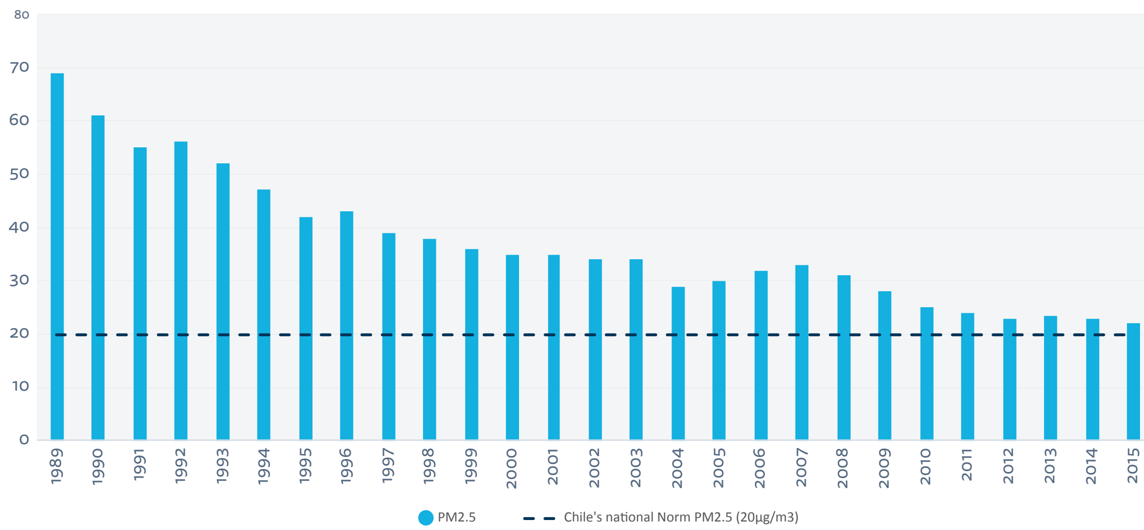
[3] The VAT in Chile is 19 percent.

[4] Fitch's national long-term credit rating scale ranges begins at AAA and ends in D. In addition to the rating options AAA, AA, A, BBB, BB, B, CCC, CC, C, RD, and D. In addition, the modifiers "+" or "-" can be added to a rating to denote the relative position within a category.

The transport sector is currently responsible for nearly 25 percent of Chile's carbon dioxide equivalent (CO_{2eq} [5]) emissions. In 2015 total emissions of CO_{2eq} across all sectors (not only transportation) were estimated at roughly 120 Mt.[6] According to the Mitigation Action Plans and Scenarios (MAPS) project, without considering mitigation, the transport sector is expected to remain responsible for around 25 percent of emissions in 2030, with total emissions (excluding AFOLU[7]) of 180 Mt CO_{2eq} (MMA, 2019).

In Santiago, air pollution has been a prime challenge, and even though private vehicles have been responsible for a great part of the pollution, particularly in terms of carbon monoxide (CO) emissions, during the previous decades buses represented the major source of particulate matter and NO_x [8] pollution in the city. Nevertheless, from the beginning of the 1990s, several actions have been adopted, including the regulation of cleaner fuels and emissions standards for new vehicles, measures that have produced a continuous improvement in the annual average of emissions, particularly in $PM_{2.5}$ [9] levels measured in Santiago. The average $PM_{2.5}$ level in 2015 was 68 percent of what it was in 1989. With this, buses are no longer the primary source of emissions in terms of PM and NOx, reinforcing the rationale to increase their share of public transport. This is an important point of relevance to e-mobility, since the shift of polluting vehicles to cleaner technologies has been the catalyst for changes to both private vehicles and the public transport system.

Figure 3-4: Annual average concentrations of $PM_{2.5}$ in Santiago, Chile, 1989–2015 (µg/m³)



Sources: Based on the Pollution Prevention and Decontamination Plan for the Metropolitan Region of Santiago, 2016, and WHO Air Quality Guidelines

Simultaneously, the share of the transport sector has increased in relative terms. It was estimated that in 2012 transport contributed approximately 40 percent of the city's total fine particulate matter ($PM_{2.5}$), whereas in 1998 transportation emissions were estimated at 24 percent of the total urban PM production (Barraza et al., 2017). $PM_{2.5}$ is primarily produced by direct emissions from the combustion processes of fossil fuels. Its main sources are the processes that occur during combustion in cars, buses, and trucks (diesel and gasoline); thermoelectric plants; industrial processes; biomass combustion; residential firewood heating; agricultural burns; and forest fires.

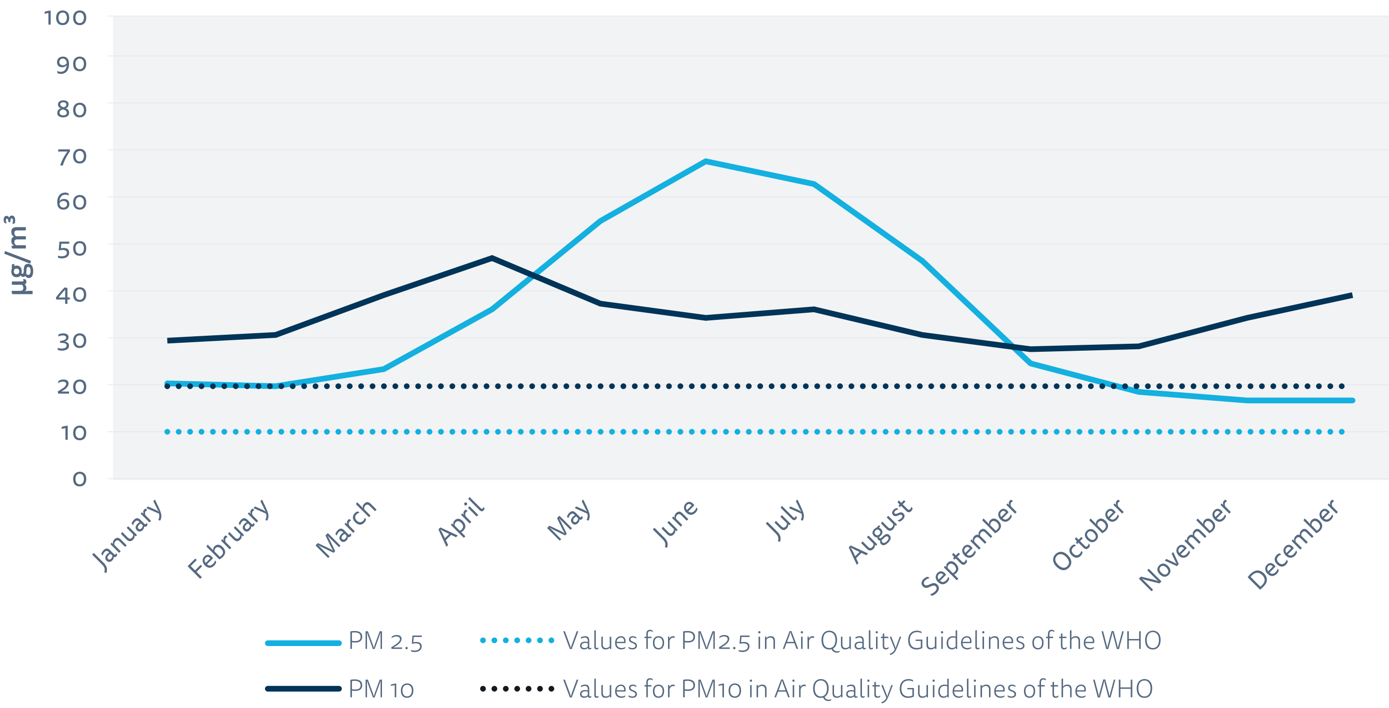
A large contribution to PM emissions is through residential heating and road transportation: they emitted up to 1,800 and 2,700 tonnes/year of $PM_{2.5}$ in 2012, respectively (USACH, 2014). The level of PM emissions in Santiago is above that recommended by the World Health Organization.[10] Also, it is highest of the major cities in Latin America (World Bank, 2019).[11]

5 CO_{2eq} unit measures the environmental impact of one tonne of these GHGs in comparison to the impact of one tonne of CO_2.
6 Mt = megatonne, one million tonnes.
7 Agriculture, forestry, and other land use.
8 Nitrogen dioxide is an irritant gas, which at high concentrations causes inflammation of the airways. NOx gases react to form smog and acid rain, and are central to the formation of fine particles (PM) and ground-level ozone, both of which are associated with adverse health effects.
9 $PM_{2.5}$ is particulate matter 2.5 micrometers or less in diameter; PM_{10} is particulate matter 10 micrometers or less in diameter. The health effects of particulate matter may include cardiovascular effects such as cardiac arrhythmias and heart attacks, and respiratory effects such as asthma attacks and bronchitis. The size of particles is directly linked to their potential for causing health problems. So, $PM_{2.5}$ poses the greatest health risk.
10 Values from the WHO Air Quality Guidelines.
11 The study compares the emission levels of PM2.5 and PM10 for Santiago, São Paulo, Buenos Aires, Montevideo, and Mexico City.

These emissions are not evenly distributed throughout the year. Residential combustion emissions occur mostly during the winter season, from May to September, contributing to extreme events of air pollution that frequently affect the city of Santiago with significant impacts on public health. Although the number of these extreme events and average concentration levels decreased over the last few decades, such events still occur and are a matter of public concern.

The central problems in the Santiago Metropolitan Region occur when $PM_{2.5}$ emission concentrations reach their maximum values, during the autumn and winter seasons (PM_{10} emissions remain constant during the year). Moreover, air pollution in Santiago is strongly influenced by the complex topography surrounding it. The southern Andes in the east, the coastal range in the west, and the transversal mountain chains in the north and south surround the basin, preventing the dispersion of pollutants and thus leading to the accumulation of gases (CO, NOX, and volatile organic compounds [VOCs]) and aerosols (PM_{10} and $PM_{2.5}$).

Figure 3-5: Average annual variation of PM2.5 and PM10, Pudahuel station, 1998–2015



Sources: Based on the Pollution Prevention and Decontamination Plan for the Metropolitan Region of Santiago and WHO Air Quality Guidelines

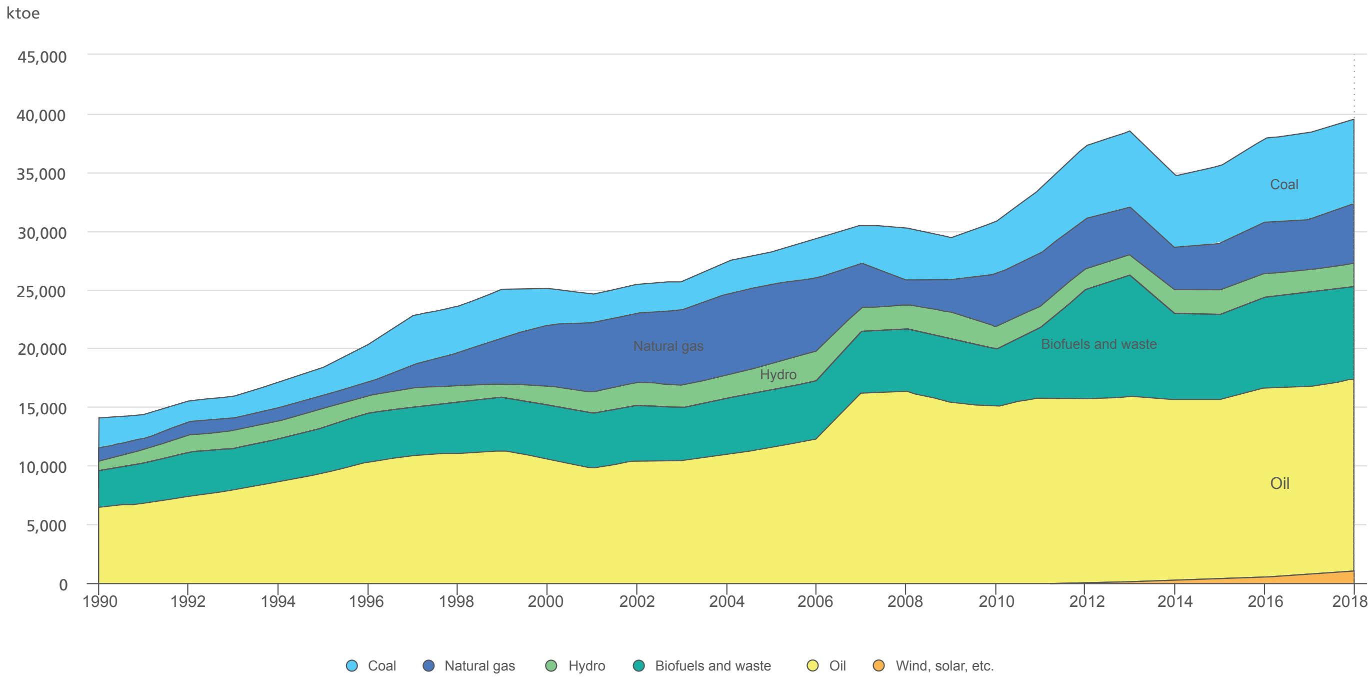
Energy field

In terms of energy, Chile largely depends on imports; its domestic production of fossil fuels is only about 34.7 percent (in 2016) of its total primary energy supply (TPES). Oil is the largest primary energy source, accounting for 41.5 percent of the TPES in 2018, followed by coal (18.1 percent) and natural gas (12.8 percent). Industry and transportation account for more than three-quarters of total final consumption (TFC). Oil is the most important energy source for both sectors, although the dominance of oil in the industry sector is not as prominent as it is in the transport sector.

Renewable energy has been an important energy source for many decades, comprising 25–30 percent of the TPES; in 2018, it accounted for 27.6 percent of the TPES. This category comprises biofuels and waste (20.0 percent), hydropower (5.1 percent), and wind and solar energy (2.5 percent).

In comparison with the member countries of the International Energy Agency (IEA), Chile's share of fossil fuel in electricity generation (61 percent) was the twelfth largest in 2016, just above the mean (58 percent), and between Italy and the Czech Republic; specifically, Chile had the fifth-largest share of oil and seventh-largest share of coal.

Figure 3-6: Chile's total primary energy supply, by source, 1990–2018 (ktoe)

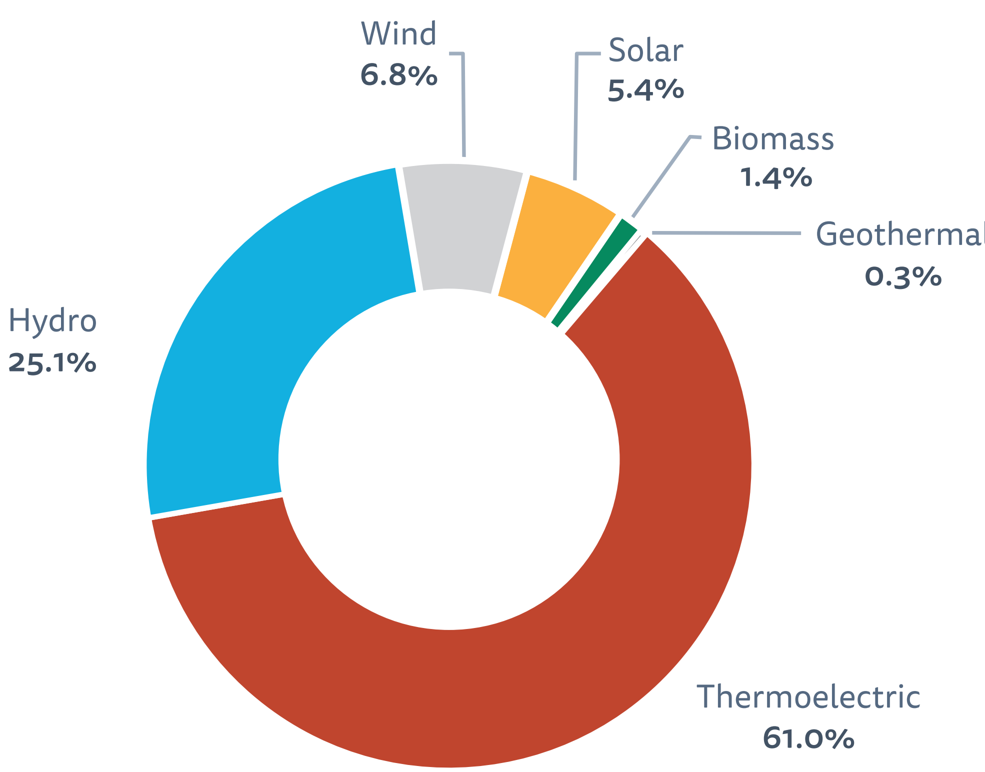


Source: IEA 2019b: https://www.iea.org/statistics/?country=CHL&isISO=true

Current composition of the energy mix

The electricity generation of the system is the result of the work of 540 power plants. The type of energy used for the generation of these power plants, by share of the total, is shown in figure 3-7.

Figure 3-7: Types of energy generation within the national energy system, as of July 2019



Source:Based on information from Chile's Electricity Generators (2019).

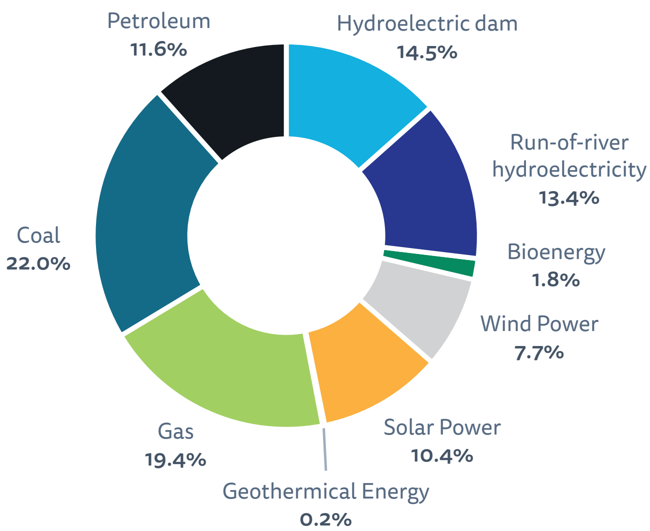
The total installed power corresponds to the sum of the capacities (megawatts, MW) of each of the 540 plants. Considering the above, table 3-3 and figure 3-8 summarize the energy mix of the system.

Table 3-3: Total Installed Capacity by July 2019 (MW)

Renewable	11,814
Hydroelectric dam	3,383
Run-of-river hydroelectricity	3,380
Bioenergy	446
Wind Power	1,938
Solar Power	2,622
Geothermal Energy	45
Non-renewable	13,334
Gas	4,876
Coal	5,535
Petroleum	2,924
Total	25,148

Source: Based on information from Chile's electricity generators, 2019

Figure 3-8: Share of total installed capacity, by energy type, as of July 2019 (MW)



Source: Based on information from Chile's electricity generators, 2019.

Furthermore, electricity demand is increasing fast, along with economic growth, and is expected to keep growing rapidly. Under the Ministry of Energy's business-as-usual scenario, demand would more than double by 2050, growing significantly faster than the population. Despite this strong growth, electricity demand per user remains low in Chile. In 2016, it was 4.1 megawatt hours (MWh) per capita, less than half the IEA average of 8.7 MWh.

At the same time, Chile aims to derive a growing share of electricity from renewable sources. The country has vast resources of solar energy and abundant unexploited potential for wind, hydro, and geothermal (IEA, 2018).

Building a low-carbon national electricity system

In its National Energy Policy 2050, which was adopted in 2015, the government set targets for a 60 percent share of renewable power by 2035 and 70 percent by 2050. The share is currently around 50 percent. According to the IEA, the country has great potential for solar and wind energy developers. New legislation encourages investment in generating capacity across the electricity sector. Integrating growing shares of variable renewable energy requires a flexible power system, and more transmission infrastructure, storage, and demand-side response. Policy makers would do well to ensure that the electricity market's design and infrastructure facilitate the integration of solar and wind power. By exploiting its vast renewable energy potential, Chile can help reduce electricity prices and dependency on fuel imports, as well as reduce the carbon intensity of power generation.

In January 2018, energy-generating companies signed an agreement with Chile's government to not build new coal plants in the country and to support the growth of other energy sources such as natural gas and renewables. However, the latest coal plant was inaugurated in 2019 by Engie.

Meanwhile, new legislation has been adopted to encourage investment in new capacity across the electricity sector. In particular, the 2016 Transmission Law not only created a single Independent System Operator (ISO), but also enhanced the role of the state in energy planning and the expansion of the transmission system. The law introduced several new features to Chile's electricity sector: it created the National Electricity Coordinator, a unified independent system operator; it supported grid expansion and cross-border connections; and it also modified transmission toll payments to increase competition in generation.

A major achievement is the interconnection, in November 2017, of the two main electricity systems—the Central Interconnected System (SIC) and the Greater Northern Interconnected System (SING). As a result, the National Electricity System (Sistema Eléctrico Nacional, SEN) was created (IEA, 2018).

Electricity distribution and price

Electricity distribution is organized through concessions, with a total of 32 distribution companies that have a permanent supply of energy to enable them to meet the total consumption of their regulated customers in their concession areas. In terms of tariffs, domestic customers with a connection higher than 2 MW (the so-called "free clients") pay a nonregulated tariff negotiated with the power company,[12] while customers with a lower connection pay a regulated fare. However, consumers that have connections between 0.5 MW and 2 MW can choose to be in the regulated or free market. Customers who opt for the free market scheme would need to stay there for at least four years and inform the distributor at least a year in advance to change to a regulated fare scheme.

12 A scheme by which the consumer negotiates an individual fee for consumption. In this scheme, it is possible that the consumer is supplied by other sources of electricity, including auto generation.

The government is studying a new regulatory framework for the distribution sector. The CNE is working on a proposal for a new distribution law that would ensure the modernization of the distribution sector, with the objective of encouraging the development of a more efficient and more intelligent distribution grid, introducing new technologies and new companies, and expanding business opportunities in the sector.

Transport system figures

Urban mobility in Santiago has historically followed a path of car-oriented development. In 2019, almost 2.2 million active motorized vehicles registered within the Metropolitan Region. In the same year in Santiago, private cars had a modal share of 47.8 percent during morning peak hours, while public transport buses had 41.1 percent, for a total of approximately 2.5 million trips within the city.[13] Even though the number of trips has grown during the last years, the modal share of public transport has slightly decreased, which challenges authorities to think of ways to promote and improve the system's quality.

Santiago's integrated public transport system (known as Transantiago until March 2019, when its name was changed to Red Metropolitana de Movilidad, commonly known as "Red") operates in the metropolitan area of the city of Santiago with an integrated fare that encompasses surface bus services, a metro line, and the suburban train service Metrotren Nos.

The system is regulated by the MTT and, more specifically, by its undersecretary of transportation through the DTPM. The decision level of the entity is national (neither metropolitan nor municipal). The DTPM is the public transport authority in Santiago and the executive entity responsible for regulating the requirements of vehicles, routes, frequencies, and rates.

The system has three components:

- **Buses -** 6,756 buses,[14] are operated by six different operators, with 380 different routes and covering more than 2,900 kilometers of road network
- **Metro -** 7 lines totaling 140 kilometers;
- **Metrotren Nos -** an extension of more than 20 kilometers and 10 stations

Currently, there are six bus operator companies[15] —Metbus, Buses Vule, STP, RedBus, Subus, and Express—each of them assigned to the operation of a group of bus services (business units).

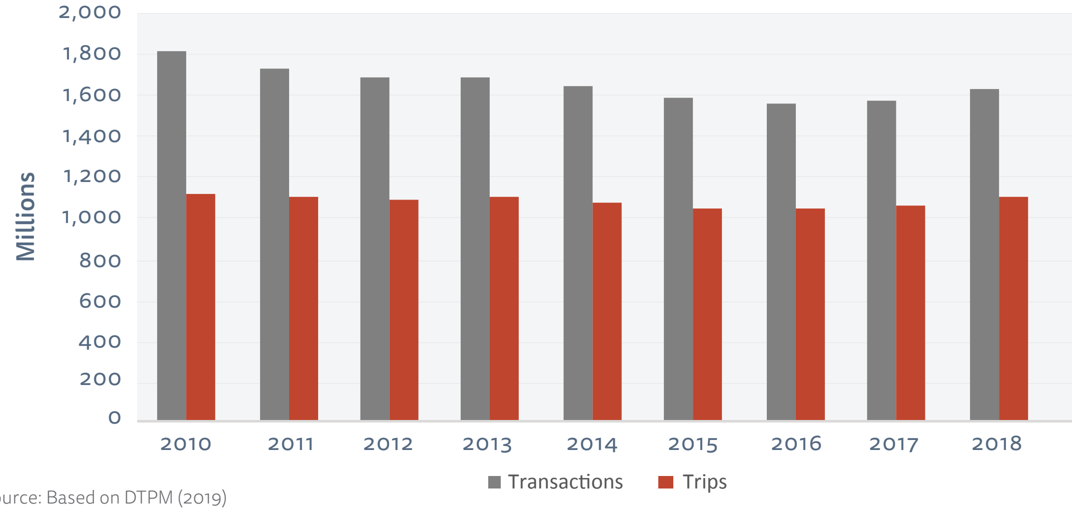
With the implementation of the Transantiago system in 2007, and continuously after that, several changes have been introduced in contracts with the objective of improving service quality, financial conditions, fleet renewal, and technologies, such as through the introduction of emission filters. Before the establishment of Transantiago, there were high levels of informal employment and market fragmentation in the public transport field (Muñoz and Gschwender, 2008).

The current concession contracts for bus operators measure their operational performance based on indicators reflecting users' travel experiences.[16] These indicators include frequency, regularity, transport capacity, quality of user service, and quality of vehicles, among others. If these indicators are under certain compliance thresholds, companies can suffer reductions in their remuneration and/or fines for a breach of service quality levels.

Red features an integrated payment system for the bus, metro, and the commuter train service Metrotren Nos, which uses a contactless smart card (called Tarjeta bip!). The fare is fixed for buses, allowing up to two transfers between buses with no extra cost in a period of 120 minutes. An extra payment is added for the use of Metro or Metrotren Nos in any of the three stages of a trip. According to the DTPM, more than 1.6 billion transactions were made in the system in 2018 (DTPM, 2018).

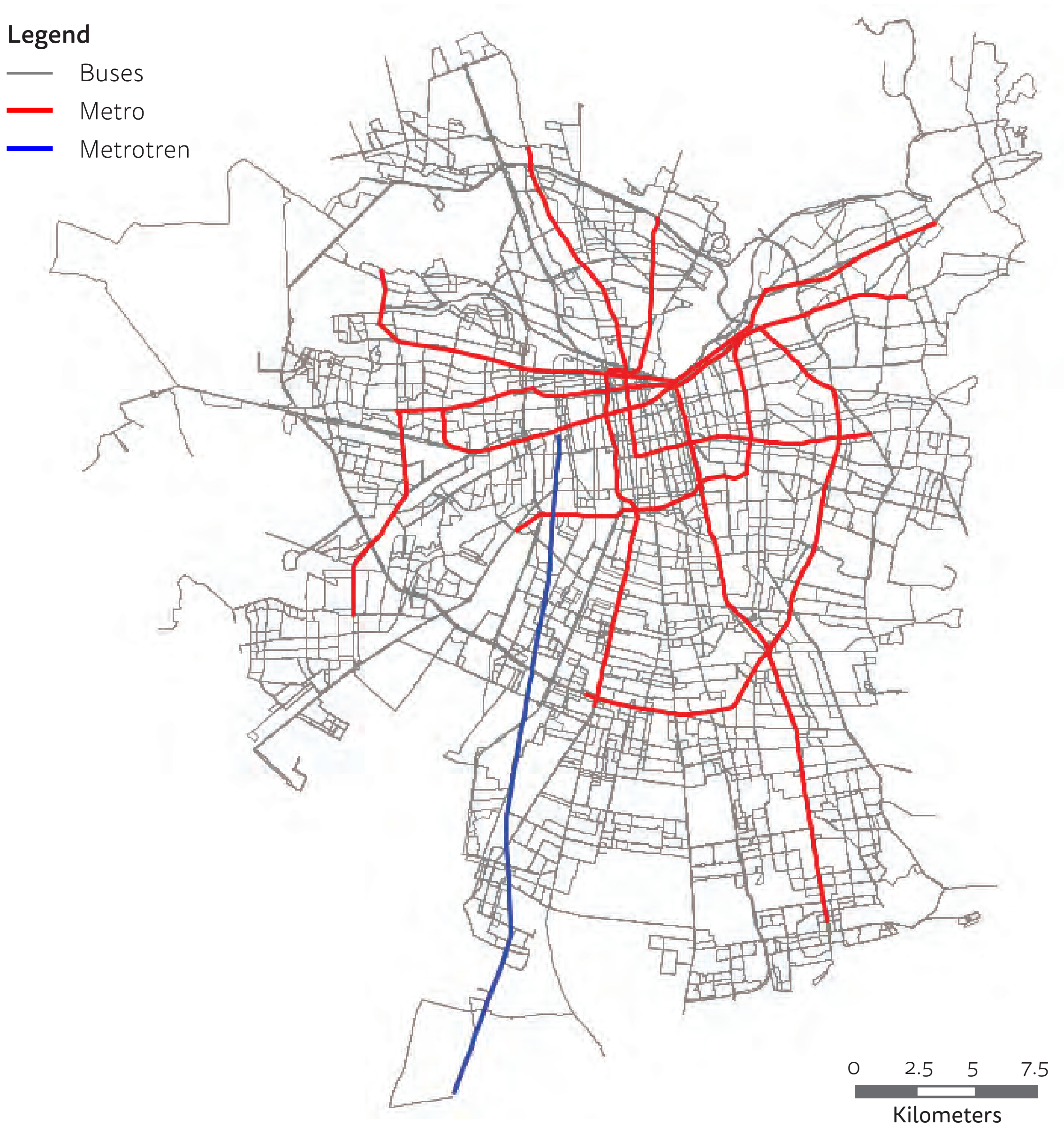
13 According to simulations conducted in ESTRAUS (the official transport model for Santiago) for the year 2019.
14 Includes base operating fleet, reserve fleet, and auxiliary fleet (DTPM, 2018).
15 Previously seven, but one of the company's contracts ended in 2019 (Alsacia).
16 The DTPM is in charge of these measures and reduces payment to the operators depending on their compliance.

Figure 3-9: Trips and transactions, 2010–18



Source: Based on DTPM (2019)

Figure 3-10: System coverage



Source: Based on DTPM (2018)

Cleaner public transport initiatives

The primary technological mitigation measures introduced over the past 30 years in Santiago include stricter vehicle emission standards (Euro V has been mandatory for light duty vehicles since 2012), improved fuel quality for both gasoline and diesel (unleaded gasoline since 1994 and a maximum of 15 ppm[17] sulfur content in diesel since 2013), as well as a massive introduction of after-treatment devices (three-way catalytic converters since 1992 and diesel particle filters since 2010).

Since 2012, new policies are being developed, such as the Zero-Emissions Mobility Program, launched by the MMA. This program, which includes several initiatives such as the $PM_{2.5}$ Decontamination Plan and the Public Transport Improvement Plan, aims to promote electric transport, putting greater emphasis on the environmental and health impact of pollution, and incorporating electrical vehicles.

Moreover, in early 2016, the MMA announced that Euro VI or USEPA 2010 technology would be mandatory for every new bus purchased and operating in the public transport system as of January 2019. Table 3-4 shows the differences among the different technologies for buses in terms of NO_x and PM_{10} emissions.

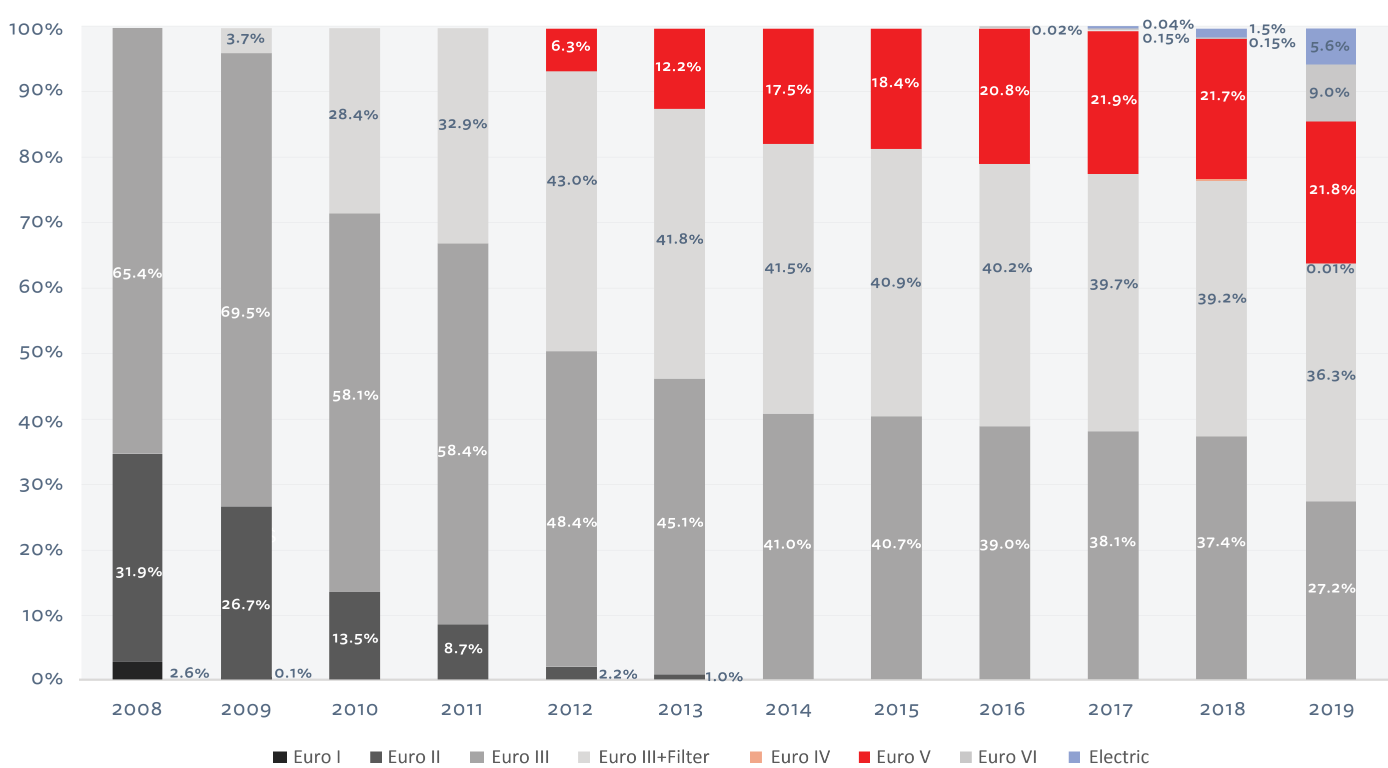
Table 3-4: Comparison of the environmental performance of diesel bus technologies

Pollutant (gr/km)	Euro III diesel	Euro IV diesel	Euro V diesel	Euro VI diesel
NO_x	8	8	7	0.1<
PM_{10}	1.9	1.1	0.9	0.1<

Source: Fleet test on warmed-up engines (Nylund, 2017)

The evolution of the buses technologies during recent years is shown in figures 3-11 and 3-12.

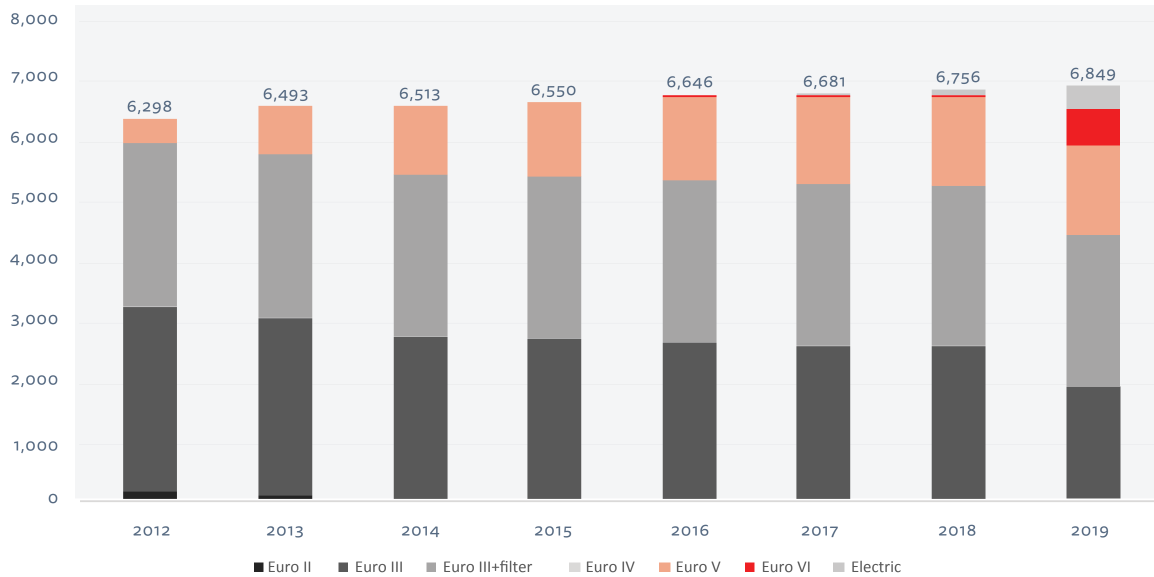
Figure 3-11: Santiago bus fleet technology proportions, 2008-19



Source: Based on data from DTPM (2020).

[17] Parts per million.

Figure 3-12: Number of buses in fleet, by technology, 2012–19



Source: Based on data from DTPM (2020).

During 2019, more buses with cleaner technologies were included, reaching 620 Euro VI buses and 385 e-buses in a total fleet of 6,849. This means that 5.6 percent of the public transport fleet was electric by the end of 2019.

The adoption of ultraclean bus standards is only the latest example of Chile's role as a regional and global leader in cleaner fuels and vehicles. In the context of the Pollution Prevention and Decontamination Plan for the Metropolitan Region of Santiago, Santiago became the first city in Latin America to adopt ultralow sulfur diesel and gasoline fuel standards in 2011. The country has led the way in the region in terms of cleaner fuels and vehicles, becoming the first Latin American country to adopt a joint CO_2 and pollutant tax in October 2014 that applies to light duty trucks and sports utility vehicles in addition to light duty vehicles.

New Bus tendering process in Santiago

By 2018, the first contracts in the system were expected to expire. The former administration had started a bidding process that would have tendered around 50 percent of the operating kilometers at the beginning of 2018, involving the renewal of at least 1,500 buses and up to a total of 3,000 in the following years. This bid requested contractors to introduce at least 90 e-buses into the system.

However, the incoming administration, led by the minister of transport, decided to discard this process, based on technical and political differences with the previous terms of reference, and to ensure equitable access for new operators. In this context, some companies extended their contracts for a couple of years. The transport minister has anticipated that changes such as smaller business units, shorter contracts, and incentive modifications would be included in the new terms of reference.

This new tender process would divide the operation of buses from their acquisition. For this purpose, fleet suppliers would be responsible for the purchase of the vehicles and the availability of spare parts. Companies would operate smaller fleets of 350–400 buses on average. The process also establishes Euro VI buses as a minimum standard for emission technologies and offers incentives for the use of e-buses, encouraging operators to choose them. Standards for buses were also raised to improve users' experience, with features such as air conditioning, Wi-Fi, USB ports, and low entrance floors, among others. The new bidding process and higher standards constituted the first step in a broader shift toward a new system that was renamed Red Metropolitana de Movilidad (Red).

Besides designing a new tendering process, the new administration took steps toward the declared goals of the new transport system. Since many buses were close to the end of their expected lifetime (at least 1,000,000 km and/or 12 years) and one of the contracts had ended (Alsacia's contract), the MTT sought to ensure the continuity of public transport services by introducing 411 new e-buses (all made in China; see chapter 5 for details).

National commitments to sustainable mobility

In 2016, 35 percent of Chile's final energy consumption came from the transport sector, of which 98 percent corresponded to petroleum products. Transportation is therefore responsible for about 20 percent of the country's total GHG emissions (Ministry of Energy, 2018).

In this context, Chile has made various commitments to mitigate and adapt to climate change.

Nationally Determined Contributions (NDC) targets

The Paris Agreement seeks to redirect the global development trajectory on a course toward sustainable development, aiming at limiting warming to 1.5°–2° Celsius above preindustrial levels (United Nations, 2019).

This historic agreement involved 196 parties, which settled on a long-term goal for adaptation[18]—to increase their ability to adapt to the adverse impacts of climate change and foster climate resilience and low GHG emissions, in a manner that does not threaten food production (United Nations, 2019).

To achieve these objectives, each country committed to specific NDCs (United Nations, 2019). Chile's unconditional target is a 30 percent reduction in CO_2 emissions per gross domestic product (GDP) unit below 2007 levels by the year 2030. Its conditional target (conditional on international financial support in the form of grants) is a 35–45 percent reduction in CO_2 emissions intensity per GDP unit below 2007 levels by 2030. Also, the Chilean government included mitigation options that consider, among others, measures related to black carbon mitigation in urban areas and within the energy sector (United Nations, 2015).

Table 3-5: Chile's NDCs and actions specific to the transport sector

Country	Scope	Unconditional commitments	Conditional commitments
Chile	Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O), Hydrofluorocarbon (HFC) and Perfluorocarbon (PFC)	Chile is committed to reduce its CO2 emissions per GDP until by 30% below their 2007 levels by 2030	Subject to the grant of international monetary fund: Chile is committed to reduce its CO2 emission per GDP unit by 2030 until it reaches a 35% to 45% reduction with respect to the 2007 levels

Source: Based on information from The Climate Action Tracker

In this context, the Chilean government announced a plan to completely phase out coal by 2040 and aim toward carbon neutrality by 2050. For Chile to able to absorb as much CO_2 as it generates, the focuses first on afforestation in the country, followed by e-mobility, the best treatment of waste, the enhancement of renewable energies, and demand for emission reductions in sectors such as mining (The Climate Action Tracker, 2019).

As of 2019, considering the latest national policy (like the National Electromobility Strategy and the retirement of coal-fired power plants), estimates suggested that Chile would exceed its 2020 pledge, and meet its unconditional and conditional NDC Paris Agreement targets with the implementation of these policies (The Climate Action Tracker, 2019).

Chile has positioned itself in the international arena as a country that seeks to support strong climate action (United Nations, 2015). In recent years, this has been confirmed by a portfolio of Nationally Appropriate Mitigation Actions (NAMAs), and the implementation of an unprecedented carbon tax, which raised $5 per tonne of CO_2 produced by power plants.

Other mitigation tools include the first tax on CO_2 emissions from fixed sources, implemented in 2014. Specifically, a tax both on global contaminant emissions (CO_2) and local contaminant emissions (sulfur oxide [SO_x], NO_x, PM) was introduced. In addition, a tax on new cars was imposed based on urban performance[19] and NOx emissions. All this is encompassed under Law 20,780, enacted on December 28, 2014.

[18] Adaptation is an "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2001).

[19] Fuel economy (kilometer/liter).

National Electromobility Strategy

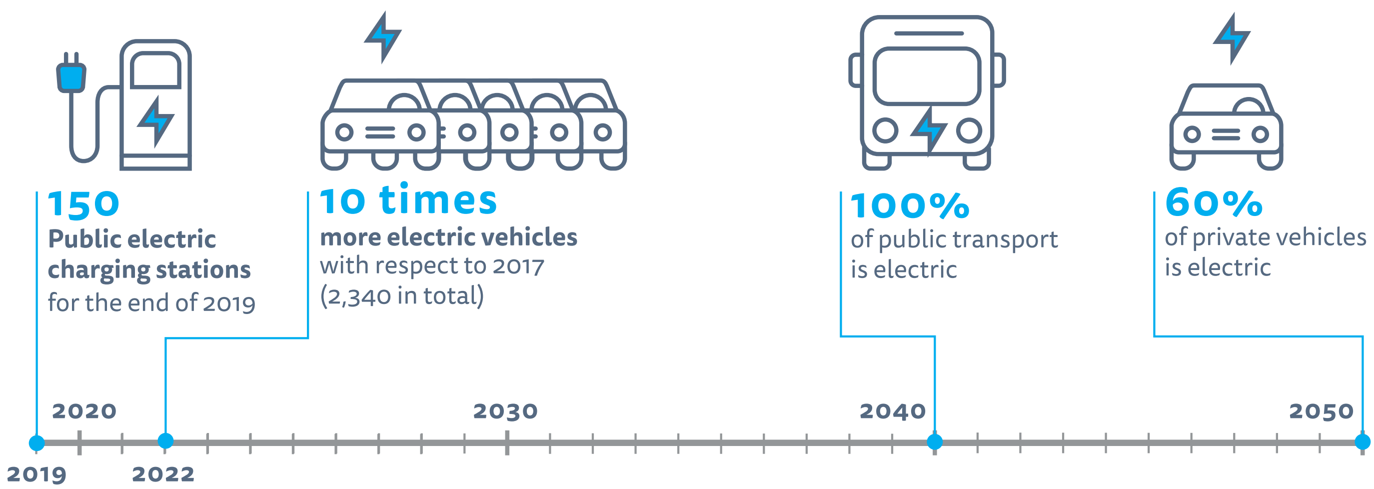
In 2017, the transport sector accounted for 36 percent of total final energy consumption in Chile, second to industry (CNE and Ministry of Energy, 2019). In the same year, Chile published its e-mobility strategy. This initiative was the result of a shared public and private effort and seeks to contribute to the mitigation of greenhouse gases, improving both the mobility and quality of life of Chileans.

The National Electromobility Strategy outlines the actions that Chile must take in the short and medium term to ensure that 40 percent of private vehicles and 100 percent of urban public transport buses will be electric by 2050. In particular, the action plan is divided into strategic axes that include development of policy and regulation, prioritizing public transport, and supporting the initial uptake of e-mobility (The Climate Action Tracker, 2019; Ministry of Energy, MTT, and MMA, 2017).

The implementation of this strategy could lead to an emissions reduction of between 2.1 and 4.6 MtCO_2e/year by 2030, which is equivalent to a reduction of between 2 percent and 4 percent with respect to Chile's emissions in the year 2018 (Ministry of Energy, MTT, and MMA, 2017; The Climate Action Tracker, 2019).

The new administration has sought to push forward these goals, declaring that it will work to ensure that 100 percent of public transport vehicles are electric by 2040 (Ministry of Energy, 2019) and 60 percent of private vehicles electric by 2050.[20]

Figure 3-13: E-mobility targets for 2050



Source: Ministry of Energy, 2019

Pollution Prevention and Decontamination Plan for the Metropolitan Region of Santiago

Worried about the level of local pollution in the Metropolitan Region, Santiago's authorities defined an environmental plan and its goals: the Pollution Prevention and Decontamination Plan for the Metropolitan Region (PPDA by its Spanish initials). The general objective of the plan is to protect the health of citizens in the region, especially children, the elderly, and those suffering from respiratory diseases (MMA, 2017).

The PPDA came into operation in November 2017 and features a series of measures to mitigate the main pollutants identified in Santiago. These include standards for emissions from bus engines (MMA, 2017).

The PPDA has led to the following policies (World Bank, 2019):

- Greater emphasis on emissions controls through technological upgrades (including restrictions on old vehicles)
- The creation of low-emissions zones
- Incentives to purchase hybrid and electric vehicles

[20] Estrategia Climática de Largo Plazo de Chile (Palma Behnke et al., 2019).

To best support energy efficiency standards, it is recommended that the Ministry of Energy, together with the MTT and MMA, promote the establishment of a suitable regulatory framework (MMA, 2017).

The MMA's National Air Quality Information System (SINCA) aims to provide timely and reliable information regarding air quality throughout the country, seeking to gradually improve knowledge, surveillance, and management of air quality. The system includes 13 monitoring stations (one of them private) in the Metropolitan Region. The stations gather information on $PM_{2.5}$, PM_{10}, sulfur dioxide (SO_2), nitrogen dioxide (NO_2), CO, and ozone (O_3) emissions, most of them in real time. The information from the stations is used to establish, for example, critical periods of high environmental contamination. The Superintendence of the Environment is the institution that oversees compliance with air quality and emission standards.

National Climate Change Plan 2017-2022

The National Climate Change Plan 2017–22 aims to support Chile in fulfilling its international commitments to the United Nations Framework Convention on Climate Change (UNFCCC). In addition, the plan has objectives of adaptation, mitigation, means of implementation, and climate change management at the regional and municipal levels. These goals are shown in table 3-6.

Table 3-6: Objectives of adaptation, mitigation, means of implementation, and climate change management at regional and municipal levels

Adaptation	Mitigation	Means of implementation	Climate change management at the regional and municipality level
Strengthen Chile's ability to adapt to climate change by: ▶ Deepening knowledge of climate change impacts and the country's vulnerability across subregions. ▶ Taking steps to mitigate negative effects while promoting economic and social development, ensuring environmental sustainability, and conserving the natural and cultural heritage.	Create enabling conditions for the implementation and monitoring of Chile's greenhouse gas (GHG) emissions reduction commitments, which contribute to the sustainable development of the country and to low-carbon-emissions growth.	Develop the enabling conditions necessary for the implementation of actions to mitigate and adapt to climate change at the national and subnational level, with a focus on the following: ▶ Institutional and legal framework, ▶ Technology transfer, ▶ Capacity building and technical assistance, ▶ Financing ▶ Negotiation international.	Develop the institutional and operational bases and the necessary capacities to advance the management of climate change across the nation and its subregions, incorporating all segments of society.

Source: National Climate Change Plan, 2017-22

This plan outlines 30 lines of action, including in the transport sector. Here, the MTT is committed to concrete planning measures to improve mobility within cities. Recommendations include dedicated bus lanes, fleet renewal, and incentives for the integration of clean technologies in buses.

The Energy Route 2018-22

The Energy Route seeks to define Chile's energy priorities and is based on comprehensive dialogue with representatives of the public sector and civil society. [21]It aims to be a tool for monitoring progress toward specific energy objectives across the coming years.

In particular, this document contains 10 national commitments for the period 2018–22. The main thrust of this agenda is low-emissions, energy-efficient transport. Key commitments include:

- Increase the number of electric vehicles that circulate in the country by a factor of at least 10.
- Start the process of decarbonizing the energy mix by scheduling the withdrawal or reconversion of coal-fired power plants, and the introduction of specific e-mobility measures.
- Train 6,000 operators, technicians, and professionals in the management and sustainable use of energy.

[21] Including of academy, nongovernmental organizations, environmental groups, neighborhood associations, unions, companies, and indigenous communities.

Environmental impact of e-mobility

There is a range of different methodologies, tools, and software used to estimate emissions related to road transport. The first group focuses on pollutants related to transport, analyzing their evolution over time or the impact of specific policies (e-buses, congestion fees, etc.). Other methodologies explicitly include cost as a variable in the analysis. In this second group, marginal abatement cost (MAC) analysis provides a framework within which to guide investment decisions, identifying the levels of abatement possible and at what level of investment. A key component of MAC analysis is the cost of each intervention, in terms of both capital and ongoing operational and maintenance costs.

Several emissions models are based on the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model, a comprehensive life-cycle model created and updated by the Argonne National Laboratory under the U.S. Department of Energy (Swedish Electromobility Centre, 2019).

MODEM is the name of the model used to estimate emissions related to transport systems in Santiago. (For more on MAC and GREET, see Appendix B.).

MODEM: Emissions model for Santiago

The emissions model used in Chile, MODEM, estimates atmospheric emissions from mobile sources. To estimate emissions, MODEM uses information on vehicle flows from transport modeling (ESTRAUS,[22] in the case of Santiago), vehicle flow profiles, and emissions factors, which generally indicate unit mass emissions (e.g., grams per kilometer traveled per vehicle).

MODEM includes methodologies for estimating emissions for different types of discharges: exhaust pipe emissions, brake and tire wear emissions, evaporative emissions, and resuspended dust emissions. It is programmed to estimate emissions for every link of the selected network for each vehicle type and technology category.

To carry out these calculations, different emission factors are used for each type of vehicle and each contaminant (PM, persistent toxic substances [PTS], CO, NO_X, hydrocarbon [HC], SO_X, CO_2, nitrous oxide [N_2O], ammonia [NH_3], and methane [CH_4]), based on fuel consumption factors. Since the estimation of emissions is based on emission factors for each vehicle category and type of pollutant, it is necessary to update the characterization of vehicle flows to carry out this task.

Inputs

MODEM works directly with the inputs and outputs produced by the four-stage transport model ESTRAUS. The model works using a network that represents roads in terms of links, and intersections in terms of nodes (not all the roads of the city, but at least all those necessary to have a good representation of the situation). Thus, it uses geographic information (nodes and links), link features (length, free flow time, capacity, fixed flow for each type of vehicle, etc.), and results of the simulation for each link in the network (assigned flow, travel time, travel speed).

Outputs

The results that MODEM generates when the analysis is done by link level are emissions by:

- Link and vehicle category per year
- Municipality and vehicle category per year
- Vehicle category per year
- Municipality and technology category per year
- "Resuspended dust" by link for each pollutant considered

Table 3-7 describes the different levels of aggregation available for MODEM results.

[22] Supply-Demand equilibrium model for multimodal urban transport networks with multiple user classes.

Table 3-7: MODEM results

Aggregation level	Description
Geographic	▶ Results by link ▶ Results by municipality and Greater Santiago
Temporary	▶ Results per hour and weekday ▶ Results per year
Pollutant	▶ Four regulated gases (CO, HC, NOx, SO2) ▶ 4 unregulated gases (N2O, NH3, CH4, CO2) ▶ Particulate matter (PM2.5, PM10)
Vehicle category	▶ 21 defined categories + additional: buses (6 types), trucks (3 types), passenger vehicles (6 types), commercial vehicles (4 types), motorcycles (2 types), and additional
Activity variables	▶ Fuel consumption ▶ Traffic volume ▶ Vehicle flows ▶ Average speed
Emission type	▶ Hot emissions ▶ Cold start emissions ▶ Evaporative emissions (hot soak, running losses, diurnal)

Source: Fieldwork conducted for the present study in 2019.

The most important element in the methodology for calculating emissions is the emissions factor. This indicates the volume of pollutants emitted per unit of distance traveled, generally expressed in grams/kilometer. There are different emissions factors for different vehicle categories, generally due to the technological differences associated with each one, such as the type of fuel used, the existence of emissions control devices, engine capacity, and so forth. The main hypothesis is that the emissions factor depends on the average travel speed of a vehicle, for which MODEM includes a definition of curves depending on the speed.[23]

The MTT set up a program to monitor bus emissions in the public transport system, and in October 2018 the first annual report on these emissions was prepared by the Secretary of Transport Planning (SECTRA), part of MTT. The report estimates the emissions of pollutants most harmful to the health and well-being of human beings (PM_{10}, $PM_{2.5}$, NO_X, HC, and CO) as well as those most responsible for climate change (CO_2). Its estimates were based on Transantiago's operations in the second half of 2018, when the system had only three e-buses as part of its fleet (functioning as pilots).

The DTPM report for 2018, meanwhile, compares estimates of atmospheric emissions in that year with figures for 2012.

Table 3-8: Estimated atmospheric annual emissions of buses in Santiago | 2018 vs 2012

Year	PM_{10} (Ton)	$PM_{2.5}$ (Ton)	NO_X (Ton)	CO (Ton)	HC (Ton)	CC (Ton)	CO_2 (Ton)	Bus x Km/ year
2012	96.7	84.9	4,518.4	1,201.6	227.0	143,470	447,287	432,849,146
2018	73.7	61.5	4,122.6	1,222.8	179.6	142,965	460,786	465,522,277
Var. 2018 vs 2012	-23.8%	-27.6%	-8.8%	1.8%	-20.9%	-0.4%	3.0%	7.5%

Source: DTPM, 2018

This report models a couple of scenarios using MODEM to develop a preliminary estimate of how the percentage of electric vehicles in the fleet affects emissions.

23 https://www.cec.uchile.cl/~tranvivo/tranvia/tv8/modem.html.

Comparison of methodologies

Table 3-9 summarizes the three models described including objectives, inputs, and outputs.

Table 3-9: Comparison of emissions models

	Usage	Advantages	Disadvantages
MAC	This methodology allows economic evaluations to support decision making in the context of climate policy, such as: ▶ Evaluating alternatives plans to reduce carbon emissions in a cost-efficient way. ▶ Illustrating the costs associated with carbon abatement. ▶ Comparing technologies and their cost-effectiveness in reducing carbon emissions.	▶ The main advantage of this methodology is that marginal abatement cost (MAC) curves are not restricted to the analysis of CO_2 reduction ($/t$CO_2$). Other units can be used, for example, to evaluate reduced fossil-fuel consumption (dollars per barrel, $/bbl) and then compare this with electricity consumption (dollars per kilowatt hour, $/kWh). ▶ Gives the total cost necessary to abate a defined amount of carbon emissions. ▶ Allows the calculation of average abatement costs.	▶ The curves are limited to a single point in time—they don't show variation over a time series. ▶ A baseline with no CO_2 constraint must be defined in order to assess the MAC against a determined year in the future. ▶ This does not permit the representation of path dependencies of the technological structure. ▶ The methodology behind the assumptions is not transparent. ▶ There is no consideration of ancillary benefits, such as the reduction of other greenhouse gases (GHGs), such as CH_4 and N_2O, as well as air pollutants.
GREET	▶ Develops indicators and a methodology for the evaluation of environmental sustainability. ▶ Evaluates the energy and emission benefits of vehicle/fuel systems. ▶ Extensive databases. ▶ Can address GHGs and the sustainability of vehicle/fuel systems. ▶ Simulates energy use and emissions across a vehicle's life cycle, from material recovery to vehicle disposal.	▶ The model was developed in collaboration with the energy industry. ▶ Includes provisions for a wide range of feedstocks, fuels, and vehicles. ▶ Includes more than 100 fuel pathways and 85 vehicle/fuel systems. ▶ Collaboration and interaction are key to success. ▶ Evaluates trade-offs between the GHG intensity of materials and their contribution to efficiency.	▶ Results are affected by assumptions about energy efficiencies of fuel production activities and emission factors of fuel combustion technologies. ▶ GREET is designed to conduct stochastic simulations. ▶ Technological advancement over time needs to be considered.
MODEM	▶ This software outputs the emissions of different pollutants, including those related to global warming (PM, PTS, CO, NOX, HC, SO_X, CO2, N_2O, NH_3, and CH_4) from mobile sources for different Chilean cities. ▶ MODEM includes methodologies to estimate emissions of different types: exhaust pipes, brake and tire wear, evaporative emissions, and resuspended dust.	▶ The software works directly with the outputs of strategic transport models frequently used to analyze projects in Chile (ESTRAUS and Vivaldi). ▶ To estimate emissions, the model uses formulas adapted for different technologies: Euro III, Euro IV, Euro V, etc. ▶ Offers emissions results at a very detailed level because it performs calculations for each modeled link in the analyzed network and for each vehicle category.	▶ Its use is limited to cities where transport model networks are available. ▶ It requires very detailed information: for example, coordinates of each link and information about fixed and assigned flow for each vehicle category. ▶ It does not consider the variable of cost. If a cost-benefit analysis is required, external inputs and calculations are necessary (the social benefit of less pollution, for example).

Source: Fieldwork conducted for the present study in 2019

Other potential impacts of e-mobility

In addition to the beneficial effects that e-buses have on emissions, the introduction of these particular buses has increased overall standards by introducing technological upgrades such as Wi-Fi, air conditioning, and more comfortable seats. A survey of bus users undertaken for this report suggests that most are willing to wait longer for an e-bus than a regular (diesel) bus. The factors behind this preference include technological improvements, less noise, and the fact that the buses have no emissions. This latest point is important; previous studies undertaken by the DTPM indicate that the fact that e-buses do not pollute is valued by only young people (under 30 years old).

In modeling terms, this extra willingness to wait could be represented through a different modal constant, higher for e-buses than regular buses. Alternatively, in some types of models, this preference is represented as attractiveness, which is basically a reduction in the cost function the user perceives (normally, travel time + waiting time + access time). Such factors will need to be input into an updated version of the Strategic Model of Santiago (ESTRAUS), used by public bodies to evaluate most of the projects or policies in the city.

A modal shift from private vehicles to public transport would have the extra benefits of a reduction in the number of private vehicles in circulation and their associated emissions. In turn, it could increase the benefits of introducing e-buses.

It is also important to consider the environmental impact of the production of electricity: introducing more electric vehicles does not have as dramatic an effect on curtailing emissions if electricity comes from fossil-fuel combustion. A generation source with less environmental impact is required in order to reduce GHGs.

Another benefit to be considered in the evaluation of these initiatives is the reduction of noise pollution. A study developed recently by the MMA for a newspaper report indicates that an e-bus generates between 25 and 70 percent less noise than a bus with an internal combustion engine. The MMA is continuing its study of this issue, to better understand the impact on noise pollution an e-fleet could have in Santiago.

E-mobility could also have some negative impact on the environment, if battery disposal is not carefully planned. Recycling batteries is essential to ensure a full zero-emissions life cycle.

Measuring the current environmental impact of e-buses

Agencia SE[24] is a nongovernmental organization that promotes, reinforces, and consolidates the efficient and sustainable use of energy. It works to estimate the environmental benefits of various e-mobility projects, and grants certificates for the reduction of emissions.

Figure 3-14 shows a certificate granted to Metbus and Enel X for a reduction in GHGs. As noted in the certificate, the first 100 BYD e-buses operated by Metbus, traveling a total of 3,658,388 km during nearly 10 months of operation, corresponded to a reduction in 2,564.1 tCO_2eq. For diesel buses, this was estimated using total distance, diesel's average street performance, horsepower, and diesel's emissions factor. For e-buses, estimations used total distance, average street performance, and electricity's emissions factor (averaged over the 10 months studied).

[24] https://www.agenciase.org/

Figure 3-14: Greenhouse gases reduction certificate—Agencia SE

Source: Agencia SE, 2019

Modeling the emissions of various fleet renewal scenarios

The emissions reduced by the adoption of Red standard buses (diesel Euro VI and e-buses) will be modeled and various scenarios will be contrasted below.

The contaminants compared are the following:

- CO_2
- $PM_{2.5}$
- PM10
- NO_x
- CO
- HC

Emissions for 2012 and 2018 were estimated using the MODEM model, as described in the DTPM report for 2018.[25] The 2018 simulations do not consider e-buses or Euro VI buses.

[25] Informe de Gestion 2018.

Table 3-10: Projected changes in emissions, 2012–18

Year	Scenario	CO_2 (tonne)	PM2.5 (tonne)	PM10 (tonne)	NOx (tonne)	CO (tonne)	HC (tonne)
2012	-	447,287	84.9	96.7	4,518	1,202	227
2018	-	460,786	61.5	73.7	4,123	1,223	180

Source: Based on information from DTPM (2018).

As part of this study, we have conducted MODEM simulations of three fleet renewal scenarios to estimate emissions, as shown in table 3-11.

Table 3-11: Three fleet renewal scenarios

Year	Scenario	Renewal of fleet project
2019	Current situation	▶ 409 diesel Euro VI (6% of the 2018 fleet) ▶ 411 e-buses (6% of the 2018 fleet)
2030	Without standard Red buses	Without electric or diesel euro VI buses
2030	Red standard projection	▶ 50% of the fleet are diesel Euro VI buses ▶ 50% of the fleet are e-buses

Source:Fieldwork conducted for the present study in 2019

The year 2030 models consider planned land use and transport projects. Some assumptions reflect vehicles' hourly and monthly profiles in 2020. The results for the modeled years are shown in table 3-12.

Table 3-12: Projected changes in emissions, 2012–30

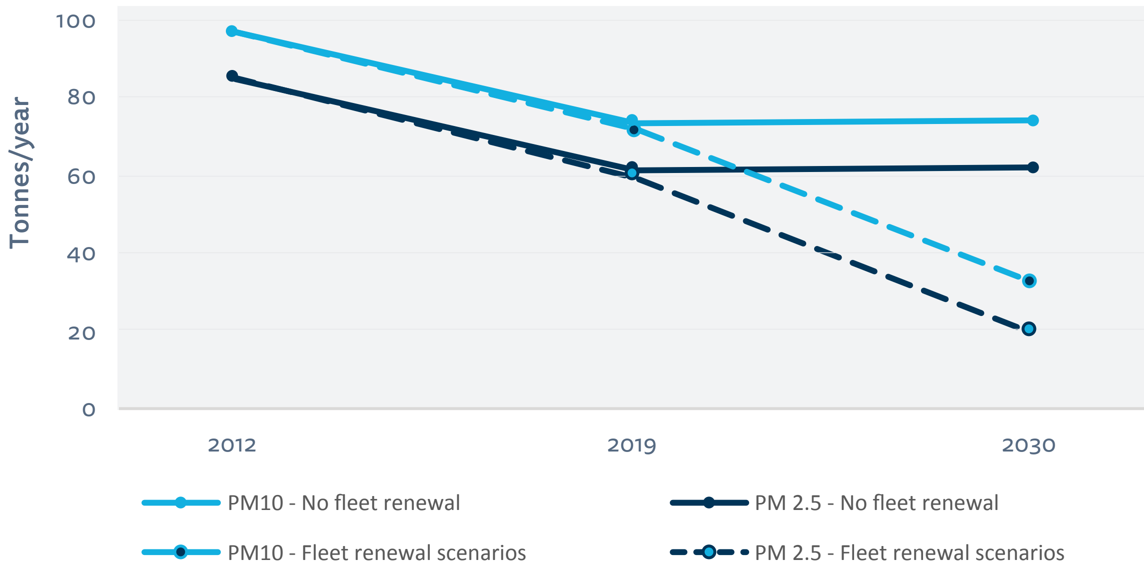
Year	Scenario	CO_2 (tonne)	PM2.5 (tonne)	PM10 (tonne)	NOx (tonne)	CO (tonne)	HC (tonne)
2012	-	447,287	84.9	96.7	4,518	1,202	227
2018	No fleet renewal [a]	460,786	61.5	73.7	4,123	1,223	180
2019	Current situation of fleet renewal	459,374	59.4	71.9	3,922	1,179	171
2030	No fleet renewal projection	460,443	61.7	74.3	4,097	1,216	177
2030	Fleet renewal projection (50/50)	391,390	19.3	32.5	444	354	18

Source: Fieldwork conducted for the present study in 2019
Note: aThis scenario represents the real situation before the arrival of the 411 e-buses and 490 diesel Euro VI buses

Figure 3-15 shows the results obtained for particulate matter.

Figure 3-15 shows that there is a decrease in PM_{10} and $PM_{2.5}$ emissions from 2012 to the 2018/19 scenarios, due to successive technological improvements in the Transantiago fleet. In addition, there is a slight reduction in the particulate material (measured in tonnes per year) emitted by the system between the 2019 scenario—with the new Red standard buses—in comparison with the scenario without these new buses. However, the main difference is observed when the different 2030 scenarios are compared.

Figure 3-15: Emissions of PM_{10} and $PM_{2.5}$



Source: World Bank, 2019

The model results show that the 2030 scenario with the Red standard (electric and Euro VI) buses achieves a 56 percent reduction in PM_{10} emissions compared to the 2030 scenario without them. The $PM_{2.5}$ decrease is even more significant, going from 61.7 tonnes/year to 19.3 tonnes/year in the scenario with the Red standard, which means a reduction of almost 70 percent.

The rest of the pollutants studied are plotted in figure 3-16.

Figure 3-16: Emissions of CO2, NOX, HC, and CO

Source: World Bank, 2019

Figure 3-16 shows that the technological change significantly reduces CO_2, NO_x, HC, and CO emissions. When comparing the different 2030 scenarios, the most notable decreases are for the NO_x and HC emissions, with a reduction of approximately 90 percent. CO_2 shows a reduction of 15 percent.

It is important to mention that these simulations are based on two important assumptions:

1. Chile's electricity generation mix was assumed constant.
2. E-buses might have less capacity than the buses being replaced, so if a significant proportion of buses are replaced by electric ones, an increase in the number of buses could be necessary to cover the demand. For these calculations, no fleet volume adjustments have been considered.

The first assumption results in a conservative estimate of the pollutants reduced. Today, Chile's electricity generation mix features significant advances in decarbonization and increases in the use of nonconventional renewable energy. However, it was decided to use the same energy matrix as the year 2019 for the 2030 projections, which could underestimate the reduction of pollutants produced by e-buses.

The second assumption results in an optimistic estimate of the pollutants reduced. Experience in Chile has shown that e-buses have less capacity than traditional buses. Therefore, a large-scale adoption of this technology should consider an upward adjustment of the fleet. Hence, the assumption that the bus fleet will be the same size in the two 2030 scenarios could overestimate the reduction of pollutants produced by e-buses.

Despite the above, there is no certainty that this difference in capacity will not be settled over the years, as a result of better technology.

Finally, the beneficial effects that fleet renewal can have on emissions depends on the buses' technology in the base situation. If the existing fleet is on average "clean," the extra benefit from introducing electric vehicles will be less significant than if the initial fleet is old, although the change can be relevant in very polluted cities, such as Santiago.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04

E-mobility business model

Timeline of the introduction of e-buses in Santiago

The process of testing, promoting, and adopting e-buses in Chile has had multiple actors, stages, and actions.

2011

First electric fast charging point constructed by Chilectra

One of the first efforts to boost the development of e-mobility in Chile was undertaken by Chilectra[26] an electricity distribution company. In 2011, Chilectra opened the first Latin American fast-charging point at a Petrobras[27] service station located in the eastern part of the city (Emol, 2011).

The project was developed by Chilectra, in partnership with Marubeni[28] and Petrobras. Chilectra was in charge of preparing the infrastructure and adjusting the electricity distribution network, while Marubeni delivered the supply equipment, which was imported from France and had a power output of 50 kilowatts (kW). Finally, Petrobras provided space at its service station for the installation of the charging facility and operated the service.

2013

First e-bus pilot in Latin America started its operation in Santiago in a partnership with BYD and Chilectra

In 2013, the first e-bus pilot study in Latin America began operating in Santiago. It was promoted by Chilectra as part of the Smart-city Santiago Plan and used a BYD[29] bus on a route agreed with Universidad Mayor. The bus route was around 18 km long, going from the Escuela Militar metro station to the university campus (Campus Huechuraba—Universidad Mayor), and then returning to the same metro station (Ahumada, 2013).

The BYD K9 bus was 12 meters long and had an autonomous range of up to 250 km. By not having an internal combustion engine, it reduced CO_2 emissions and generated diesel savings of more than 2,000 liters per month (Ahumada, 2013).

One of the most significant lessons of this pilot study, according to the then innovation manager of Chilectra, was the need to adapt the buses to the characteristics and standards of the streets of the city of Santiago and the system´s existing services, which are detailed further in this chapter.

UITP[30] and C40[31] analyzed measurements related to this type of bus. The C40 study, entitled "Low Carbon Technologies Can Transform Latin America's Bus Fleets," was presented in April 2013. The C40 team measured emissions and evaluated the economic and technological performance of hybrid and electric buses in four cities (Bogotá, Río de Janeiro, São Paulo, and Santiago) (C40 Cities, 2013).

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[26] Chilectra was owned by the Italian company Enel. It was renamed Enel Distribución Chile S.A. in 2016 as part of the strategic renewal of Enel in Chile.

[27] Petrobras is a Brazilian corporation in the petroleum industry.

[28] Marubeni is a representative of automotive brands in Chile. In 2011, Marubeni was a Nissan distributor. Today, Marubeni represents Citroën and Volkswagen.

[29] BYD is a Chinese manufacturer of automobiles, buses, battery-powered bicycles, forklifts, rechargeable batteries, and trucks.

[30] UITP is the International Association of Public Transport.

[31] C40 is a network of large cities committed to addressing climate change.

The measurements were carried out under normal traffic conditions[32] in Santiago, Chile, and had the support of the bus operator Subus, one of Transantiago's bus operating companies. The results showed a 73 percent reduction in the energy consumption of e-buses compared with traditional diesel buses. The document concluded that e-buses would be economically competitive in the long term, mainly because their operating costs are lower than those of traditional diesel buses, with key benefits for the financial and regulatory system (C40 Cities, 2013).

2014

Development of studies related to the implementation of e-mobility in the public transport system

In 2014, Chilectra worked together with the Mario Molina Research and Development Center to prepare a technical study named "Opportunities for the Development of Electric Mobility in the City of Santiago: Proposal for Public Transportation" (Centro Mario Molina, 2014). The report included an evaluation of the implementation costs of various electrical technologies, and compared these to diesel technology. Trolleybuses and buses with batteries were considered to be electrical technologies. From the "electrical scenario," the benefits in terms of a reduction in the total fuel and energy consumption of Santiago's public transport system were estimated, together with the reduction of local pollutant emissions. The report also included an analysis of the feasibility of integrating e-mobility for the Transantiago´s services (Centro Mario Molina, 2014).

The analysis aimed to promote the transformation of the Transantiago fleet to include e-buses, considering that the contracts of Business Units 6 and 7 were due to terminate in 2015. At that time, it was expected that the renewal of the fleet would occur in 2018 in relation to a new set of operating contracts (Centro Mario Molina, 2014).

This study concluded that by 2022, 35 percent of Santiago's public transport fleet—around 2,300 buses—could be transformed into e-buses (battery buses or trolleybuses), which would result in a 22 percent decrease in the GHG emissions of the public transport system (Centro Mario Molina, 2014).

2016

Second BYD e-bus pilot started operating in the downtown of Santiago financed by Enel (previously Chilectra)

In 2016, Chilectra, together with the Municipality of Santiago, promoted a new e-bus pilot study, which offered a free service through the historic city center. This initiative was supported by BYD, the Ministry of Environment, and the MTT. The chosen bus model was again the BYD K9 bus, which included free Wi-Fi and cell phone chargers at some seats. During the bus operation period, energy cost savings of 70 percent were achieved compared to a diesel buses (Municipalidad de Santiago, 2016).

In parallel with the pilot project in the Municipality of Santiago, Chilectra (which was renamed Enel Distribución in October 2016) continued studying the feasibility of a bus fleet with electricity as its energy source. This effort had the objective of incorporating 2,300 e-buses into the tendering process that was planned for the year 2018 (Centro Mario Molina, 2014).

Enel delivered a technical report to the authorities connected to Santiago's public transport system. The report contained proposals covering economic, financial, technological, operational, and regulatory aspects of the plan, with the aim of introducing e-buses as part of Transantiago.

[32] Tests were carried out under normal traffic conditions at maximum loading capacity using simulated weights and considered criteria such as normal operating conditions for public transport services, topography, and maximum coverage of the main urban area.

Mid 2017

Metbus started operating the first 2 e-buses operating in the 516 Transantiago service by Metbus, in a partnership with BYD and Enel

In May 2017, the minister of transportation and telecommunications announced that two e-buses would start operating as part of the Metbus fleet in the second half of the year. Implemented in November of that year, this was the first e-bus pilot scheme to include a regular Transantiago service. The route chosen was the 516, which runs from Maipú (in the west of the city) to Peñalolén (in the east of the city), a distance of around 30 km that included a 10 percent slope when passing through the Avenida Grecia corridor. According to interviews with the operator company, the objective was to test this bus on a difficult route (long and sloping) to find evidence that this technology would also work on other bus routes in Santiago.

This milestone was achieved through an agreement between the private companies Enel, Metbus, and BYD, and the MTT. The objective of this pilot scheme was to test the autonomy, maintenance, charging processes, and availability of buses, among other technical considerations.

The role of Enel was to provide Metbus with the financing for the buses, the charging infrastructure (four charging points, two in Maipú and two in Peñalolén), and the energy to operate them—all through a leasing scheme. BYD supplied the two buses, and in addition, agreed to take care of maintenance and ensure the availability of the buses every day.

The buses were the 12-meter-long BYD K9 models, which had a range of 250 km, a full charge time of three to four hours, with Mode 3 charging at 80 kW of AC[33] power and international Type 2 connectors, Wi-Fi, air conditioning, padded seats, and USB chargers.

Figure 4-1: Yutong ZK 6128 model used in Santiago

Source: MTT, 2019

Late 2017

Buses Vule started operating a new e-bus on the 315e Transantiago route, in partnership with Engie and Yutong

In December 2017, a new pilot was launched by a consortium formed by Engie,[34] Yutong,[35] and Buses Vule,[36] this time with a Yutong ZK 6128 bus on the 315e route.

This third e-bus serving a regular Transantiago route (following the two BYD buses operated by Metbus) was 12 meters long with Wi-Fi, USB ports, air conditioning, and an autonomous range of roughly 320 km (which could vary

[33] Alternating current.

[34] Engie is a French multinational company in the field of energy and is present in more than 70 countries. In Chile, Engie participates in electricity generation and transmission.

[35] Yutong is a Chinese manufacturer of commercial vehicles, especially e-buses. In 2016, it was the largest bus manufacturer in the world by sales volume.

[36] Buses Vule is a Chilean public transport company that operates Transantiago services (Business Unit 3).

due to the electricity consumed by air conditioning in different seasons). Based on Mode 4 charging at 75–150 kW of DC[37] power and Chinese GB connectors (Guobiao standard), the service went from the northern part of Santiago to the historical center, covering a circuit of 23 km.

The agreement between Engie, Buses Vule, and Yutong was similar to the one between Enel, Metbus, and BYD. Engie was responsible for financing the Yutong bus, and providing the charging infrastructure, electricity, and other associated services. Again, all these elements were supplied under a financial leasing scheme to Buses Vule, which operated the service. In this case, unlike with Metbus and BYD, Buses Vule was in charge of the maintenance, while Yutong only provided only the bus and the spare electronic parts, as well as guarantee schemes.

2018

Cancellation of previous tender process, ending of Alsacia's contract and introduction of 100 new BYD e-buses for the operation of Metbus services

In parallel with these initiatives, in 2017, the tendering process for the operation of the public transport system in Santiago was put into place. This process required negotiations between bus manufacturers, energy companies, and bus operators, as the tender process required that each business unit have a minimum of 15 e-buses. In March 2018, the tendering process was canceled. One contract (Alsacia's) was not renewed. Nevertheless, the progress already achieved in the negotiations facilitated the potential implementation of an e-bus fleet. This, together with the successful operational performance results of the pilot schemes, drove the different stakeholders to increase the scale of their plans with a greater number of e-buses. Soon the strategic alliance between Enel and Metbus was consolidated and the model was replicated through the purchase of 100 new electric BYD buses, which arrived in Chile in November 2018, and began their operation on December 15, 2018. These buses started operating along routes 507c, 516, and 519 throughout the Grecia corridor. This process was incentivized by the MTT, which, through a "fleet expansion payment" (Pago por aumento de Flota),[38] supported the new investment.

Figure 4-2: The first 100 e-buses operated by Metbus

Source: World Bank, 2019

The investment made by Enel exceeded $30 million and included the construction of two depots for electric charging, one in Peñalolén (with 63 charging points) and another in Maipú (with 37 charging points).

[37] Direct current.
[38] An existing mechanism in the bidding contracts, which will be defined in detail in the section titled "Key Elements of the Public Transport System Contracts."

The Peñalolén bus depot has solar panels that generate energy used for bus charging and depot operation. Charge management software decides the periods during which the buses are charged, so as to avoid the peak periods of electricity demand and thus decrease energy costs.

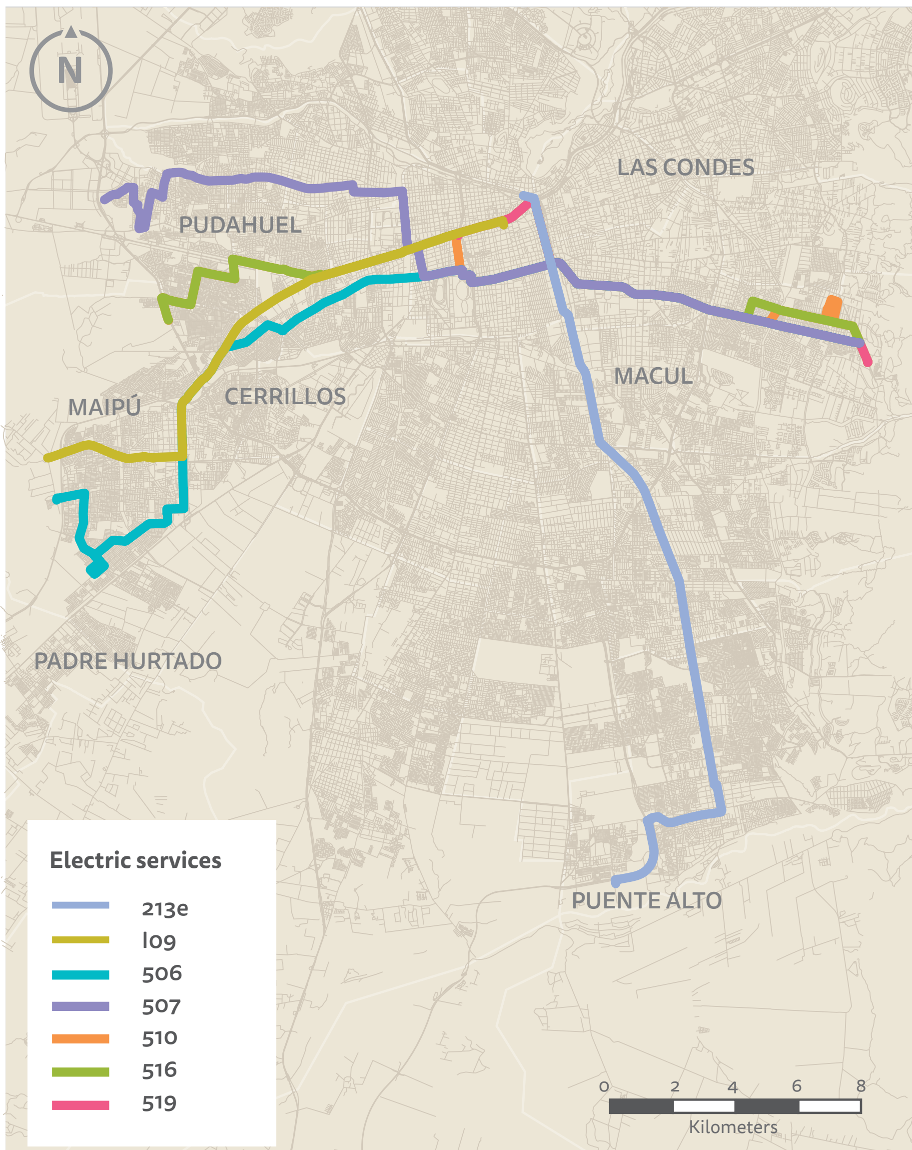
Early 2019

STP and Buses Vule operate 100 new Yutong e-buses, financed by Engie

Months later, in January 2019, the authorities announced the addition of 100 new e-buses to the system, this time manufactured by Yutong. This was to cover the gap in services associated with the end of Alsacia's contract. The operation of these e-buses was assigned to Buses Vule and STP, with 75 and 25 buses respectively. The mechanism that allowed this acquisition is similar to that already described for the pilot scheme with the Yutong bus.

The 75 buses operated by Buses Vule were assigned to the routes I09 and I09e going from Rinconada de Maipú to Santa Rosa. The buses arrived in January 2019, but only started operating in April as there was insufficient installed power. This fleet operated from the e-depot in Rinconada, constructed by Engie Energía Chile, with a capacity of 6 MW[39] the biggest depot of its kind in Latin America.

Figure 4-3: E-bus routes



Sources: Fieldwork conducted for the present study in 2019.

[39] Installed capacity, not necessarily the power actually used.

2019

183 new e-buses added to the system in a partnership between Metbus, Enel and BYD

The latest e-fleet to join the system arrived in October 2019 (MTT, 2019). This fleet of 183 new buses was the result of an agreement between Enel, Metbus, and BYD, and operates on the Avenida Grecia corridor, which became the first 100 percent e-bus corridor in Latin America. The financing, acquisition, operation, and maintenance of these buses followed the same scheme previously used by these three firms. The scheme included the construction of the charging infrastructure in three new depots. This was financed directly by the bus operator, and not through leasing as before.

Figure 4-4: Metbus e-depot in Peñalolén

Source: World Bank, 2019

During this period, studies, pilot schemes, and agreements between different actors were developed, resulting in significant progress. So, over a period of 10 years from the start of the system as we know it, the e-bus fleet operating in Santiago grew to 386 e-buses as of October 2019, with 25 extra e-buses expected during 2020. This last partnership between RedBus and the bus manufacturer King Long will result in the system reaching 411 e-buses by 2020.

Santiago's e-mobility business model

Key elements of the public transport system contracts

To understand the context in which the e-buses have been introduced in Santiago, it is relevant to consider the fundamentals of the public transport system. Red (previously known as Transantiago) works on a concession contract between the state and each bus operator company, to regulate the operation of a package of bus services. Like most public transport systems around the world, Red receives a significant subsidy from the state (around 40 percent of the system's cost, according to Informe de Gestión 2018) in order to cover student fares and other gaps between the system's costs and users' payments (including, for example, fare evasion losses).

Currently, there are six bus operator companies[40] —Metbus, Buses Vule, STP, RedBus, Subus, and Express— each of them assigned to the operation of a group of bus services (business units) corresponding to the set of routes won in the respective bidding process. Red has an electronic payment system that uses a smart card (bip!), and revenues are collected and managed by the regulator.

The original length of the concessions' contracts was 10 years, with the first operations in 2007. This has been important in the context of the implementation of e-mobility in Santiago, as the concessions of many business units came to an end during the implementation period. Nevertheless, the contracts include clauses to extend the concession periods, which some operators have applied. Table 4-1 presents the end-of-contract dates for each operator company, including the extension (where applicable). How these contracts' expiration offers an opportunity for other operators to include e-buses in their fleet will be explored later in this report.

[40] Previously seven, but one of the companies' contracts ended in 2019 (Alsacia).

Table 4-1: End of the contract period and the extension period for each bus operator company

Bus operator companies	End of the contract period	End of the extension period
Metbus	October 2018	February 2020
Express	June 2019	June 2020
Subus	August 2020	—
STP	May 2018	May 2021
RedBus	May 2018	May 2021
Buses Vule	November 2021	—

Source: Derived from DTPM

Existing remuneration scheme of private operators

The remuneration scheme for bus operators is established by the following equation:

$$monthly\ payment = PPT * transactions + PK * kilometers - discounts$$

Where:

$$PPT = payment\ per\ transported\ passenger$$

$$PK = payment\ per\ kilometer$$

Since the 2012 contract reform, approximately 70 percent of bus operator revenues are from the initial payment per transported passenger (or ticket validations), while the other 30 percent is obtained from the payment associated with the kilometers traveled. An operator may have some of its payment withheld due to noncompliance with operational standards.

This is an important modification from previous contracts, by which the percentages were almost the opposite (previously, an average of 70 percent of revenues were obtained from the operated kilometers and 30 percent from monthly ticket validations). This change aims to support the transport system in sustainably meeting demand by giving some of the responsibility for controlling fare evasion to the bus operators themselves.

Even though there is no direct incentive coming from the payment structure, other elements of the new contract conditions created an enabling environment for the introduction of e-buses.

There are two main reasons for a private operator company to buy more buses for its fleet. The first is a change in its operational plan, whether because of an increase in the length of routes or a reduction in speeds. The second is when the current fleet's life cycle is at its end. The life cycle of a bus fleet is typically at least 1,000,000 km and/or 12 years of operation; once this has been reached, there is an imminent need to renew the fleet.

A contract set up between the operators and the state ensures financial stability over time, working as a demand-supply equilibrium. This is achieved through an updating mechanism in which the payment the operators receive from the system is adjusted if any of the concession's conditions that affect the financial equilibrium of the contract change significantly. This characteristic of the contract specifies the situations when the operator could negotiate an increase (or decrease) in its payment. Particularly, this contract characteristic can be applied to the introduction of the new fleet as follows:

- If the new buses correspond to a fleet increase (that is, more than a 3 percent increase over the previous operative fleet) needed to cover an increase in the operational kilometers of the business unit (for example, due to new routes to operate), the state will cover the difference between the cost of the new technology and the old buses, through an update of the monthly payment to the bus operator company.
- If the new fleet is acquired because of the renewal of the existing bus fleet but does not modify the operational kilometers of the business unit, the state will not make any investment and the payment to the company will remain the same.

This is an important element to have in mind, as the first significant fleet of e-buses (200 buses) was introduced to the operators' fleets as an increase in operational kilometers. This means that, for those initial buses, it was the state who assumed the increase in capital costs associated with the new technology, and not the private operators. At the same time, the operators projected lower operational costs with this technology compared with their previous diesel buses. Despite this being a significant incentive for the private companies, this scenario presented itself as an opportunity for both parties as it coincided with the end of Alsacia's contract, which meant a huge amount of money spent by the state could now be directed to cover the extra cost of the renewal with an e-fleet. The details of these costs and negotiations will be discussed later in the report.

Apart from this payment updating mechanism, there are mainly two elements of the current contracts that have acted as incentives for the promotion of e-buses and the introduction of e-mobility in the public transport system in Santiago. It is important to mention that these elements were not designed specifically for this process, but were part of the contracts beforehand. These are the following:

- The operators' quote for fleet provision is paid directly by the state to the company that provided the buses (the investor), as the operator transfers the monthly debt to the financial entity (AFT)[41] in charge of collecting earnings and managing operators' payments. The AFT subtracts from the payment to the operator

[41] A mixed company that oversees the financial aspects of the public transport system, including the collection, management, and distribution of income between operators. Metro S.A. is currently in charge of its administration and logistics.

the amount corresponding to the leasing contract it has with the energy company and pays that sum directly to the energy company. This key characteristic allowed both Enel and Engie to reduce the risk of their investment.

- In addition, the operators and the providers signed a provision contract, approved by the state, which specifies that no matter what company is operating the e-buses, the state guarantees the buses will remain within the system at least until the debt is paid. In this contract, the state agrees to the financial conditions and guarantees continuity of the service. Thus, the energy companies (or any other investor) have the assurance that they will be paid as the debt will be transferred to the next operator. This is another element of the PPP that reduces the risk of the investment and ensures the continuity of the business, beyond the current private bus company in charge of the operation. Also, this characteristic worked as an incentive to introduce e-buses, as it allowed the buses to be funded in a larger time frame than that left for each operator as part of the system. This was translated into affordable monthly quotes (the current provision contracts have a 10–12 year extension).

This way, the current contracts acted as sufficient incentives for the introduction of e-buses in the public transport system of Santiago without the need to change any of their conditions. Other factors that helped the process to be successful include its timing (at the end of operational contracts and the life cycle of several bus fleets), the negotiations among stakeholders that took part in the process, the short-term promise of a future bidding process, and the purposeful alignment of all actors to move toward e-mobility.

Description of the PPP for e-buses implementation

The business model used for the implementation of e-buses in Santiago consists of a public-private partnership (PPP) between the state and the private companies involved. As with any PPP, every actor has different motivations and responsibilities that prompt its initial involvement and further participation in the process.

The first, and key, actor, as most of the interviewees mentioned, is the bus operator company. As described in the timeline, Metbus was the first company to include e-buses in its fleet (285), operating the first e-corridor in Latin America. It was followed by Buses Vule (76) and STP (25), and finally by RedBus (25). All the PPPs in which these companies participate are different in terms of the responsibilities and roles each actor has within the partnership. Table 4-2 summarizes the different

Table 4-2: Roles and responsibilities of the actors

Type	Actor	Role and responsibilities
Energy Company	Enel / Engie	Financing of bus fleet; e-depot construction; charging infrastructure installing; energy provider
Investor	NEoT Capital	Financing of the bus fleet
Bus Manufacturer	BYD	Fleet provision and adequacy of the bus; charging management; preventive, corrective and predictive maintenance of the e-bus electronics
Bus Manufacturer	Yutong/ Kinglong[a]	Fleet provision and adequacy of the bus
Bus operator	Metbus	Operation
Bus operator	Buses Vule/ STP/Redbus	Operation; charging management; maintenance
State	MTT	Funding of new bus fleet (increase on operational kilometers); service planning; transport regulation
State	Ministry of Energy/SEC-CNE	Energy land capacity studies; authorizations for electricity grid modifications; regulation of the compliance of the e-depots standards

Source: Fieldwork conducted for the present study in 2019.
Note: [a]Yutong's representative in Chile is Gildemeister, and King Long's is Vivipra.

responsibilities that each company and the state have in the implementation of the first e-buses in Santiago.

The general PPP considers an investor who buys the bus fleet and holds a financial leasing contract with a bus operator. In most of the cases, the energy companies Enel and Engie played that role, as international financially strong companies. Even though financing buses is not the core business of energy companies, they saw this investment as an opportunity to introduce the e-buses in the market and generate the requirement of charging infrastructure and energy. This was the model applied to finance the bus fleet of Metbus, Buses Vule and STP, meanwhile RedBus has its own financial solution with an international investor (NEoT Capital).

This leasing contract is based on the monthly payment of an amount corresponding to the fleet provision quote, the price of the charging infrastructure, and the sale of energy, all provided by the energy company.

monthly leasing payment = fleet provision+charging infrastructure+energy[42]

[42] For the last three Metbus e-depots, the charging infrastructure was not part of the equation, but it was paid at the beginning of the leasing contract.

As explained in the previous section, the contracts between the state and the bus operator companies ensure financial stability over time, so when the operator adds buses to its fleet due to an increase in operations (new services or additional kilometers), the state will compensate that extra cost if it represents more than a 3 percent fleet increase. According to the DTPM, in this case the difference between this new technology and a diesel bus corresponds to $1,500 monthly (including all aspects of the leasing, like the e-buses and the charging infrastructure costs). If the acquisition of buses corresponds to renewal of the old fleet, but no operational changes occur, the cost will be entirely assumed by the operators.

The first 200 e-buses were added to the system using this updating mechanism, where the state covers the difference in the cost of this new technology by increasing the monthly payment to the operator. This process was guided as a negotiation between the state and the operators, in which Metbus, STP, and Buses Vule would assume the operation of the services previously operated by Alsacia, whose contract ended, and for which they all needed new buses (as Alsacia's old diesel buses had already completed their lifespan). This meant an increase in their operating kilometers of more than 3 percent added to the fleet, which made the state raise the amount of their monthly payment and assume the capital expenditure (CAPEX) difference between both technologies. In this case, the decrease in the operating expenditure (OPEX) was a benefit for the operator while the increase in CAPEX was covered by the state. These costs savings for the private companies were the result of introducing e-buses with lower OPEX under old contracts whose payment conditions were based on OPEX for diesel technology only.

Although it would seem like a very advantageous situation for the private companies, as they would have new buses without assuming any of the extra CAPEX costs and also lower OPEX costs, there was uncertainty regarding how the different processes associated with this new technology would affect their operations. Thus, the negotiation process also considered projected costs for the operators associated with new personnel (both depot and office based), restructuring teams, organizational changes, and trainings, among others.

Nevertheless, the operators interviewed for this report mentioned that their estimates, after almost two years of operation of the first e-buses, show that buying and operating the e-fleet by themselves with no economic contribution from the system (without any state subsidy for fleet renewal) could be as economical as a diesel fleet. This is because the decrease in OPEX would compensate for the increase in CAPEX within a period of 10 years. This CAPEX/OPEX equilibrium shows that when designing systems with an entirely electric fleet, the cost should not be higher than for a diesel fleet if the system is designed for the appropriate amount of time (according to the operators' estimates, the business would be viable within 10 to 14 years of payment).

With an operation of 6,000 km/month, Metbus estimates a reduction in OPEX costs equivalent to $1,800 per month per bus. Likewise, the difference in CAPEX (bus and charging infrastructure) between an electric and a diesel bus is around $1,500 per month if paid within a 10-year contract, showing a reduction in total costs per month per bus, plus the reduction in maintenance costs. In addition, at the end of the leasing contract, if the operator is still in the system, it will be the owner of buses, which will still have 30 percent of residual value, as the lifetime of the buses is estimated at around 14 years.

With this information, some operators have started (or are planning) to renew their old fleet at their own expense. Examples of this are the 183 new Metbus buses introduced during October 2019, and the 25 RedBus buses that will arrive in Santiago during 2020.

Table 4-3 summarizes the e-bus implementation stages of the bus operator companies that have introduced this technology.

Table 4-3: An overview of the introduction of e-buses as of 2019

Company	Energy Company	Manufacturer	Pilots	New fleet	Fleet renewal	Total fleet[a] (2019)
Metbus	Enel	BYD	2	100	183	1,155
Buses Vule	Engie	Yutong	1	75		1,456
STP	Engie	Yutong		25		607
RedBus	Enel (only energy)	King Long			25[43]	792
Total e-buses	-	-	3	200	208	411

Source: Based on information from DTPM (2018) and updates after interviews.
Note: [a]Includes operational and reserve fleet.

Maintenance costs are another important element in the total cost of ownership (TCO) of e-buses. Metbus estimates that the maintenance cost is reduced from Chilean pesos (Ch$) 190/km for a diesel bus to Ch$63/km for an e-bus—a savings of 67 percent.

However, not all PPPs shared the roles and responsibilities of maintenance in the same way. Yutong and King Long, for example, limit their tasks to provisioning the fleet, ensuring the suitability of the buses, and providing spare parts. Instead, the after-sale services agreement between Metbus and BYD held the fleet manufacturer responsible for the electric maintenance of e-buses and the buses' charging process, in addition to the management of spare parts. This will be further discussed in the following section "Case Studies: Enel and Engie".

Regarding the evolution of the price of the e-buses, the first BYD buses implemented as pilots in Santiago cost around $450,000, more than twice the diesel Euro VI cost. Nevertheless, when negotiating the incorporation of a bigger bus fleet, with the understanding that this represented the first introduction of e-buses into the Chilean market, the bus manufacturers offered a much lower price, around $300,000.[44] This made the business significantly more competitive with the diesel Euro VI buses than before.

Table 4-4: Comparison between diesel and electric bus

Item	Diesel (12 m)	Electric (12 m)
Capital expenditure (CAPEX, cost of the bus)	$190,000 – $200,000	$290,000 – $300,000
Performance	2 km/Lt	0.9 – 1.0 km/kWh
OPEX	$0.42/km	$0.10/km
Maintenance cost	$0.27/km	$0.08/km

Source: Based on interviews conducted for this report.

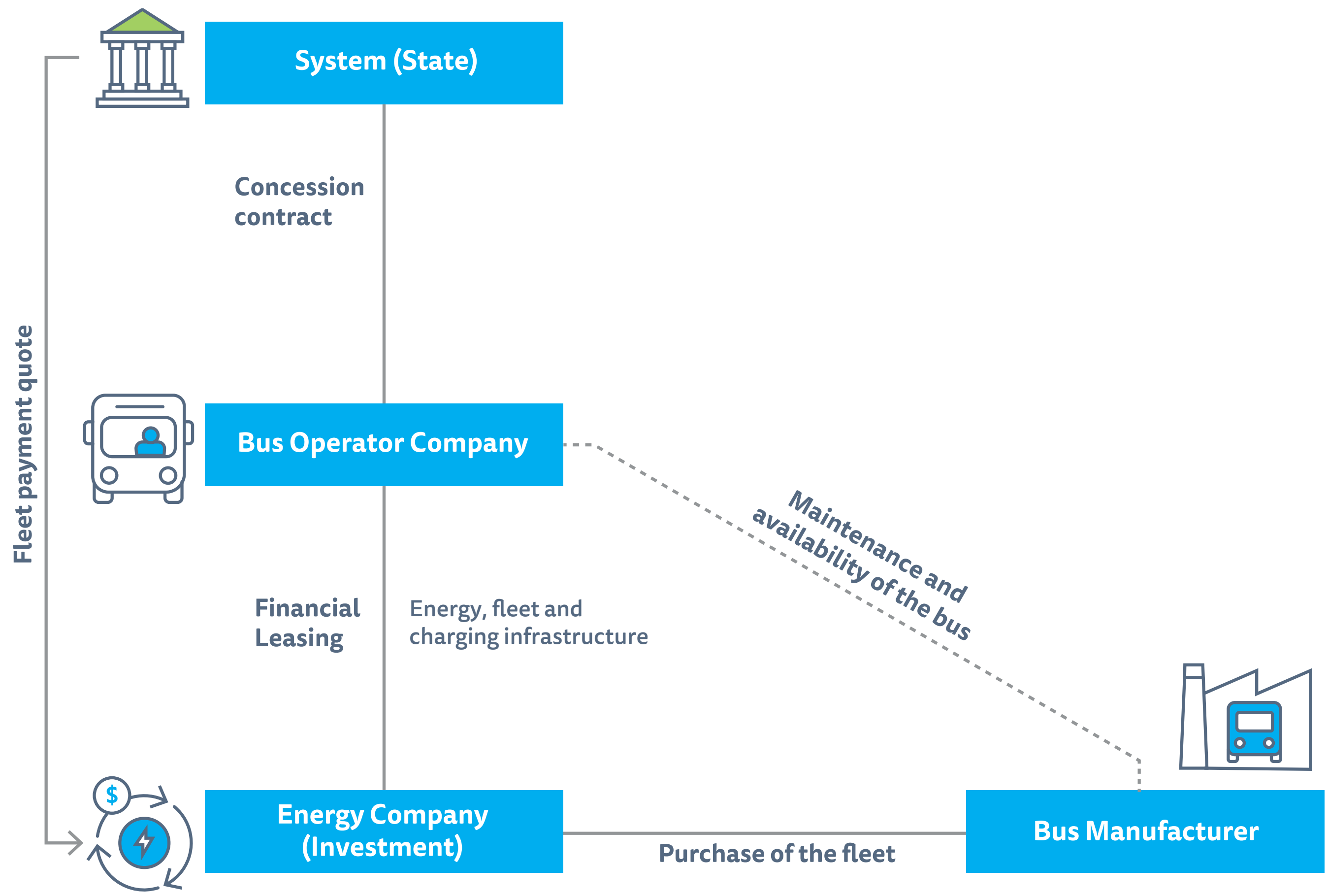
Note: Exchange rate of Ch$712 to the U.S. dollar (October 14, 2019).

Another important part of the e-bus business model is the fee rate associated with the financial leasing contract. For Transantiago the loan rate was historically 7.8 percent, a figure that Enel used as a basis for offering the same rate on the loan of the first 100 buses. After that, for the incorporation of the next 100 buses (for Buses Vule and STP), Engie offered a lower rate of 7.3 percent, which Enel then incorporated into its next loan for the 183 buses.[45]

It is expected that for the future incorporation of new e-fleets, the loan rates will decrease significantly. They are expected to be around 6 percent in the next negotiation process, as the scale of the investment will be higher (more than 300 new buses) and also because of the involvement of new actors, such as investment banks (both local and international).

43 Expected during 2020.
44 All prices presented do not include VAT.
45 Information provided by the energy companies during interviews conducted for this report.

Figure 4-5: Organizational diagram of actors' interrelations in the PPP



Source: : Fieldwork conducted for the present study in 2019

The evolution of the public transport system into a greener fleet has been cost-effective for the system because of the timing and the opportunities of when it was implemented. The ending of Alsacia's contract, which was highly expensive for the system, was used as an opportunity to introduce 690 new buses, financed with savings generated by Alsacia's replacement. According to the DPTM, this resulted in annual savings of nearly $1 million for the system. This was one of the drivers, among others, of the government's support of the adoption of e-buses in Santiago's transport system.

The government played a supporting role from the beginning: initially by authorizing the introduction of the first 200 buses, and after that by facilitating the process and helping to reduce approval times for the operation of the vehicles and the construction of infrastructure. As mentioned previously, the system was going through a brand transformation led by the government, from Transantiago to Red, and the opportunity to upgrade the fleet to a better and cleaner technology supported that approach, as well as being the first step toward NDC targets and other national environmental commitments. State technical teams played an important role in planning and regulation.

In summary, table 4-5 presents the different actors' motivations that enabled the fast adoption of e-buses in Santiago.

Table 4-5: Motivations of the actors within the PPP

Actors	Role	Motivations
Enel	Energy companies	Boost their core business of charging infrastructure installing and energy selling
Engie		
BYD	Bus Manufacturers[a]	Introduce e-bus technology in the Latin American market
Yutong		
King Long		
Metbus	Bus Operators Private Companies	Achieve lower operating expenditure (OPEX) cost; offer better level of service; increase transactions
Buses Vule		
STP		
RedBus		
Ministry of Transport and Telecommunications	National Authorities	Improve quality service of the system; develop change of brand (Red); reduce fare evasion[b]; achieve nationally determined contribution (NDC) targets

Source: Fieldwork conducted for the present study in 2019.
Note: [a]Chilean representatives of Yutong and King Long may differ slightly on their motivations in terms of the profitability periods (long or short term). [b]Some operators have mentioned that e-buses have reduced fare evasion, since users appreciate the improvement in services.

Case Studies: Enel and Engie

In this section, illustrative cases for the different private initiatives, Enel X and Engie, will be developed. Details are provided on the different actors involved in this process, including their roles and responsibilities, the conditions for fleet operation, the different technologies and performance levels of the buses, and financial considerations associated with each partnership.

Stakeholders

As previously discussed, new actors were included in the new PPPs. These new actors, different for each of the concessions, performed key roles to make the business model successful.

The tasks performed by the energy companies were essential. For the first two experiences of the introduction of e-buses in Transantiago, Enel X and Engie adopted many roles, some exclusively and some shared with other actors. The following list presents seven tasks where energy companies performed a crucial role:

- Supporting the implementation of pilots
- Coordinating the participation of the different actors
- Making the initial investment in the bus fleets
- E-depot construction and charging infrastructure installation
- Power management for the charging process
- Providing energy for the e-depots
- Supporting the process of change from diesel to electricity
- Contributing to the discussion on new bidding rules

Among these, some were not exclusive to the energy companies. For example, bus manufacturers and the Ministry of Transportation also played important roles in supporting the implementation of pilots and the coordination of participants.

In the third PPP—between Enel X, RedBus, and King Long—e-buses were introduced later in the process, so the implementation of pilots did not have the same impact as these in previous successful experiences. In this new PPP, a new actor, NeoT Capital, appeared as an investor in the bus fleet. With this, Enel X ceased to support the acquisition of e-buses financially, dedicating all its efforts to its actual core business.

After the pilots came the planning and modification of electric infrastructure. The average increases in grid capacity for project implementation typically did not exceed 1.5 MW. In the case of the Buses Vule's e-depot, the request was for 6 MW, much higher than the usual needed for electric infrastructure projects. As expected, the electricity grid was not prepared for an increase of this magnitude, and required exceptional planning and coordination among different actors to get everything ready on time.

First, the Enel Distribución utility company was in charge of making the electric grid adjustments, since it were the only actor that had the ability to do so (as an energy distributor in Santiago). The Ministry of Energy also participated, facilitating the different stages linked to increasing capacity, and speeding up the necessary studies and approval processes. A secondary role was also played by the Ministry of Public Works (Ministerio de Obras Públicas, MOP) to increase power for the electric infrastructure of, in this case, Buses Vule's e-depot. The adaptations that had to be made to the distribution grid included building new feeders, which passed through the road infrastructure that is currently the MOP's responsibility.

Furthermore, at this stage a new public actor was included: the Superintendence of Electricity and Fuel (SEC), which was put in charge of the regulations and technical specifications for the construction of e-depots. It also plays a relevant role in terms of the approval for the connection of the terminals to the electric grid and their setup.

Each PPP partners with different bus manufacturers for the provision of e-buses. As previously stated, Metbus with Enel X acquired BYD e-buses for the operation of the pilots and the following implementation of e-buses; meanwhile STP and Vule, together with Engie, did the same process with Yutong e-buses. Finally, the most recent PPP between RedBus and Enel X acquired King Long e-buses, all Chinese bus companies.

In terms of maintenance, the case of the Enel-BYD-Metbus partnership, recognized as the first example in Latin America where a significant number of e-buses were acquired and deployed, works with an after-sales service agreement between Metbus and BYD that makes the fleet manufacturer responsible for electronic maintenance of the e-buses, in addition to the management of spare parts (as in most after-sales contracts). Meanwhile, the maintenance of the bus body is still Metbus's responsibility. Notably, in this case BYD also oversees preventive, corrective, and predictive maintenance, and suffers a reduction in its monthly lease payments if the buses are not charged and available to be used when needed. Under this scheme the operator loses control over maintenance (which has historically been part of its responsibility) and faces higher costs but less risk of penalties for not having the fleet available.

This maintenance contract between Metbus and BYD was not initially offered by the manufacturing company. As an exercise in minimizing the risk of operating this new technology, Metbus based its requirement on a contract that BYD had with another bus company in a different country, and asked for the same conditions. This means that BYD's after-sales services, now offered as its standard, are the result of negotiations during its first-time experience with e-buses in Chile.

In the case of the Engie-Yutong-Vule partnership, as well as for STP, the bus operators oversee maintenance issues, so Yutong has no responsibility other than providing the spare parts. At least for Buses Vule, this is no hurdle for operations, as it has made clear that it wants to oversee maintenance, in order to have full control over the availability of the fleet and to minimize maintenance costs.

The MTT played a key role during the process of planning and regulating the entire transport system, making it a crucial supporting stakeholder for the implementation and adoption of e-buses. Its main tasks had to do with coordination, establishing the technical planning requirements for the services, and negotiating financial adjustments with the bus operators, among others.

Therefore, the negotiation processes for the introduction of the first 200 e-buses to the system were based on an increase in the operational kilometers for Metbus, Vule, and STP. This meant that the state, through the MTT, assumed the increase in capital costs related to the new buses by increasing the monthly payment to the operators, using one of the contracts' existing adjustment mechanisms.

This is different than what happened during the second phase of the introduction of e-buses (183 from Metbus and 25 from RedBus), since these replaced old buses that had reached the end of their lifespan (either by exceeding 12 years of service or 1,000,000 km of operation). Thus, since these fleets required renovation without modifying the operating conditions of the business unit (no additional kilometers), the state did not have to make any payment adjustment—the monthly quote to the companies remained unchanged.

Table 4-6 shows a series of responsibilities and roles, and the new actors that carried them out for each analyzed case study: Enel X–Metbus–BYD association; Engie–Buses Vule and STP–Yutong; and for the latest partnership Enel X–RedBus–King Long–NeoT Capital.

Table 4-6: Responsibilities, roles, and actors within the PPPs

<table>
<tr><th>Responsibilities and roles</th><th>Enel X - Metbus - BYD
Actors</th><th colspan="2">Engie- Vule/STP - Yutong
Actors</th><th colspan="2">Enel X - RedBus -King Long
Actors</th></tr>
<tr><td>Support the first implementation of pilots</td><td colspan="3">Energy companies and bus manufacturers</td><td colspan="2">-</td></tr>
<tr><td>Initial condition of actors</td><td colspan="3">Energy companies (Enel X and Energie)</td><td>Enel X</td><td>RedBus</td></tr>
<tr><td>Financing of e-bus fleet</td><td>Enel X</td><td colspan="2">Engie</td><td colspan="2">NeoT Capital</td></tr>
<tr><td>E-depot construction and charging infrastructure installation</td><td>Enel X</td><td colspan="2">Engie</td><td colspan="2">Enel X</td></tr>
<tr><td>Energy provision</td><td>Enel X</td><td colspan="2">Engie</td><td colspan="2">Enel X</td></tr>
<tr><td>Support the process of change from diesel to electricity</td><td>Enel X</td><td colspan="2">Engie</td><td colspan="2">Enel X</td></tr>
<tr><td>Ensure adequacy of electric networks and power increases</td><td colspan="5">Enel Distribución</td></tr>
<tr><td>Fleet provision and suitability of buses</td><td>BYD</td><td colspan="2">Yutong</td><td colspan="2">King Long</td></tr>
<tr><td>Provision of spare parts</td><td>BYD</td><td colspan="2">Yutong</td><td colspan="2">King Long</td></tr>
<tr><td>Preventive, corrective, and predictive maintenance</td><td>BYD</td><td>Vule</td><td>STP</td><td colspan="2">RedBus</td></tr>
<tr><td>Charging management</td><td>BYD</td><td>Vule</td><td>STP</td><td colspan="2">RedBus</td></tr>
<tr><td>Operation of buses and depots</td><td>Metbus</td><td>Vule</td><td>STP</td><td colspan="2">RedBus</td></tr>
<tr><td>Financing the capital expenditure (CAPEX) of the new fleet</td><td>MTT (first 100) / Metbus (183)</td><td colspan="2">MTT</td><td colspan="2">RedBus</td></tr>
<tr><td>Service planning and regulation</td><td colspan="5">Ministry of Transport and Telecommunications (MTT)</td></tr>
<tr><td>Energy land capacity studies and electric grid modification approvals</td><td colspan="5">Ministry of Energy and Superintendence of Electricity and Fuel (SEC)</td></tr>
<tr><td>Regulation of compliance with e-depots standards</td><td colspan="5">Superintendence of Electricity and Fuel (SEC)</td></tr>
</table>

Source: Fieldwork conducted for the present study in 2019 and 2020.

Considering the above, the actors involved in the process were varied and the roles performed were diverse, allowing the business model to be successful, and proving that there is not only one recipe to follow. One of the significant aspects of the evolution of this business model is the intervention of new actors willing to finance the acquisition of e-buses for a fair price similar to that of the earlier diesel buses, thus overcoming the first barrier that appears when implementing this new technology in public transport systems. Initially, the energy companies provided financing through leasing contracts, but the participation of investors like NeoT Capital changed the scenario. Today, there are new actors investing in the future. Furthermore, Enel X, together with two other partners (after their experiences in Santiago), have recently decided to form a special purpose vehicle (SPV) to finance the acquisition of e-buses for public transport systems in America. This investment fund would allow the current business model to evolve in other cities, boost the business in places where it has already started, and may even lower the rates associated with current financial leasing contracts.

New actors and PPPs are expected to emerge during 2020, particularly for the projected arrival of 365 e-buses that will operate in the Alameda corridor. These new actors will introduce new models and changes in their previously assumed responsibilities, as described in the examples analyzed. This will be further discussed in the report, when presenting the next short-term steps to be taken by the system.

Financial considerations

Before the adoption of e-buses, the fleet investors were usually linked to bus brands. For example, the German bank KfW[46] supported the acquisition of the Mercedes

[46] The KfW, formerly KfW Bankengruppe (banking group), is a German state-owned development bank.

Benz diesel buses operating in Santiago's streets. With the introduction of electric vehicles in the public transport system, this was no longer the case, as the same actors would not finance a business in which they saw new risks. The actors involved in this process had to therefore start a search for new financiers.

Enel X and Engie, two energy companies that wanted to sell their electric infrastructure and energy services to the system, discovered that the national banks were not willing to be part of this new business or assume the associated risks. Therefore, they made the decision to directly finance the purchase of e-buses, and encourage e-mobility by assuming this new responsibility.

Enel X generated three different contracts with Metbus. The first for the acquisition of the fleet, the second for the construction of infrastructure, and the third for the provision of energy. Engie's negotiation with STP and Vule came after and followed the same structure, also including these three contracts but with their own conditions.

The first contract, a financial leasing for the acquisition of the e-buses, was structured in both cases with similar rates as the previous fleet purchases in Santiago, which were between 7 and 8 percent. The objective of both energy companies was not to get a high profit from this contract, but to make the business model viable, transferring these financial costs to the operator through the fleet provision contract. Meanwhile Enel X's contract with Metbus to finance 100 e-buses represented an amount of $30 to $35 million. Engie had to elaborate two contracts, one for the 75 Buses Vule e-buses and another one for the 25 STP e-buses, which together added up to $35 million.

The loan rate of these leasing contracts implicitly considered the new costs associated with this new business that the energy companies were about to assume. This may indicate that international development banks or other institutions whose purpose is to finance these investments could offer a significantly lower rate. Or even more, that new loans assumed by these now experienced companies could offer better prices.

The second financial arrangement is represented in the infrastructure provision contract. As previously stated, this contract was already part of the core business of Enel X and Engie, since they provided services related to energy and energy infrastructure. In this way, even though there were various learnings associated with the process, as with planning grid changes with short deadlines, new technical specifications for the chargers and other elements of the depots, the heavy work of installation, and the tasks associated with the maintenance of the new e-depots, the services offered for providing the infrastructure were equivalent to those of other infrastructure projects previously carried out by the companies.

The last contract between the energy companies and the operators is a power supply contract. This one is different from the other two, as its payment is associated with the consumption of energy. However, this contract follows the same rules as most contracts that energy companies already have with unregulated clients (with energy provision of over 5.000 kW).

Electricity tariffs differ depending on the customer base, which is typically made up of residential, commercial, and industrial connections. E-depots are industrial connections with different rates depending on the time of day. They consider the peak demand for electric power for a consumer, among other factors. For the operators this was a big change, since they had never been faced with an energy provision contract involving this amount of power and these types of conditions. They realized that there are periods of the day, called peaks, during which the cost of electricity is higher, when they can be charged between 20 percent and 25 percent more to charge their buses. This was a significant learning process for the operators, and the energy companies were a key support.

Technology and performance

Performance and autonomy indicators are relevant in deciding which technology, brand, or model of buses to adopt. These factors will impact the different processes related to private operator companies' responsibilities, ranging from the operational tasks inside the depots to the impact on bus operations in the streets. Therefore, it is important to have accurate, comparable, and reliable information, both for the companies and for the state to execute their regulatory responsibilities well.

The Centre for Vehicle Control and Certification (3CV), that operates under the MTT, created a technical laboratory some years ago to certify the characteristics of different types of vehicles operating in Chile, as there is no relevant vehicle manufacturing in the country. At first, the work conducted was related to study factor emissions and technologies, but was soon extended to include certification processes for buses. These initial processes did not include many analyses of emissions and energy efficiency, because they did not have the appropriate technology to do so.

When the system started to include Euro V and VI bus operations, there was no available method to test engine efficiency. This represented a big challenge for the team in charge, who took advantage of previous local knowledge on emissions measurement and started working on a methodology to incorporate a component of energy efficiency within the buses' certification process.

Thus, 3CV took this opportunity to plan a new bidding process for the public transport system and to design a procedure for diesel vehicles that was soon to be adapted for e-buses, changing the concept of consumption for energy efficiency.

Nowadays, the factors considered during the certification process of e-buses include safety, dimensions, type of engine, and energy efficiency. This process is based on testing different vehicles in a specific cycle that aims to represent the average situation and conditions that the buses may face when operating in the streets of Santiago. For defining the test cycle, the information available on the operation of Transantiago buses was key. With these data, the characteristics under which Santiago's public transport buses operate were studied, to define a test cycle that specified speed, acceleration, deceleration, passenger load, and slope. These measurements are today standardized for the introduction of any new bus within the public transport system, and are regulated by a state protocol to obtain the energy consumption of the buses.[47]

It is important to highlight the advantage of performance tests for different types of vehicles with varied characteristics in a controlled laboratory that aims to represent actual street conditions. Since the same test cycle is used for all buses, it allows for a fair comparison of performance, and isolates any other possible impact associated with road conditions or environmental issues.

Following this methodology, the test results that were obtained for different types and brands of e-buses (some of them now operating in Santiago's streets) are shown in table 4-7.

Table 4-7: Test results obtained by the Centre for Vehicles Control and Certification (3CV)

Bus			Engine		Batteries capacity (kWh)	Weight test (kg)	Passengers capacity	Consumption (kWh/km)	Autonomy (km)
Type	Brand	Model	Type	Power (kW)					
B2	**BYD**	**K9 FE**	**Electric**	**300**	**276.5**	**15,495**	**81**	**1.57**	**176.1**
B2	**Yutong**	**ZK6128BEVG**	**Electric**	**215**	**324.4**	**16,250**	**87**	**1.48**	**219.7**
B2	**King Long**	**XMQ 6127G PLUS**	**Electric**	**280**	**374.7**	**17,345**	**90**	**1.74**	**215.0**
B2	Foton	eBus U12 QC	Electric	350	151.5	14,790	90	1.67	90.9
B2	Zhongtong	LCK6122EVG	Electric	350	351.2	16,330	88	1.58	222.3
A1	BYD	K7	Electric	180	156.6	10,802	45	1.13	138.6
A1	Foton	EBus U8,5 QC	Electric	130	129.0	10,592	47	1.24	104.0

Source: Official document obtained from MTT public data. Information for internal combustion engine buses can also be found on the MTT webpage: https://www.mtt.gob.cl/archivos/5597.

The models that are today operating or considered for further inclusion within Transantiago's operations have been highlighted in bold (first three). Table 4-7 thus shows that, for testing under the same conditions and for the same type of buses, there are significant differences between each e-bus brand.

The BYD K9 e-bus engine has greater power than the other two e-buses, which could be an advantage when it comes to operating on roads with pronounced slopes with a greater number of passengers (aside from the fact that it is the lightest model among the three analyzed e-buses). It is followed closely by King Long's XMQ bus, whose engine has 280 kW of power. On the other hand, when analyzing the performance of batteries, the King Long XMQ bus offered a capacity of almost 375 kilowatt hours (kWh), considerably higher than the other two models, followed by the Yutong ZK6 bus with about 325 kWh and the BYD K9 bus with 277 kWh.

In terms of passenger capacity, the King Long XMQ e-bus offers a capacity of 90 passengers—10 percent more than the BYD K9, which has the least space for passengers, not only between these three e-buses but compared with all the B2 models studied.

The average energy consumption is an essential element when selecting a bus technology. Table 4.7 shows that the Yutong e-bus is the most efficient bus, with less than 1.5 kWh per kilometer (kWh/km) traveled, followed by BYD with 1.57 kWh/km and finally King Long with 1.74 kWh/km. These differences may significantly affect the business when it comes to the final calculation of consumption, especially in medium to large transport systems with a high number of operating kilometers.

[47] Available online: https://www.mtt.gob.cl/archivos/5597.

Finally, the level of autonomy of a bus is obtained from the battery's capacity and the average consumption. The Yutong ZK6 is the e-bus with the greatest autonomy—even though it does not present the highest battery capacity, it may reach almost 220 km of autonomy due its low consumption. In second place, we find King Long's XMQ bus with 215 km, and the BYD K9 bus comes last with 176 km during one cycle.

These differences directly affect the operation of buses in the streets. Other key elements that are not measured by this process and should also be included in the analysis will be presented in the next chapter.

Operating conditions of the fleet

The operating conditions for each e-bus service vary significantly depending on the routes they operate. Issues such as the length of the route, the slope, and the road infrastructure conditions make the operational requirements differ significantly. In table 4-8, information about the different routes is presented, in terms of their start and end points, as well as the length of each route.

Table 4-8: E-bus routes

Operator	E-buses services	Starting point	Ending point	Length (each direction)
STP	213e	Puente Alto	Santiago Centro	26.6 km
Vule	I09	Maipú	Santiago Centro	19.0 km
Metbus	506	Peñalolén	Maipú	36.6 km
	507	Peñalolén	Pudahuel	31.2 km
	510	Peñalolén	Maipú	30.0 km
	516	Peñalolén	Maipú	28.7 km
	519	Peñalolén	Santiago Centro	15.8 km
RedBus[a]	C06	Las Condes	Huechuraba	18.5 km

Source: Fieldwork conducted for the present study in 2019 and 2020.
Note: [a]To be implemented during 2020.

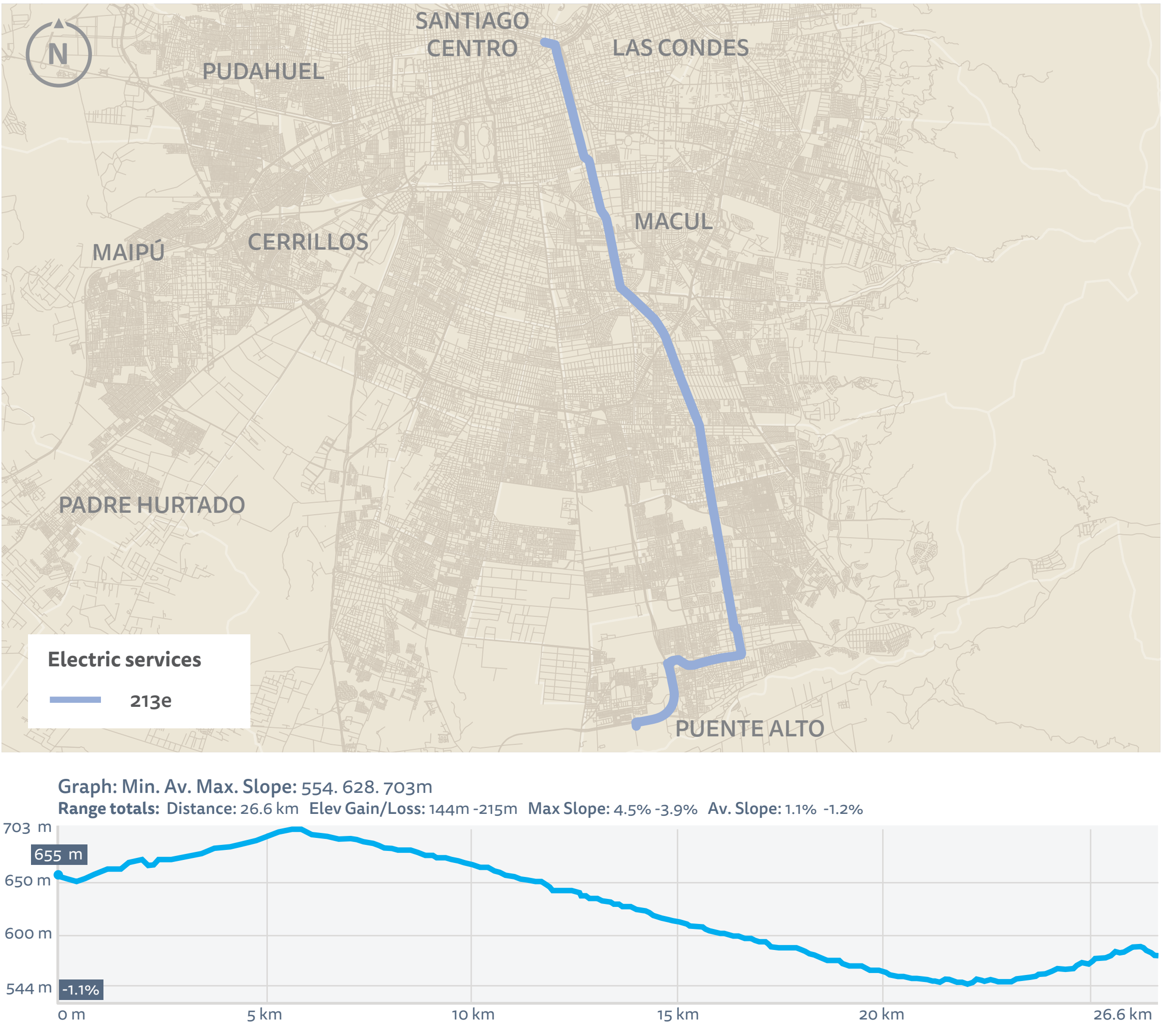
The 213e service operated by STP operates from Puente Alto, in the southeast part of the city, to downtown Santiago. It is a route in high demand during the morning peak hours for people who live in the south and central sectors of Santiago, mostly because a major part of the city's work and commercial activities are concentrated in Santiago Centro.

As can be observed in detail in figure 4-6, the slope within this route varies with an average inclination of -1.2 percent, reaching its lowest at -4.5 percent. In addition, its maximum elevation is 700 meters above sea level (in some points of Puente Alto), with the route ending at an elevation of 550 meters above sea level when arriving downtown.

This route makes use of more than 20 km of segregated road infrastructure for the exclusive operation of public transport. The corridor extension goes from the Concha y Toro Corridor in Puente Alto, passes by the Vicuña Mackenna corridor, and then arrives downtown.

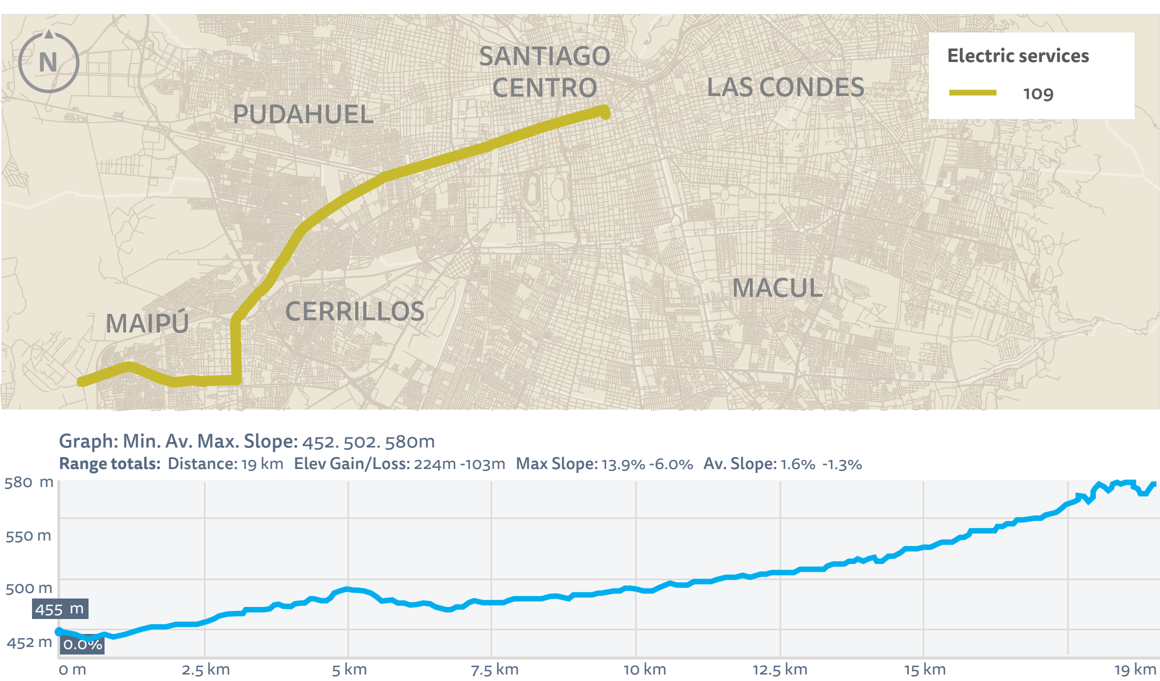
For its part, the Buses Vule I09 service runs 19 km starting in Maipú, going from the west of the city to Santiago Centro. The altitude does not vary more than 150 meters through the route, and it has an average inclination of 1.6 percent. The I09 service operates nearly 5 km in the Pajaritos–Gladys Marín corridor between Américo Vespucio (Maipú) and Manuel Rivas Vicuña (Santiago Centro).

Figure 4-6: 213e route



Sources: Source: Fieldwork conducted for the present study in 2019 and 2020 with Google Earth.

Figure 4-7: 109 route

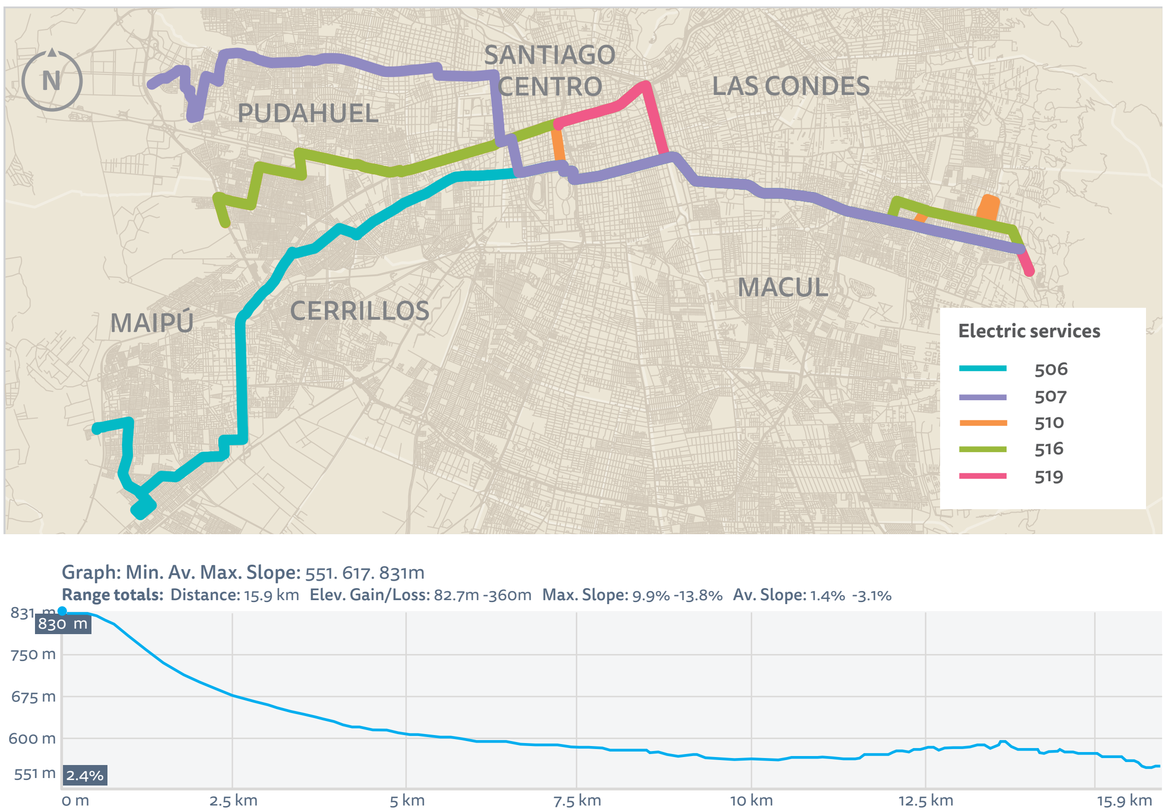


Sources: Fieldwork conducted for the present study in 2019 and 2020 with Google Earth.

For its part, Metbus operates five electrical bus services, which share a large part of their routes with the same starting point in the Peñalolén e-depot. These services go from the east of Santiago, toward the center and the west of the city, depending on the ending point of each service. Along the route, they constantly descend from a height of almost 850 meters to nearly 500 meters in the center of Santiago. The average slope of the route is almost -3.1 percent, reaching its lowest inclination point at -13.8 percent. This unique characteristic of the Metbus e-buses routes must be considered in their batteries' charging strategies, as driving along these slopes through the length of their journeys affects the regeneration process of the batteries significantly.

In addition, these services operate for a large part in the Grecia corridor, a route of more than 15 km that connects the upper sector of Peñalolén with Avenida Matta, in Ñuñoa. Just like the Santa Rosa corridor where the STP buses circulate, this kind of segregated infrastructure allows for minimum interference by other vehicles during bus operations.

Figure 4 8: 506, 507, 510, 516, and 519 routes

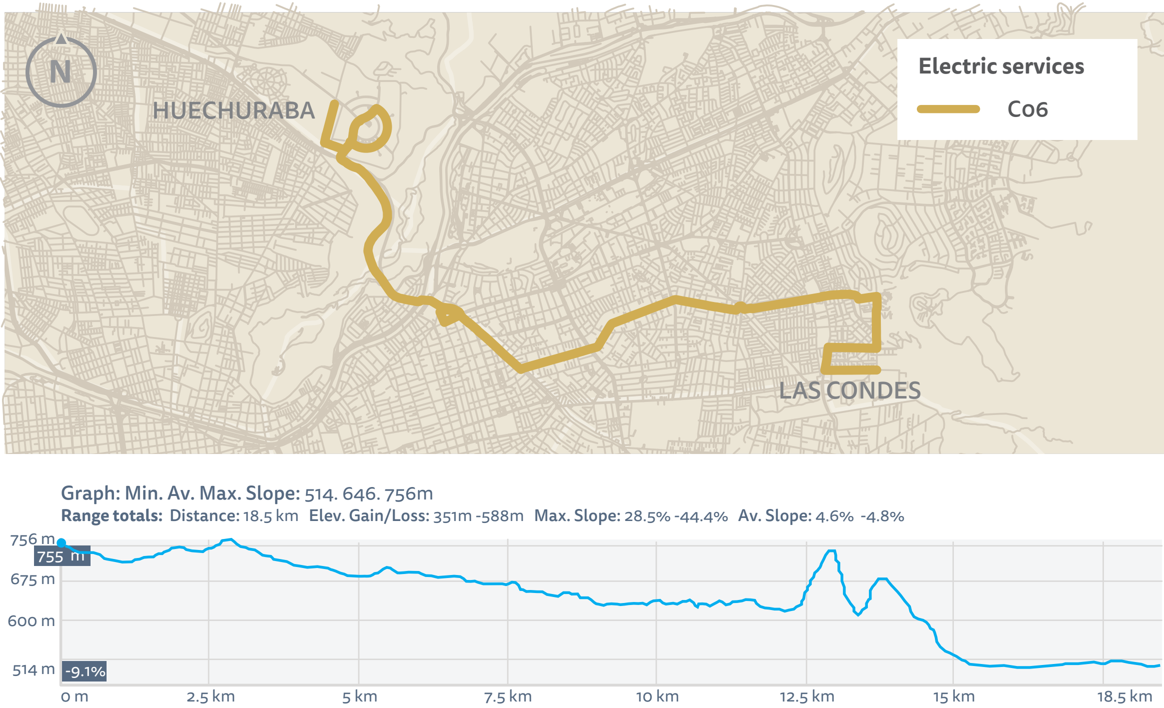


Source: Fieldwork conducted for the present study in 2019 and 2020 with Google Earth.

Finally, during 2020 the RedBus service C06 will operate with King Long's e-buses. This will be one of the shortest electrical services in the system, with less than 19 km of extension. Furthermore, this is the first of eight services that will operate in mixed traffic with no exclusive infrastructure for its operations (such as bus corridors or bus-only lanes).

As regards the slope of this route, the service begins in Las Condes, in the east part of Santiago, which has an altitude of 755 meters, and starts its descent until it arrives at Huechuraba, the ending point of the service in the northeast of Santiago. During its journey, the service faces an average inclination of -4.8 percent, with the lowest at -44 percent when it descends the San Cristóbal hill (an area known as "La Pirámide"). This high elevation point can be observed clearly in figure 4-9 and represents the highest slope that an e-bus operating in Transantiago has had to face (followed by Metbus services operating in Av. Grecia).

Figure 4 9: C06 route



Sources: Source: Fieldwork conducted for the present study in 2019 and 2020 with Google Earth.

Enablers for the adoption of e-buses

As a synopsis, this section will discuss the main enablers that allowed the adoption of e-buses in the city of Santiago, Chile.

Pilots and bus certifications

The pilots conducted in Santiago's streets were key to understanding and embracing this new technology as a real opportunity. They allowed for the buses to adapt to the characteristics and standards of the streets of Santiago and the existing services where they would operate. They also offered important insights into the implementation of a strong certification process for the buses, which was the responsibility of the Ministry of Transport through the 3CV agency, which developed a methodology for testing different characteristics of e-buses that were not tested for diesel buses.

End of contracts and cancelled bidding process

The fact that most concession contracts between the state and operators were near their end provided an opportunity for the transfer of some bus services from one company to another (increasing the second company's operating kilometers), and for the renewal of the existing fleet after more than 10 years of operation. These conditions enabled the beginning of negotiations for introducing e-buses.

Also, the cancelled bidding process at the beginning of 2018, which established a minimum of 15 clean buses for each business unit, prepared the context for negotiations between bus manufacturers, energy companies (as financiers), and bus operators, allowing for a focus on the implementation of the current e-bus fleet beyond any bidding processes.

Government priority: Flexibility in electric analyses and depot construction times

Santiago's public transport system—Transantiago—had been characterized by several problems since its launch (Muñoz and Gschwender, 2008; Hidalgo and Graftieaux, 2007). When the government sought to reform the system, one of the first measures taken by the MTT was to change the system's name from Transantiago to Red, while also making deep changes to the system's business model and raising the standards of the bus fleet. As a consequence, a fleet of 490 Euro VI diesel buses and more than 400 e-buses recently joined the system, resulting in almost 1,000 buses meeting the new Red standard in 2019.

Santiago would not have hundreds of e-buses in its streets if their introduction had not been one of the government's priorities. The actions of both the government and the DTPM have been crucial as catalysts and enablers for the adoption of e-buses and the implementation of e-mobility in the public transport system.

Chinese market development

The development of the e-bus market has been driven almost exclusively by Chinese manufacturing. Since the Chinese government's decision to adopt e-buses to combat pollution in their cities and foreign energy dependence, the growth of this technology in China's bus market has been remarkable.

According to Bloomberg New Energy Finance, in 2017, 99 percent of the world's 385,000 e-buses were operating in China, all manufactured locally. At the end of that same year, the city of Shenzhen made its 16,000 buses electric, reducing particulate matter emissions.

In this way, Chinese manufacturers began their expansion into other markets. Yutong and BYD entered the Chilean bus market with more than 100 e-buses each. For its part, in 2020, King Long will be launching 25 more e-buses. Other Chinese manufacturers, like Foton, have shown interest in the business model scheme and the new bidding process. The entrance of these various actors has forced manufacturers to improve their offers in Chile (in prices and additional after-sales services), making e-buses even more competitive compared to traditional diesel buses.

Chile's Free Trade agreements

As previously discussed, the Chilean state's policy on international trade is to generate open markets. This has been achieved through a series of free trade agreements (one of them with China) that allows the free transit of products with no import custom duties. This has facilitated the entry of e-buses at no additional cost, supporting public transit with new technologies.

However, this type of policy is not uniform in Latin America. Unlike Chile, other countries in the region, like Argentina, Brazil, or Mexico, have imposed fees on imported buses to protect local manufacturing. This has been a constraint to accessing new bus technologies in these countries.

Electrical companies as investors

One of the key factors in the adoption of e-buses has been the role played by Enel and Engie. As both firms have a consolidated business that allows them to take financial responsibility without great risk, they offered to invest through the purchase of e-buses.

Despite it being outside their core business area, Enel X and Engie have delivered fleets for operation through a financial leasing contract with each operator. The selling of associated services (such as the construction of e-depots, e-bus charging management, and the associated energy) has brought them revenues, generating a new business space for them.

Neither traditional Chilean nor international banks were open to financing this type of technology, highlighting the key role of Enel and Engie in the early introduction of e-buses in Chile.

Low financial risk of the country

A fundamental characteristic of Chile was its low financial risk, an element that was key for companies like Enel and Engie when making the decision to invest in this new business. As previously discussed, Chile's political, economic, and financial stability rating at that time was A, and it had favorable financial risk ratings in Fitch's, Moody's, and S&P rankings. These evaluations demonstrated Chile's strong ability to uphold financial agreements, offering a favorable business environment, which lowered uncertainty costs.

Contract characteristics

Another attribute that facilitated the participation of Enel and Engie was the assurance offered by the state on payments. The lease payment is given directly to the financier (in this case Enel or Engie), through a payment release tool signed by the operators. This allowed electric companies to reduce the risk of nonpayment due to any difficulties the bus operator company might have.

Another feature that encouraged electricity companies to enter this business was the certainty of business continuity for at least 10 years. The state of Chile signed provision contracts that assured the financiers that, regardless of the future of the bus operators, the fleet would stay in the system and debts would be paid completely. This, in addition to the country's low financial risk, gave Enel and Engie the opportunity to do business with low risk.

Key elements for e-buses implementation

The business models observed in Santiago feature several key elements (discussed below) that might be considered in any successful e-fleet implementation.

E-buses

The implementation of an e-fleet introduces new challenges. The capabilities and performance of e-buses available in the market differ among providers, in terms of the technologies used and the performance of the buses on the street.

Battery capability and the distance that can be travelled between charges are the key elements of e-bus performance. Battery capabilities can differ among bus manufacturers, which can help an operator decide whether to choose one bus type over a competitor.

The degree to which batteries can be charged through braking is also a key element of bus performance. Some buses allow recharging only during deep braking, while others allow recharging of the battery every time the brake is applied, depending on how the bus's control modules are designed. Also, the chemical composition of the batteries may influence the degree of energy lost during operation.

To optimize recharging, charging management software charges the batteries to 97 percent of their capacity, so that the bus starts its recharging process from the time it starts. However, the batteries do need to be charged to their limit on occasion, to balance the battery cells.

E-buses might also need custom modifications, or specifications for operation in a particular city. In the case of Santiago, the specifications had to be changed during the manufacturing of the requested fleet. Road characteristics might influence decisions on speed and acceleration limits,[48] the vehicle body material (steel or aluminum), the brake system, or the welding and anchoring, among others.

Another relevant issue to consider is the range of the bus in a real operational situation. Bus manufacturers undertake simulations in their test facilities that put buses in stress situations in order to measure the maximum range of the battery and other performance indicators. Even though the input from these simulations is relevant, pilots are key for testing the actual battery range in the "real world." Bus operators in Chile have highlighted the importance of the first e-bus pilots for estimating performance indicators in real situations, to obtain real-life figures for business analysis, particularly in terms of autonomy and efficiency.

In cities where there are many hills along the bus routes, it is important to design the services considering not only the capability of the bus to climb the hill, but also the maximum number of people that the bus can carry without compromising performance. This may also vary within brands of e-buses depending on the bus design. In these cases, it is relevant to consider tests and measurements of the design.

Spare parts are another relevant issue to consider. First, the bus manufacturer should ensure the timely availability of spare parts to operate the bus fleet effectively. Also, the manufacturing characteristics of the bus might include different levels of flexibility among manufacturers, mainly in terms of the possibility of using alternative spare parts, which can be a significant issue when estimating corrective maintenance expenses.

This leads on to the level of guarantees each manufacturer offers for its vehicles. This will depend on the contract the bus operator company has with the brand, in terms of the responsibilities specified for each part. Generally, the guarantees can be separated into different categories:

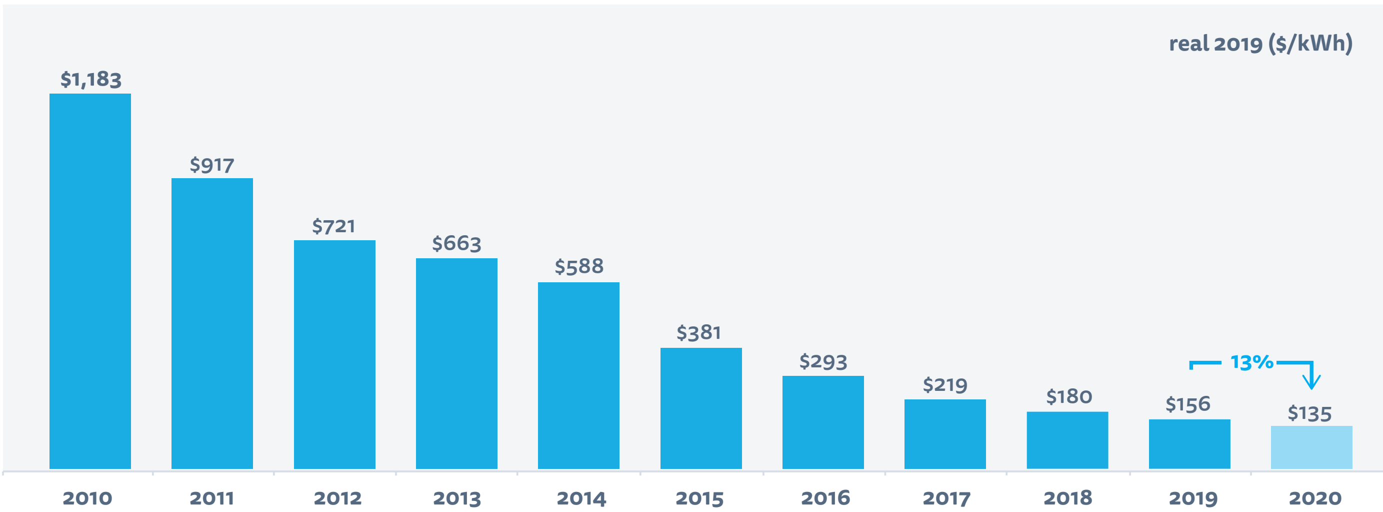
- Products with alternative spare parts, like the seats and tires of the bus. Most of the time, no guarantee is offered in these cases.

[48] Buses Vule requested a 52 km speed limit, and a 5 km speed limit in reverse

- Products that can be certified by the brand in charge of the construction of the bus component, or technology that is owned by the brand, like control modules and electric engines. These are often included in the guarantees offered by the manufacturer. As an example, in the case of the Yutong and King Long vehicles, CATL[49] is the Chinese company specializing in battery manufacture, whereas BYD supplies its own batteries (Bloomberg New Energy Finance, 2018).

Most of the battery guarantees are offered for a period of 7–8 years or nearly 600,000 km (due to battery lifetime expectations). Some manufacturers offer a 10-year guarantee (or 800,000 km) based on the belief that technology will get better or cheaper during this time.

Figure 4-10: Lithium-ion battery price—volume-weighted average



Source: Bloomberg New Energy Finance, 2020

Over the last 10 years the price of batteries has reduced considerably, by 88 percent between 2010 and 2020, and is expected to fall even further over the coming years, reaching an estimated price below $100/kWh by 2024 (Bloomberg New Energy Finance, 2020).

A battery's lifetime of 7 years assumes a reduction of power from 324 kW to 226 kW (over the period of the guarantee), according to one of the manufacturers interviewed. The body of the bus is guaranteed for an estimated 14–15 years (or 1 million kilometers) and the engine for 5 years, and the manufacturer guarantees the chassis of the bus for 2–3 years.

One issue that was highlighted by most of the interviewees is the lack of any real solution for the disposal of batteries. Even though there is literature about recycling or the secondary use of the batteries, to date there are no real examples and the issue has not been included in any of the analysis done by either the government or the companies involved. Second-life storage projects may use e-bus batteries in stationary storage applications, with a lower estimated cost than the price of new batteries of around $49/kWh (Bloomberg New Energy Finance, 2018).

Because of all the above factors, there are different timings associated with each stage of the process. Manufacturing the buses correctly, compliance with regulations, the on-time delivery of the buses, and the availability to start operating are some of the issues to be considered when planning the implementation of an e-bus fleet.

In the case of Santiago, the stakeholders interviewed highlight that the implementation and approval times were shortened in order to have everything ready on time. Various interviewees mentioned that the government's initiative was key for keeping to the schedule.

E-depots

At the end of 2019, Santiago had seven depots with electric charging facilities (e-depots). The first two were constructed by Enel in the existing Metbus depots to receive the first 100 e-buses. After that, STP and Buses Vule prepared their depots for the next 100 e-buses. The needed charging infrastructure was constructed by Engie as part of its agreement. The list of current e-depots is

[49] Contemporary Amperex Technology Co. Limited (CATL).

shown in table 4-9.

Table 4-9: E-depots in Santiago

Company	Location	Number of chargers	Charger Power (kW)	Connector of the charger
Metbus	Maipú	35	80	2 Type2 AC
Metbus	Peñalolén	61	80	2 Type2 AC
Buses Vule	Maipú	37	150	2 DC GB/T
STP	Puente Alto	13	150	2 DC GB/T

Figure 4-11: Map of e-depots

Source: Research conducted for the present study in 2019

Source: Interviews conducted for the present study in 2019

For the arrival of 183 additional e-buses, Metbus has started the construction of three more e-depots. Also, one of the Metbus depots has become completely electrical (with no diesel infrastructure) and uses solar panels for the generation of energy to charge the e-buses.

Some relevant issues need to be considered during the construction of charging infrastructure in depots. Even though there is enough electricity generation in Chile to power all the e-depots necessary for the replacement of the entire bus fleet with electric technology, it is important to plan when to expand this electricity consumption. The period for the planned energy consumption should be considered carefully as the system could collapse if it exceeds the set limits for a short period or used an unplanned amount of energy (there may be bottlenecks in terms of peak power [MW] in certain parts of the distribution grid such as substations and transformers). In the case of Santiago, the increase in energy requirements did not reach that limit, but did exceed the margin planned, so this issue was relevant when interviewing the state energy regulators.

Another highlight of Santiago's experience with e-buses is the management of charging. The cost of electricity is not the same throughout the day: there are hours when demand increases (or supply decreases) and the prices rise. Therefore, it is essential to know what time of day to charge to achieve savings that are beneficial for the system. Charge management software can thus make relevant contributions to the system, because it can plan when and when not to charge, restricting the charging during no-charging periods.

Smart charging also balances demand, so that ten buses could be charged using only as much power as five buses, by switching charging between buses very quickly. This means that the estimate of the number of e-depots required to equip the entire bus fleet with electric technology should consider when the buses will be charged. For example, there may not be local grid capacity to charge all buses at the same time, but smart charging would help to manage the charging of all buses with the power available in the grid.

In addition, the energy capacity of the land where the e-depot will be built must be considered. The energy required for an electrical depot exceeds the usual requirements of any other type of construction. Studies of the potential of each existing depot to include energy-charging infrastructure are the first step. This, in turn, depends on projections for the growth of e-mobility.

This process of analysis and authorization can take several months, even years, and can be costly. Decisive action from the authority, or changes in the regulatory aspects of the processes, could help to speed up approval and study times. Inadequate planning often makes it necessary to request additional energy capacity from the relevant entity, usually the energy distribution company.

The Superintendence of Electricity and Fuel (SEC) set regulations for the consumption of energy and for distinguishing between domestic and industrial consumption of electricity. These two control mechanisms impose special requirements for the construction of charging infrastructure in a depot. In Santiago, the first e-depot was built by Enel, which became aware of these requirements only after starting the planning and construction of the chargers. Since it had to include new elements in the original design of the charging infrastructure, construction costs rose. The case of Engie is different, as it requested assistance from the regulatory entity before starting to design the e-depot, which allowed it to develop high-quality facilities more easily.

The relationship between how much power capacity to install in the depot and the power requirements and number of chargers needed is another relevant subject that should be addressed in the design and engineering of charging infrastructure in depots. For example, when Enel installed the chargers in the first Metbus depots, the number of chargers was more than required for the number of e-buses operating. However, when it added more e-buses to its operations, it did not have to build more infrastructure, making this a one-time investment.

The time that it takes to charge the e-buses will depend on the type of charging infrastructure used. Overnight charging at the depot using a traditional plug-in slow charger of 15–22 kW can charge an e-bus in around 10 hours. Chargers installed in Santiago range from 80 to 150 kW, as shown in table 4-9.

Table 4-10: Traditional plug-in charging speed and times

Charging speed	Time
Slow charging (15-22 kW)	10 hours
Fast (22-50 kW) and Rapid (50-120 kW) charging	2-6 hours

Source: Bloomberg New Energy Finance, 2018

The technology of the bus, whether it has an AC or DC connection, will determine the technology of the charging infrastructure. This opens a debate on whether interoperability is a relevant issue to be considered in the planning and design process. As Santiago works with a concession model where companies charge and operate their buses in their own depots, there should not be any problem if the Metbus and STP/Vule e-buses use different technologies for their chargers (DC vs AC, both Chinese technology), but when using any other concession model, interoperability is a relevant subject that should be considered.

Another key issue for the proper functioning of e-depots is the periodic maintenance of the charging infrastructure to protect it from electrical, electronic, and computational issues. Maintenance should be performed in a planned manner, as it is for the e-depots in Santiago, where it is carried out by the energy companies (e.g., Engie performs maintenance of its chargers every six months).

Fast charging (with pantographs) has not been considered for the operation of e-buses in Santiago, because of the high infrastructure cost. Besides, the current e-bus services do not need to be charged along their routes because their current range is enough to cover their daily operations, so the system was designed to use slow overnight charging.

New renewable energy technologies such as solar panels are being considered for inclusion in new e-depots, with disused (second-life) bus batteries providing energy storage for solar-generated electricity. This ensures a complete renewable energy cycle, with green technologies being used for both the generation and storage of energy.

Energy companies may generate clean energy certificates for operators that guarantee the use of renewable energies for the provision of electricity in their e-depots. However, there is no clear way to trace this in the energy generation process.

Another innovation in the charging process is the idea of returning the unused energy from the buses back to the system on completion of their daily operations. This could generate a new business for the bus operators as they could sell energy back to the electricity distribution companies (in Santiago's case, Enel).

Planning and operation

The planning related to the adoption of e-buses is a key element to ensure proper operation of the buses on the streets.

The selection of the service where the e-fleet will operate is the first step in the planning process. The following were highlighted by several interviewees as relevant elements of that step:

- Number of passengers associated with the operation (validations per day), as an indicator of the relevance the service has within the system.
- Operating kilometers per day, in order to guarantee the battery's autonomy is enough to cover the full operation of the service.
- Location and feasibility of the depot associated with the service.
- Public visibility of the service.
- Degree of vandalism (services with low vandalism levels were prioritized).

Table 4-11 lists e-bus design specifications related to their battery its performance in Santiago.

Table 4-11: Battery's design and performance specifications

Item	Range
Autonomies	250-400 km
Batteries Size	290-350 kWh
Batteries guarantees	5-10 years / the equivalent in number or cycles
Average consumption	0,85 – 0,95 km/kW

Source: Interviews conducted for this study and Bloomberg New Energy Finance (2018).

Note: Bands presented were constructed with the performances of different e-buses operating in Santiago (Yutong and BYD), and with different route characteristics.

Another relevant issue to consider is how and when to charge. Charging management, particularly smart charging, is important not only to estimate the necessary power of the depot, but also to guarantee the availability of buses for operations. As explained before, the first restriction is not to charge during hours when prices are high due to increase in demand. The kilowatts of the chargers will determine how fast the buses can be charged, and provide relevant input to estimate the number of chargers needed and to organize the overnight charging of the buses.

The replacement of the existing fleet with e-buses brings challenges during the modification of the operational plans of each service involved. E-buses have less capacity for passengers than do the equivalent 12-meter diesel buses, so, to maintain the capacity of the service, its frequency needs to be increased. Also, to meet the same demand requirements, the service would need more buses than before.

Problems arise when the original frequency/capacity of the service is so high that it is not possible to add enough e-buses to supply that demand. This may also happen when a service considers replacing articulated buses with 12-meter e-buses, which is particularly relevant in Santiago as many routes need to be covered by buses with high capacity. Nevertheless, this can be managed with the inclusion of short services to redistribute the supply in sections of greater demand.

The gradual inclusion of e-buses means that a new system coexists with the old one. This reality brings new challenges regarding fleet management due to the inclusion of new elements and the different requirements e-buses have versus diesel ones. The need for electric charging and different limits on autonomy, among others, are the reasons why e-buses must be associated with a specific service (or depot). This decreases the flexibility to reassign buses to services in need of immediate operation and may increase the need for backup fleets of each technology type.

In terms of road infrastructure, Santiago has reserved segregated lanes or closed corridors for e-bus services to minimize their interference with other vehicles and to ease operations. Another important aspect of the routes is the slope of the road, as climbing a hill may imply energy losses that affect autonomy and might limit the operations.

Human resources

Human resources are among the key requirements for efficient operation of a fleet of e-buses, as the training of workers on this new technology will be essential to achieve savings in operation and maintenance.

One of the processes to be learned is the charging of batteries. Charging in the wrong way can damage the battery, which would lead to problems in bus availability and high repair costs. In addition, the optimum charge level will vary depending on the operation, the location of the e-depot, the type of charge, and other factors, which must be fully understood by the operator and the personnel in charge. The driver must also be trained in capabilities such as how to manage the recovery of energy during braking, use of the on-board computer, and internal operation of the bus.

The technical teams in charge of defining the operation must also be prepared for the transition to e-buses. The issues to be considered by the regulatory entity will change, as there will be specifications related to charging times, maintenance, and bus capacity. In addition, restrictions regarding the installation of depots near residential areas could change, due to lower levels of noise and pollution. The regulator will need to understand these changes and consider them when planning the operation.

The training of maintenance workers is also a key aspect to be considered. E-buses, compared to diesel buses, have engines that are simpler in some ways, although they contain more computational elements. These issues imply a different type of maintenance than that required by internal combustion engines. Furthermore, the charging infrastructure also needs to be maintained and repaired.

Educational institutions must adapt when facing these new challenges and will need to start teaching these new technical skills. That has already been happening in Chile, where educational centers (such as Duoc UC)[50] have begun to prepare future professionals for the maintenance of e-buses. Constant communication between the relevant government departments and educational institutions will be essential so that classes and courses can be developed and adapted to the meet the new challenges of electrical mobility.

Next steps

Short-term projections for e-mobility in Santiago

As mentioned in chapter 5, RedBus will be operating 25 new e-buses by the end of 2020. These buses correspond to partnerships of RedBus with different companies that offer independent solutions for fleet provision, charging provision, and electric infrastructure for the depot.

An interesting feature of this business model is that RedBus has its own solution for financing the different elements (fleet, charging, and electric infrastructure provision) with NeoT Capital, an investor specialized in renewable energy and e-mobility services. This arrangement gave it the flexibility to choose different solutions for each technical element, without many of the restrictions that might have been included had the provision of finance been linked to a specific set of technological options. For example, it expects to make a bid for the purchase of energy after the construction of the depot, as it paid Enel only for installing the electric infrastructure, in contrast with past experiences in Santiago in which deals were made for the electric infrastructure, chargers, and energy all together.

RedBus' technical solution for fleet provision is King Long's e-buses. It chose this Chinese company because of its history in providing diesel buses to other cities around the world. Based on the international experience that RedBus has through Transdev's worldwide operations, it declared that King Long offers a high standard of vehicles.

For charging, RedBus partnered with ABB, a company that offers Internet-based electric-vehicle-charging infrastructure. This European technology for chargers involves a DC connection with flexibility to shift from 50 to 150 kW of power, emulating fast charging when needed. Unlike the previous DC charger, which has a lifetime of approximately 5 years and is used by Buses Vule within its depots, these ABB chargers may last up to 10 years. Nevertheless, they cost almost twice the price of the previously installed Buses Vule and STP chargers.

As for maintenance, RedBus decided to train its own personnel with technical assistance from the manufacturer of the bus and the charging technology provider. When interviewed, the RedBus representative highlighted the importance of drivers for the correct operation of e-buses, which justifies training them appropriately. Training will be provided by King Long and ABB.

Another project that has been confirmed and is due at the end of the Express company's contract with the government is the Alameda project. The state has negotiated with the existing bus operators to transfer to them the operating kilometers of Express, increasing their business with the operation of new bus technologies such as diesel Euro VI and electric buses.

[50] Chilean professional institute.
[51] The Chilean company of Transdev, a French-based international bus operator.

For this project, it is expected that 50 diesel Euro VI and 150 extra e-buses will be operated by Metbus, while STP would be increasing its fleet with 215 extra e-buses, all starting their operation in April 2020. With this, the public transport system of Santiago would include almost 800 e-buses.

The business models will be different for each PPP. Enel has been clear on its position of not financing new e-buses; it will only participate in an SPV,[52] as its core business is providing energy and infrastructure, not buses. It is expected that new actors will be included in this second stage of the implementation of e-fleets, such as local and international banks for investment in buses and/or infrastructure CAPEX.

One actor that has already been confirmed is COPEC.[53] Even though the company has been historically linked to sales and distribution within the petroleum industry, during the past three years it has been conducting a process of expansion to include e-mobility services within its business. This idea, initially thought of as a long-term process, grew stronger with time until the company decided to expand and adapt its business to these new emerging technologies. This led to a new working area inside the company focused on e-mobility, that started with applied research and networking with the stakeholders involved in the business. Two main elements supported this process: the high visibility of the company's services at the national level and a strong focus on client needs. Its new approach to mobility is being addressed with different applications: service stations, residential solutions, public chargers, and industrial solutions (such as vehicle fleets).

This new area within COPEC presents differences not only in terms of the scope but also in terms of the flexibility in methodologies used for the evaluation of projects to adapt to e-mobility's fast-changing market. Because of these special working characteristics, after approximately one year, the company decided to move this team, at that time working inside the Development Division, to create a new subsidiary company: an independent company adapted to these new business requirements with more flexibility but still associated with the sales force, operational facilities, and client relations of COPEC.

The main challenge for COPEC is to compete with companies that generate energy as part of their business, as COPEC has to resell packages of energy previously purchased, which may translate into higher costs of energy. Nevertheless, this can be compensated in many other ways as part of the financial solution offered.

During interviews held with company representatives, the fact that the client was well known from before was cited as a major advantage. In the case of Transantiago, since COPEC was already involved in the provision of fuel and lubricants, this new area was considered part of the process of adapting the business to the client's needs.

Nevertheless, COPEC did this by building a SPV with international partners for the financing of the fleet, as it could reduce its risk significantly if it took on a smaller part of the investment. This would also translate into more competitive loan rates, as credit would be offered by an actor that had already participated in this kind of business, and the rate would not include the uncertainty of new investors.

The leasing includes the depot as charging infrastructure and represents between 5 and 10 percent of the total cost of the business. However, COPEC's business focus is on selling energy, software for charging management, and maintenance of the charging infrastructure. Other possible services, such as the integration of a fleet management system to the management of the charging, are still under evaluation.

It is important to mention that the construction of this new e-depot represents a big challenge, not only because it will be the first constructed and installed by COPEC, but also because it is expected to be the biggest in Latam. While Vule's e-depot was constructed with a power capacity of 6 MW for 75 buses, this new e-depot would have a capacity of 9 MW to charge 215 e-buses, with the proportion of chargers and buses being 1 is to 4. However, this would introduce significant challenges in the charging management of the buses.

E-mobility context in other cities in Chile

Besides Santiago, the government has focused efforts on bringing e-mobility to other cities in Chile. Authorities have announced that Temuco and Concepción will be the next cities to include e-buses in their public transport fleets.

Concepción (which groups several municipalities) is the second-largest city in Chile, with approximately 1 million inhabitants. For its part, Temuco city (also known as Gran Temuco) is the sixth-largest urban agglomeration in the country, with more than 300,000 inhabitants.

Both cities are situated in the southern part of the country and are expected to add e-buses to their fleets during the year 2020. Information on the magnitude, routes, and characteristics of the services is scarce; however, it is planned that 25 e-buses will be arriving in Concepción. There is less information on Temuco, but intentions are to electrify a service that circulates through the city center. Additionally, there are other cities under study, such as Antofagasta, where less progress has been made.

The financing of the fleet is expected to be covered through regional funds obtained by the law called "Ley Espejo." This law gives the regions of the country, apart from the Metropolitan Region, the equivalent amount of

[52] A subsidiary of different companies created to isolate financial risk.
[53] National marketer and distributor of fuels and lubricants.

money spent for Red Metropolitana de Movilidad. With this, the state's subsidy for Santiago's public transport system is twice the cost of the system for the state, as half of it goes to the other regions.

Each regional government owns part of the amount obtained through the Ley Espejo, and depends on a regional council to approve the spending of those funds. The provision of energy, charging infrastructure, maintenance of the buses and the depot, as well as training for bus drivers, are all expected to be covered by these funds, with the council's approval.

The implementation of priority infrastructure for e-buses, high-standard bus stops, and inspection cameras, among other components, are expected to be financed by both the central and regional governments.

A particularity of this model is that the initial services that will be implemented in Concepción and Temuco might use the stations of Ferrocarriles del Estado (EFE, a public rail service company) as depots and their electrical power for the charging of the e-buses. This would enable faster implementation as there is no need to add any extra power to the grid but only the charging infrastructure.

These electric services will operate with smart cards associated with an electronic payment system, which denotes a big change in comparison with the current cash payment directly to the bus driver.

Among the main problems faced by the government in raising the standard of buses in other cities in Chile is the atomization of operators. In contrast to what happens in Santiago, in the rest of the country it is usual to have public transport systems operated by various small firms, with their associated small fleets, in a context of low regulation by the authorities. This atomization of the system makes it difficult to coordinate with the actors to agree on conditions for the provision of e-fleets and reduces the guarantees for the government that the buses will be operated properly.

Another barrier to e-mobility in other cities in Chile is the risk aversion of the current bus operators. Historically, the operators have opposed a series of transformations of the public transport system, arguing that they may be drastically affected. This has not been different in the case of introducing e-buses, mainly due to the high investment costs. If it is not possible to involve bus operators from the beginning by showing them the benefits of this measure, their risk aversion can be a barrier to the successful implementation of this policy.

The coexistence of two systems (diesel buses and e-buses) is another challenge to the implementation of this new technology. This implies a complex task for citizens as they will have to adapt to different standards, characteristics, and information when using the public transport system. In addition, some of the new e-buses will have to be paid with a smart card unlike the rest of the services, which would add more complexity for users planning their trips.

The inclusion of new actors in the current transport business model, such as the regional government and EFE, may also be challenging. If a greater number of actors are involved in the process of implementation, it may complicate the coordination and agreements between stakeholders. Besides, the fact that they do not have experience in the fleet renewal businesses may slow the process down or increase the risk of failure—elements that must be considered when expanding Santiago's experience with e-mobility.

Bidding process

After the cancellation of the bidding process in March 2018, the current government set out the objective of generating a new tender in 2019 that would allow contracts to be shorter and more flexible. The government defined objectives, such as separating bus operations from fleet provision in different tender processes in order to facilitate operational continuity. With this new structure, the state makes it possible to switch an operating company without the impact of losing the bus fleet, as could happen in the integral scheme.

However, notwithstanding the efforts of the authorities, the basis for this new bidding process has only recently been approved (by the end of May 2020), and only for fleet provision (the first phase of the process).

Thus, the state will have two types of contracts with independent companies. The first is a bus operation contract, which aims to provide urban bus transport in the city of Santiago. This contract will be based on kilometers operated, number of passengers, and the quality of service offered. The service quality indicators will be linked to aspects such as the fulfillment of the schedule and compliance with standards related to frequency, quality of user service, stops, and bus conditions, among others.

The second type of contract is a fleet provision contract. This will aim to supply the system with buses and their respective guarantees. In addition, the fleet provider must certify the maintenance of the buses. A monthly fee to the provider is intended to pay for the investment and the provision of buses to the system. The fleet supplier is expected to be a SPV, so that the balances of this firm can be linked only to fleet provision and not to other activities carried out by the parent company, such as energy supply. The contract will be extended for 10 years for diesel buses and 14 years for a fleet of electric vehicles, including a battery replacement during the contract period.

Fleet maintenance has been defined as the responsibility of the operator, so that it internally manages any trade-off between operation and maintenance. The operator directly carries out the maintenance of the buses, since it can hire another firm to do this work. Given this, it would be possible to replicate the current relationship between

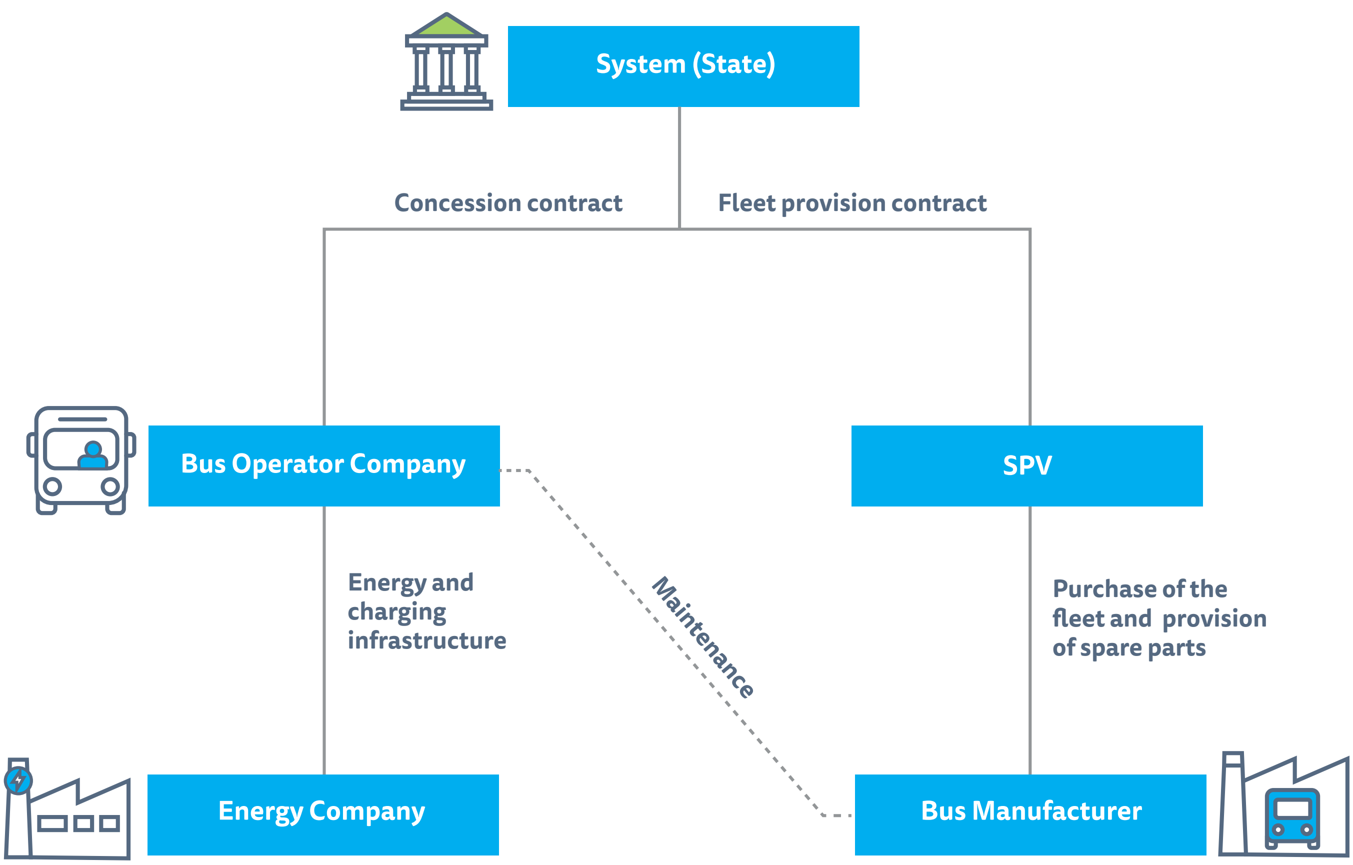
Metbus and BYD, in which the bus manufacturer performs the maintenance process and the operator only provides the service, but the bus manufacturer does not have the obligation of being part of that process.

Therefore, the bus operator is required to conduct an independent periodic certification process through a third party, that needs to be approved by the bus manufacturer. This provides an extra level of security so that the fleet provider is informed of the condition of the buses regardless of the operating company that is selected or is operating the buses. This would allow for one of the main objectives of the authority, that is, to shorten the duration of operating contracts to 5 years, or 7 years if the fleet proposed has a share of e-buses greater than 50 percent. This contract will be extendable to 10 or 14 years (associated with the fleet's technology proportion) depending on the quality of the service, thus generating incentives for the operators. If not extended, the buses will be part of the concession and passed to the next bus operator.

Finally, the bus operator is expected to sign a contract with a private company that provides fuel or energy. In the case of a fleet of e-buses, the bus operator seeks to establish a relationship with an energy company, which will give it energy and charging infrastructure.

Figure 4-12 schematizes the relationships that the new bidding process expects to generate.

Figure 4-12: Organizational diagram of actors' interrelations in the new bidding process for an e-bus fleet



Source: Fieldwork conducted for the present study in 2019.
Note: SPV = special purpose vehicle.

With the above, the different models used to finance, acquire, operate, and maintain e-buses in Santiago may continue to be employed, but this scheme has characteristics that will change the incentives and motivations of the actors, now that there is a direct contract with the bus provider and new conditions for the bus operators. Following is an analysis of the different issues associated with the new system, in terms of the promotion of new technologies, maintenance risk allocation, an allowance for greater competition, and greater operational flexibility.

How does this structure promote new technologies?

According to the DTPM, the new structure considered in the bid aims to give every applicant the same treatment; that is, it does not give preference to one type of technology versus the other, or the old system operators versus the new ones. In particular, in the case of e-mobility, more than incentives, there are some factors that seek to level the playing field for the different technologies to compete under the same conditions.

The first of these is to offer a longer-term contract for a supplier of an e-fleet than a diesel fleet. In particular, the state promises the e-fleet provider that its buses will be in the system for 14 years, instead of 10 years as is the case for diesel vehicles. As much as this may be seen a natural incentive for the introduction of e-buses over any diesel technology, this extension has more to do with extending the years of the concession of e-buses, as their higher CAPEX would make them less attractive than diesel buses.

This is aligned with the design of the bid for the operation of buses, as private companies that choose to provide public transport services with a fleet composed of more than 50 percent e-buses would automatically be granted a concession contract of seven rather than five years.

On the other hand, and in alignment with national decontamination targets, the MTT decided to add extra points in the technical evaluation for nonpolluting technologies. This means that the operator receives proportional points for the percentage of its fleet that does not emit local pollutants.

The last element related to the inclusion of new technologies is the evaluation of energy efficiency. When comparing different buses with the same technology, there will be some that will require more energy (measured in kcal) than others for the same distance. Thus, adopting brands of e-buses that are more efficient produces energy savings for the system. E-bus providers will therefore obtain extra points if their buses, compared with that of their competitors using the same technology, are more efficient (measured through the consumption of energy per kilometer).

It is important to consider how the two tender processes will relate to each other. First, the evaluation of the bus provision tender will take place. For that, the state will seek to find bus providers of different groups of fleets, depending on size and technology (among other characteristics). From this evaluation providers will be selected for each group of buses, and the operators will have to choose which group of buses they will use for their operations. This means that if an operator uses a specific bus type for its service, it will have the chance to evaluate and choose between the different providers that were selected in that fleet type during the first bid, which can be electric, diesel, gas, or any other technology. This list will be provided by the state to the operators, to help them design their offers.

The second bidding process, for the operation of the buses, will incorporate the evaluation of both CAPEX and OPEX. This the only way to compare the different technologies fairly, since an e-bus's OPEX is much lower than that of a diesel one, while its CAPEX is higher. Thus, the incentives of both the bids are aligned.

How well does the structure assign risks associated with maintenance?

The structure of this new system works on the premise of allocating the risks to the party that can best handle them. In that sense, maintenance is part of the operator's responsibilities, as it has more control over the operation and the daily need for buses.

This way, any failure will be responsibility of the operator, unless proven otherwise, and it will only be the responsibility of the fleet provider when the failure is related to guarantees. Nevertheless, there is a control mechanism associated with the certification process that will be conducted by a third party and signed by the fleet provider. This way, the bus supplier, who owns the buses and was promised a concession for 10–14 years, is constantly updated on the situation of the buses. The idea of having this certification process is to keep the fleet provider updated and somehow committed to the maintenance process, as it will be signing the certification each time.

The operator and the supplier will sign a document that formalizes their relationship. There are only two ways in which a bus can be declared unavailable and get discharged (with no more payment quotes associated). The first is when it has not operated for three consecutive months because of guarantee issues, which is the responsibility of the supplier. The second is when it is declared a total loss. For any other case other than guarantee issues, if the bus did not operate for a day, then the responsibility of not operating falls on the operator. Consequently, if the operator does not replace that bus with its reserve fleet, it will not be penalized because of the missing bus, but will be fined as applicable for its noncompliance with quality indicators.

In terms of guarantees, there is a certain amount of time that the fleet supplier has for covering failures related to guarantee coverage. For example, if there is a spare part that must be replaced, the fleet supplier has a defined period of time to accomplish this before being fined. The fleet supplier is also in charge of overhaul maintenance of diesel buses and the changing of batteries in e-buses. This last point represents a clear risk for the fleet supplier. Nevertheless, it should provide a charging strategy (approved by the bus manufacturer) to the bus operator company, that must follow it or the wear of the battery will be the operator's responsibility.

How well does the structure allow for increasing competition?

The major change this process introduces to the system is the separation of the two bids: one for the provision of the fleet and the other for the operation of buses. This modification lowers the entry barriers for new operators, as a big investment for purchasing buses is no longer a requirement. Thus, it may increase the number of tender applicants for the operation of buses, as they will be no longer be buying and managing the assets.

On the other hand, the technical evaluation of bus operator companies is based on their operating experience during the previous years, with those that have had experience in urban public transport systems receiving additional points. There would be no minimum requirements for applying (which could increase the number of competitors), but only a request to demonstrate experience, the lack of which can at the end disqualify a firm during further evaluation.

In terms of fleet provision, the fact that the fleet quote is assured and paid directly by the state lowers the risk for companies significantly. This should act as an incentive for applicants, since it has been tested through the years. Nevertheless, the bidding structure makes it hard for bus providers to use economies of scale, as they are asked to apply to groups of buses and not an entire fleet. Even if selected, nothing guarantees that their buses will be on the streets, as the bus operator is the one that chooses the fleet to be used. Thus, the business presents uncertainties for future providers that may translate into higher prices (because of higher loan rates) or fewer competitors.

There are some elements that affect competition within the system, meaning operations in the streets. First, having shorter contracts may have a positive effect on operators' performance, as they have more incentives to generate good results to apply for extensions in a shorter period. Also, compliance with the operational plan is an important supply indicator and plays a relevant role in the discounts associated with operations, so it should be expected that the companies will put in their best efforts to achieve them.

The escalation of penalties associated with noncompliance is also another important element of these contracts. A bus operator company may be penalized because of noncompliance with quality indicators that, if recurring, may be traduced into fines or, even worse, removal from services or levying of incremental fines that may lead to the expiration of the concession. All of these also affect possible contract extensions. These contract characteristics may act as a boost for competition if they encourage better compliance, but they can also affect the decision of companies to bid or not as they will be faced with a higher-risk contract compared with the previous ones.

How well does the structure allow for increasing operational flexibility?

Operational flexibility is key for conceiving a system that adapts to different situations. Today, more than ever, we need dynamic transport systems that respond to constantly changing travel patterns. The introduction of e-buses presents challenges when it comes to operations as they not only have to coexist with diesel buses that use different infrastructure, but they also have different operational requirements, such as trained drivers and access to special charging infrastructure.

The bidding process has established a requirement for standardized DC European chargers, to allow flexibility to change routes or services. For example, if a bus has to cover a different route than expected, this decision aims to ensure operational continuity. This requires the standardization of the entire charging process, including the communication protocol with the bus.

Importantly, the contract gives authority to the bus companies to increase the flexibility of their operations as long as they meet the operational plan requirements. In this sense, it is the operator's decision to reassign buses to different services, if this plan allows it to offer the level of service established in the plan (level of supply every half hour).

Other elements, meanwhile, must be addressed. For example, it is a common practice for drivers to be reassigned to different services and depots during the day. However, this will not be that simple now as not all depots have the charging infrastructure needed for the different types of buses that may be on the streets. Also, buses reassigned to services that use different depots may not find available charging systems. These are challenges to address in the medium term in order to allow greater operational flexibility.

Advantages and disadvantages of 3 fleet provision business models

In table 4-12, three business model schemes for the acquisition, operation, and maintenance of a fleet of buses are analyzed with respect to their advantages and disadvantages.

Table 4-12: Business model comparison

Business model 1	Business model 2	Business model 3
Integral Scheme	Two components - 1	Two componets - 2
Concessionaire carries out fleet provision, operation of buses, fleet administration, maintenance activities, and operations at depots.	One agent oversees fleet provision and the other fleet and depot operations. Operator is in charge of the maintenance.	One agent oversees fleet provision and the other fleet and depot operations. Fleet provider is in charge of maintenance.

Source: Fieldwork conducted for the present study in 2019.

In the following section, these business models will be analyzed with a theoretical approach, highlighting their advantages, disadvantages, and associated risks. Importantly, these models may be adapted to bidding processes that address some of their risks and disadvantages.

Business model 1

Integral scheme

In the integral scheme a concessionaire carries out the activities of fleet provision and operation, as well as the operation of the depots. These activities also include fleet administration and maintenance activities. This case is similar to the original scheme of Transantiago.

Advantages

- Facilitates the contractual management (administration of the concession) for the management entity, as it must supervise a smaller number of agents in the system.
- Achieves efficiencies in the management of costs and expenses, since the operator's incentives are aligned.
- Concessionaires and the government have related experience in this scheme.
- Allows the operators to take advantage of economies of scale.
- Eliminates interface risks between large activities: acquisition, operation, and maintenance.
- Has a proven funding scheme known to financiers and operators.

Disadvantages

- Creates an obligation for the concessionaire to carry out three dissimilar activities: (i) acquisition of buses, (ii) operation; and (iii) maintenance, which implies that it might not be able to concentrate on and specialize in its main task, which is to operate.
- Creates high financial exigencies for the concessionaire, since it must have capital to finance the buses, acquire spare parts, and take charge of the operation.
- Compromises the continuity of the service in extraordinary cases, because the fleet cannot be disposed of quickly.
- Grants a dominant position to the operators of the system, as they are the owners of the fleet and are responsible for the operation of the vehicles.
- Results in less flexibility on the part of the authority in the administration of contracts and, therefore, in the supply of the service.
- Restricts the technological modernization of the fleet to the extent that it is subject to the terms of the concession.

Business model 2

Two components

The operator is in charge of maintenance: One agent is responsible for fleet provision, and the second for fleet and depot operation and maintenance. This case is similar to the next Red bidding, when the operator chooses to do maintenance on its own.

Advantages	Disadvantages
▶ Allows specialized agents that can guarantee the proper implementation of activities. ▶ Generates a high degree of flexibility for future expansions to the system and ensures the renovation of buses due to obsolescence, changes in technologies, environmental requirements, etc. ▶ Gives flexibility to the system (depending on contract conditions) by allowing the fleet to be reallocated between operators when conditions or the service needs change. ▶ Facilitates the technological renewal of the fleet. ▶ Allows operational contracts to focus exclusively on the provision and quality of service. ▶ Allows the implementation of shorter operating concessions, or concessions different from the lifetime of the bus. ▶ Facilitates the financing schemes of the fleet available in the market, because the owner of the fleet has the financial soundness necessary to make larger investments in vehicles needed by the system; also facilitates investment in fleets that require higher capital costs and lower operating costs, such as e-buses. ▶ Opens the possibility of implementing fleet reassignment schemes, which may mean a better level of regulation to meet the needs of the service in a timely manner. In this way, the power of the concessionaires over the system can be limited, which provides greater flexibility in the administration of contracts and therefore in the operation of the service, allowing effective measures to cancel the concession for failures or noncompliance with the obligations of fleet operation.	▶ Increases the contractual management duties of the management entity by having it supervise a greater number of agents in the system. ▶ Reduces operational efficiencies if the operator does not participate in the fleet selection (not the case of the Red bidding process). ▶ Creates little interest among operators to ensure adequate maintenance of the fleet. ▶ Creates conflicts between the supplier and the fleet operator in the event of bus failures and during warranty management.

Business model 3

Two components

The fleet provider is in charge of maintenance; as with business model 2, it has two agents. However, the first agent is responsible for the provision and maintenance of the fleet and the maintenance of depots, while the second is responsible only for operation of the buses. This case is similar to the next Red bidding process, when the operator chooses to externalize the maintenance.

Advantages	Disadvantages
▶ Apart from the above, maintenance by the supplier ensures that the fleet is in good condition. ▶ Conflicts over the management of the manufacturer's warranties are minimized.	▶ Fleet maintenance can be more expensive because the supplier can use original spare parts more intensively. ▶ The probability of conflicts between the operator and the fleet provider increases, since fleet maintenance is part of the activities considered in the planning and programming of the operation, making it difficult to clearly assign responsibilities and impose sanctions or penalties if necessary. ▶ It is difficult to schedule operation and maintenance because the same agent is not responsible for them. This results in a possible impairment of the quality of service provided to the user by the operator's inability to plan and ensure the availability of the fleet.

Risk analysis of the separation of provision and operation

There may be higher costs to the system, mainly for the following reasons.

First, the coexistence of different agents in fractioned schemes generates an increase in the administrative burden of the management entity and may lead to an increase in the technical fares.

Second, in order to avoid conflicts and dilution of responsibilities among the agents involved in any of the new business models, the management entity must invest in greater contractual management and control mechanisms that promote the development of activities/responsibilities under each concession, without major friction among the agents involved.

Third, the inclusion of a new actor in the provision of the service (fleet supplier) generates a new administrative burden as the new business models involve two different actors, each with its own independent management and administrative area.

Fourth, the agent that supplies the fleet is different from the one that performs the maintenance. This means that the latter loses its bargaining power in the acquisition of spare parts, unless the costs of common spare parts are projected for the lifetime of the buses (e.g., indexed with references such as exchange rates). Also, there will be rising maintenance costs in business model 3 because the fleet supplier may prefer to use original spare parts.

Table 4-13 summarizes the main administrative costs of each business model.

Table 4-13: Analysis of three different business models

Agent	Business model 1	Business model 2		Business model 3	
	Integral	Fleet supplier	Operator	Fleet supplier	Operator
General management	X	X	X	X	X
Operations management	X	-	X	-	X
Maintenance management	X	-	X	X	-
Coordination between operation and maintenance	-	-	-	-	X
Human resources management	X		X	X	X
Administration and finance management	X	X	X	X	X

Source: Steer, 2019

It is possible that in an eventual competitive process for the acquisition and/or availability of the fleet for the system, the financiers and suppliers could reach agreements to offer higher interest rates than expected, in order to favor each other. This is known as collusion risk. To avoid this risk, at the structuring stage of the process a very detailed cost analysis (market study) should be carried out with many companies in order to establish the maximum amounts acceptable to the government in the acquisition of the fleet.

After the division of the business lines, there is a risk associated with possible conflicts between the new agents (the supplier and the operator). This risk is known as interface risk. These conflicts may arise from a possible dilution of responsibilities between the agents, and lack of clarity in the assignment of contractual risks and reaction mechanisms in the event of the occurrence of certain events that affect the new agents in the system.

In addition, the functioning of one contract or agent will depend on that of the others. Therefore, the proper functioning of the separation of lines of business depends on an appropriate legal definition of the responsibilities of each agent, especially in the case of the fleet supplier with the agent responsible for maintaining the fleet.

In the first instance, there is a risk that the operating concessionaires provide service of low quality or are willing to abandon the operation of the system because they did not have to make a significant investment to enter the business. This risk can be mitigated with the establishment of performance incentives and recovery of the fleet to service levels according to their age.

The most important and visible interface risk is the assignment of fleet maintenance to one of the two agents. The distribution of functions can generate limbos in the responsibilities assigned to each of the contracts, which could affect the correct maintenance of the fleet and the lifetime of the vehicles, among other aspects.

In this case, the responsibility for maintenance becomes more complex; when the operator does not own the fleet and only provides working capital, if it recovers it in the first few years and if the incentives are not clear, in the following years it would not mind guaranteeing the useful life of the fleet. This makes it difficult to establish responsibilities for poor fleet performance.

It is important to mention that in the integral scheme, as the operator is not responsible for the maintenance of the fleet, it may not follow the manufacturer's protocols and this may affect aspects such as the vehicle warranty provided by the manufacturer. This risk can be mitigated by a maintenance program agreed to by both actors, with the revenue of the agents being impacted in case of noncompliance.

In assigning maintenance responsibility to the agent providing the fleet, a risk is generated in the operation of the system for two main reasons:

- If this responsibility is not assigned to the operator, it is difficult for it to carry out its main activity.
- The coordination of fleet maintenance scheduling and the need to have it in operation becomes complex.

It is essential to generate performance indicators that have the dual function of generating incentives and deductions for the operator to stimulate better service provision. If the maintenance of the fleet is not the responsibility of the operator, it can claim that the poor performance in providing the service is due to poor maintenance management by the fleet supplier.

Another interface risks is the loss of coordination between operators in the system (e.g., in services that are "shared" between operators such as the use of yards as parking and for maintenance activities, among others).

The interface risks described above can result in an increase in the cost of insurance and guarantees to be contracted by each of the agents.

05

Service improvement using new technologies

In this chapter, we will consider how technology is leveraged in the field of public transport to improve service and standards.

New technologies with the renewal of fleets

A fleet renewal process brings with it the opportunity to introduce new technological aspects that improve the quality of service. In this way, the adoption of e-buses and new technologies for diesel buses such as Euro VI in Santiago has raised overall standards, including by integrating air conditioning, Wi-Fi, USB chargers, padded seats, and low-floor entrances in the new buses.

In the context of Chile's capital, air conditioning helps alleviate high temperatures in summer. In addition, this technology becomes more necessary inside a bus, where temperatures tend to be higher than outside. For their part, Wi-Fi, USB chargers, and padded seats make the trip more friendly and comfortable, improving the user experience. These aspects are even more significant in large cities, where the duration of travel increases and riding a bus can be tedious and annoying. Finally, a low-floor entrance contributes to generating a universal public transport system for all citizens.

In addition, the e-bus telemetry and operation information may provide relevant data regarding the monitoring of buses. It is possible to study in detail the conditions in the path of each bus of the system, evaluating speed reductions at specific points of the route or other difficulties that e-buses present, such as range of batteries, maintenance elements, and differences in energy consumption across routes, allowing for the possibility of continuous improvement. How this information is used will depend on the protocols and openness of systems that allow optimization, as well as the existence of contractual compliance and asymmetries of information between the state and service providers.

These are not the only technological features available on the bus market. Pedestrian proximity sensors, out-swinging type doors, security cameras, software to display variable system information inside the bus and at stops, and a passenger counter, are among other improvements that should be evaluated for each public transport system.

Users' perceptions

In order to determine the valuation and evaluation of e-buses operating in Red, a user experience survey was conducted, following the methodology described in Appendix A.

Sample characteristics

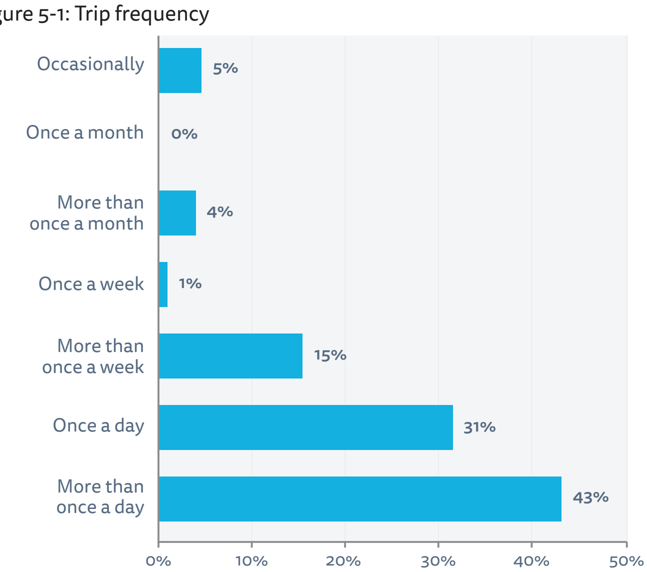
In the sample, 488 complete surveys were obtained, exceeding the sampling size calculated (384 surveys) with a 5 percent margin of error. The characterization of this sample and the result of the valuation of the e-bus are presented below.

Trip characteristics

Regarding the activity carried out by respondents at the time of receiving the flyer, 96 percent of people surveyed were in the process of making a trip (waiting to get on or off a bus). Among these 96 percent respondents, 84 percent were using an e-bus versus 16 percent who were riding on a traditional diesel bus. When the reason for the trip was analyzed, it was highlighted that the trips are mainly for study (48 percent) or work (34 percent), followed distantly by paperwork, health, or/and shopping (7 percent).

This is consistent with the frequency of the trip, since 74 percent of respondents who were making a trip do so at least once a day, as presented in figure 5-1.

Figure 5-1: Trip frequency



Source: Fieldwork conducted for the present study in 2019.

User characteristics

Regarding the personal characteristics of the respondents, gender and age range data are presented in tables 5-1 and 5-2.

Table 5-1: Respondents gender

Gender	Frequency	Percentage
Male	237	49%
Female	242	50%
Other	3	1%
Prefer not to answer	6	1%
Total	488	100%

Source: Fieldwork conducted for the present study in 2019

Table 5-2: Respondent´s age range

Age range	Frequency	Percentage
Under 18	15	3%
18 to 24	227	47%
25 to 39	159	33%
40 to 59 years	75	15%
60 and over	12	2%
Total	488	100%

Source: Fieldwork conducted for the present study in 2019

Valuation of e-bus attributes

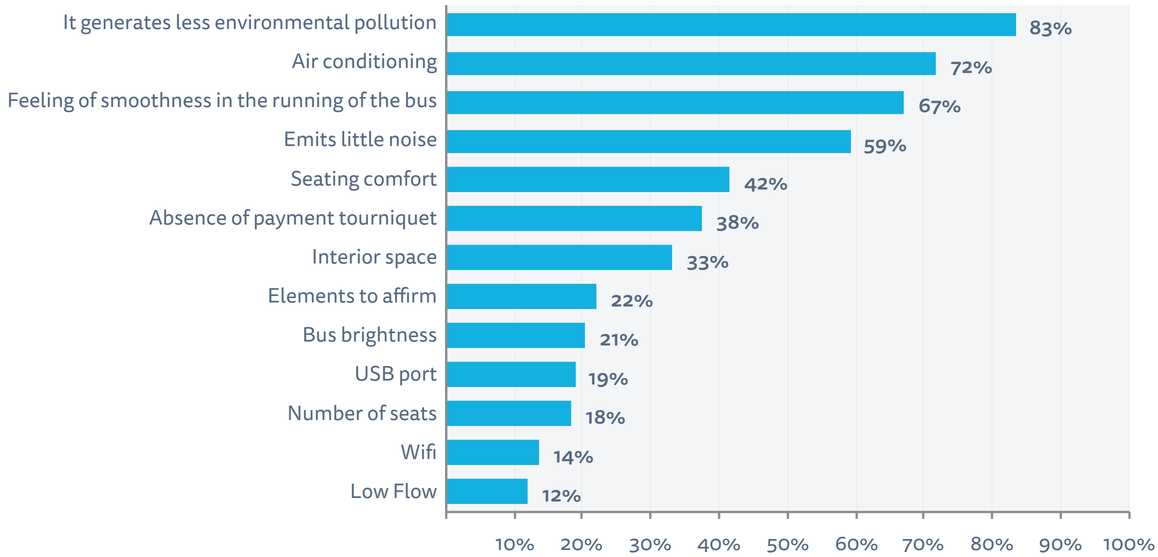
The survey included four questions aimed at understanding users' perception of e-buses in the Santiago transport system. The first question invited the respondents to select the 5 most valuable attributes from a list of 13.

Figure 5-2: Ranking of 5 best e-bus attributes (among a list of 13 attributes)

Source: Fieldwork conducted for the present study in 2019.

The factor most commonly mentioned was: "It generates less environmental pollution." This quality was highlighted among the first five best e-bus attributes by 83 percent of respondents. The next most commonly selected factors were "air conditioning" (72 percent), "feeling of smoothness in the running of the bus" (67 percent), and "emits little noise" (59 percent). Figure 5-3 illustrates the comprehensive feedback.

Figure 5-3: E-bus attributes most valued by users



Source: Fieldwork conducted for the present study in 2019

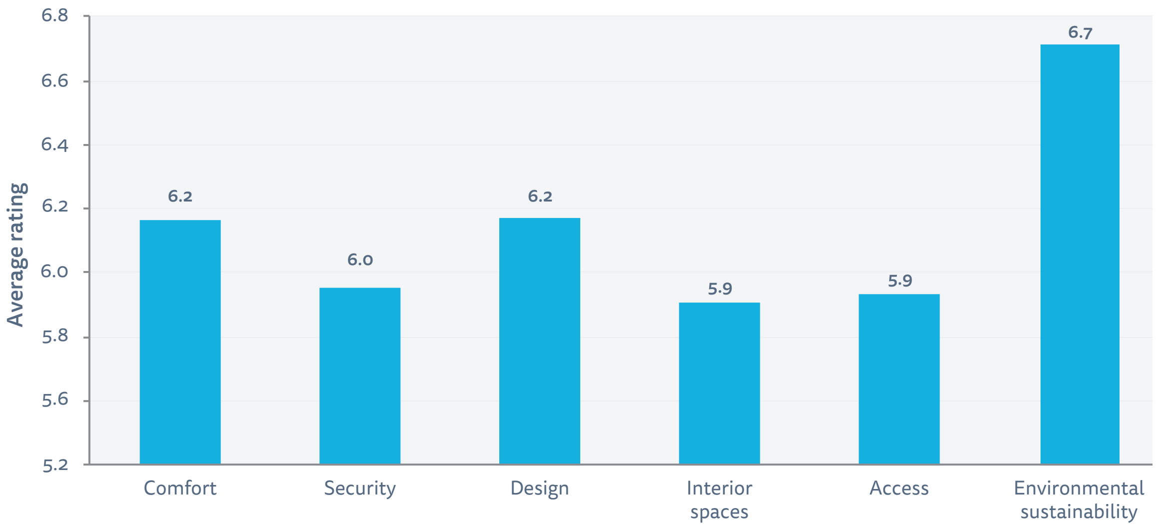
The second question was an evaluation: a rating scale of the characteristics of the e-bus from 1 to 7. For this, six aspects are considered: comfort, safety, design, interior spaces, access, and environmental sustainability.

Figure 5-4: Evaluation of aspects of the e-bus

Source: Fieldwork conducted for the present study in 2019

The highest evaluated characteristic is environmental sustainability, obtaining an average grade of 6.7. Comfort and design are evaluated at the same level with an average rating of 6.2. Interior spaces and accesses receive the lowest scores at 5.9. Figure 5-5 presents the findings.

Figure 5-5: Average rating of the general characteristics of an e-bus

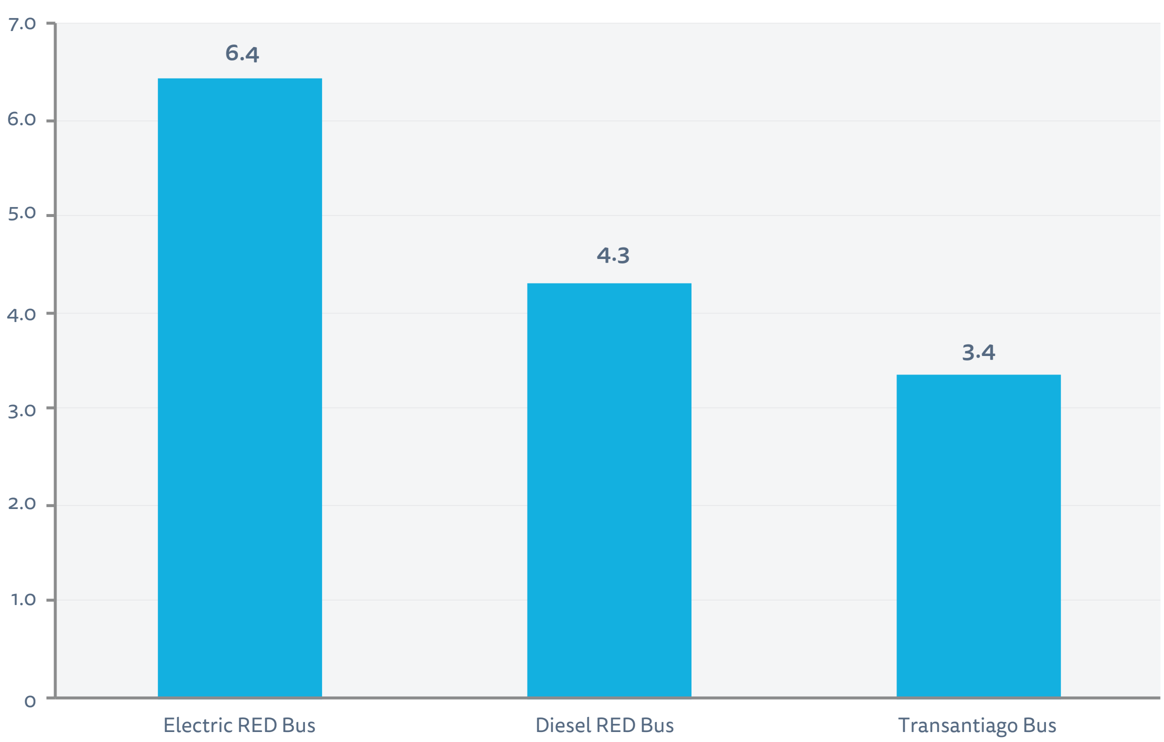


Source: Fieldwork conducted for the present study in 2019

The third question was a global assessment of the different types of buses used within the Santiago public transport system, based on a rating scale from 1 to 7. The types of buses evaluated were e-bus (Red), diesel bus (Red, Euro VI), and diesel bus (Transantiago).

The e-buses received an average total of 6.4, the nonelectric Red buses a 4.3 grade, and the Transantiago buses a 3.4 grade, as shown in figure 5-6.

Figure 5-6: Average rating of the different types of buses in Santiago's transport system



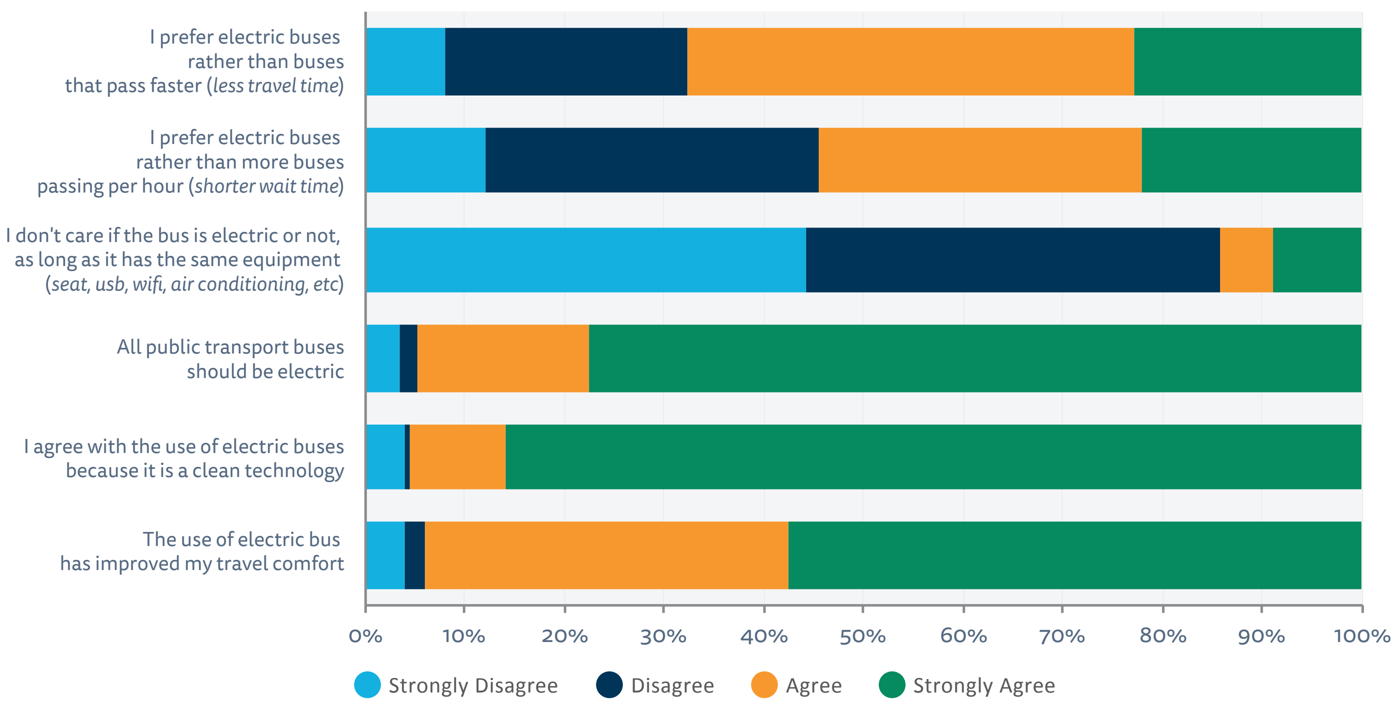
Source: Fieldwork conducted for the present study in 2019

Finally, the fourth question determines the responders' level of agreement with six statements related to the use of the e-bus. The question and result are presented in figures 5-7 and 5-8.

Figure 5-7: Level of agreement with statements about e-bus

Source: Fieldwork conducted for the present study in 2019

Figure 5-8: Analysis of level of agreement with statements about e-bus



Source: Fieldwork conducted for the present study in 2019

Figure 5.8 shows that respondents mostly agree with the use of e-buses within the public transport system. Many said that this new technology has improved their comfort level and that they support the use of e-buses because of the clean technology. As far as the comparison between best equipment versus electrical technology, 85 percent of the respondents said that the bus being electric is more important than the comfort level. Finally, it is observed that 50 percent of users agreed to investing in this technology while maintaining the same number of buses versus an increase in the fleet with any other technology.

Exercise: willingness to wait for an e-bus

A small exercise of choice between two trip alternatives was included in the survey. Both alternatives consider a trip with the same characteristics (wait and travel time, fare, occupancy level, etc.) except for the type of bus (electric versus nonelectric).

This exercise aims to determine users' willingness to wait to use an e-bus. This willingness to wait was measured in terms of the additional waiting time that the user would sacrifice in order to use an e-bus.

The design considered three different cards of which the respondent could choose between waiting two minutes for a Transantiago's diesel bus (this waiting time was fixed) or waiting three, five, or seven minutes for an e-bus.

Figures 5-9, 5-10, and 5-11 represent the three cards. In case the user did not agree to wait for an e-bus, the survey did not show the following cards.

Figure 5-9: A 2-minute versus 3-minute wait

Source: Fieldwork conducted for the present study in 2019

Figure 5-10: A 2-minute versus 5-minute wait

Source: Fieldwork conducted for the present study in 2019

Figure 5-11: A 2-minute versus 7-minute wait

Source: Fieldwork conducted for the present study in 2019

Table 5-3 represents the results of this exercise. In the case of card 1, which was shown to all respondents, 89 percent of users were willing to wait one more minute to board an e-bus. Eighty-nine percent of people were shown the second situation. With card 2, it was calculated that 74 percent of respondents were willing to wait five minutes (versus two minutes for the diesel bus) to use an e-bus. Finally, the results of card 3 demonstrate that 58 percent of those who saw this card were willing to wait an extra five minutes for an e-bus.

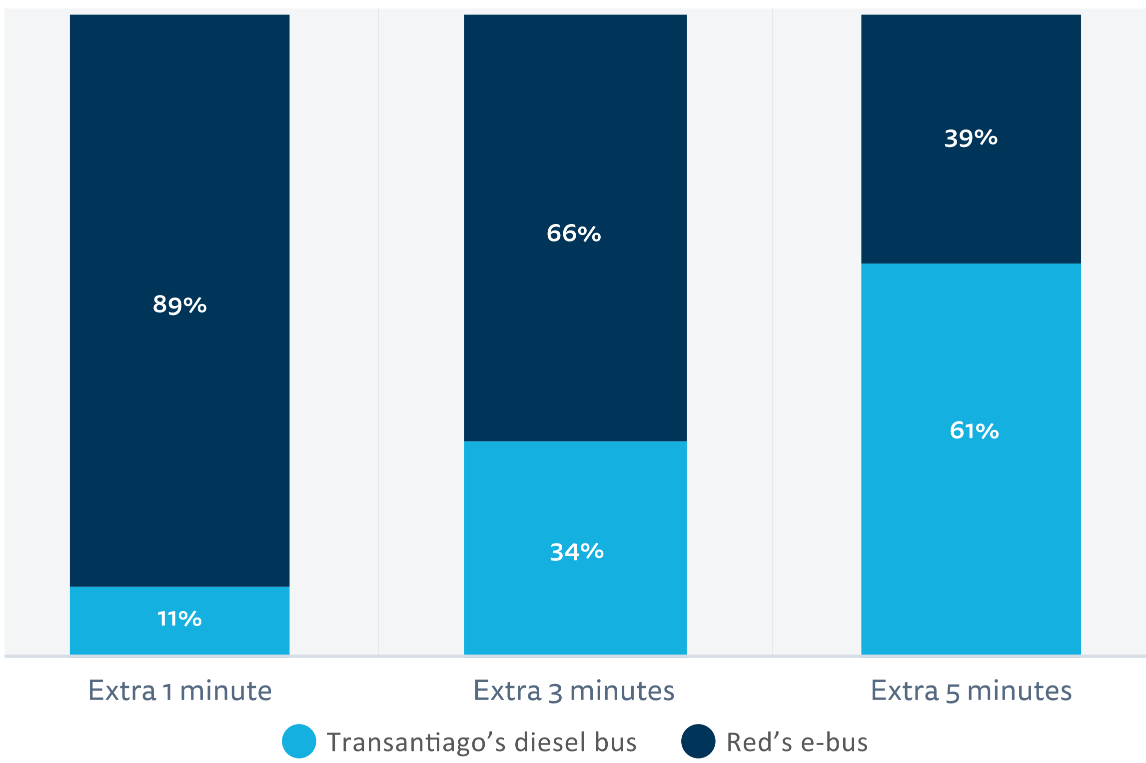
Table 5-3: Result for each card

Card	Extra waiting time	Transantiago's diesel bus	Red's e-bus	Sample
1	Extra 1 minute	52 (11%)	436 (89%)	488 (100%)
2	Extra 3 minute	112 (26%)	324 (74%)	436 (100%)
3	Extra 5 minute	136 (42%)	188 (58%)	324 (100%)

Source: Fieldwork conducted for the present study in 2019.

Figure 5-12 shows results with respect to the total sample (488 respondents). Here it is seen that 89 percent of respondents are willing to wait an extra one minute, 66 percent an extra three minutes, and 39 percent would wait an extra five minutes to use an e-bus.

Figure 5-12: Willingness to wait to use an e-bus



Source: Fieldwork conducted for the present study in 2019

Additionally, with the responses of the three cards, a multinomial logit model was calibrated, as shown in table 5-4.

Table 5-4: Model of choice between e-bus and diesel bus

Parameter	Coefficient	Test t	[95% Conf. Interval]	
Waiting time	-0.634	-15.5	-0.715	-0.554
E-bus constant	2.668	17.23	2.365	2.972

Source: Fieldwork conducted for the present study in 2019.

The model resulted in a statistical significance with 95 percent confidence and correct signs of the parameters of the equation (see column "coefficient" in table 5-4). This implies a negative impact on the utility of the person when waiting time increases and a positive e-bus constant representing a good evaluation of the e-bus compared with the old standard. The modal constant of the e-bus can be expressed in terms of wait times, determined as the ratio between the constant parameter and the timeout parameter. The results demonstrated a 4.2-minute wait as the constant.

Open-ended comments

As a final component of the survey, respondents could provide open-ended comments if they wished to do so—391 comments were received. In general, the comments were positive and focused on aspects such as the use of clean technology, emission of less noise, comfort of the bus, and air conditioning.

> "*II think e-buses are the best we have had in public transport, they do not pollute and are comfortable, regardless of the waiting time. I prefer them."*

Some aspects that could be improved are related to the lack of fresh the air in the interior of the bus, the lack of a back door to get off the bus, and outside visibility when riding in the back of the bus.

> "*When sitting in the last row it is not possible to see the bus route through the windows, so it is difficult to know when to leave the bus."*

> "*The absence of rear doors generates traffic jam in the internal circulations of the bus, making it difficult to leave it when the bus is full."*

> "*Sometimes the humidity of the air is too strong due the air conditioner. From time to time it is too high or too low, which isn't nice. Also, when the bus is full, I feel suffocated because there are no windows to open and the air conditioner only works at the back of the bus. But I love the USB charger! It is the best in the world! They look alike the buses from Australia. These buses could be like the Danish buses that have space for bikes."*

Respondents also had comments related to the operation of the buses.

> "*Regarding electric buses, I would like them to be faster or have a higher frequency."*

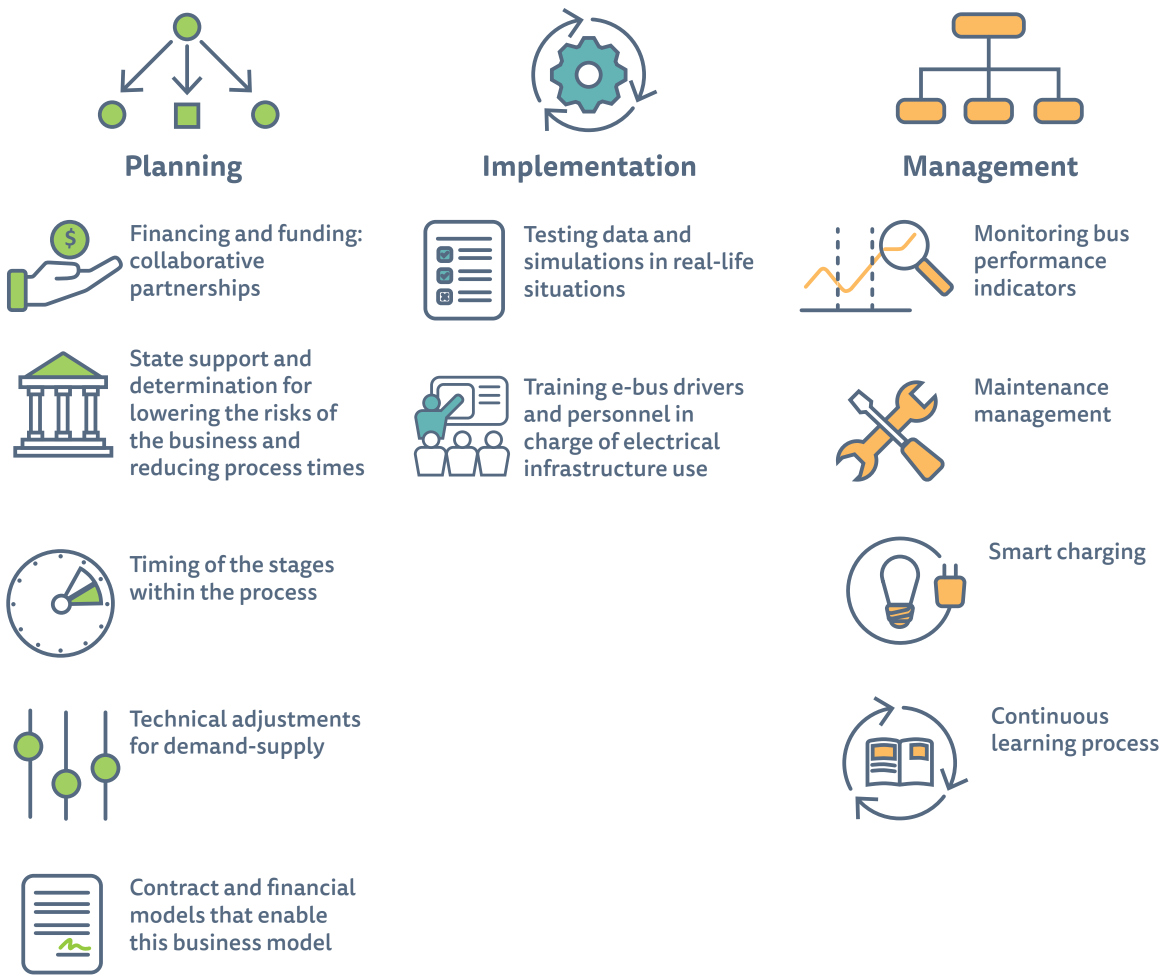
> "*The fleet of e-buses could be increased to accelerate the process of progressive increase in their frequency, so that as soon as possible old buses with lower than the Euro V technologies are taken out of the system."*

06

Lessons learned and recommendations

In this section, we present the main lessons from Santiago's experience with e-buses, and discuss how to use this knowledge for the planning, implementation, and management of e-buses in other cities.

Figure 6-1: Lessons learned and recommendations



Source: Steer, 2019

Planning

- The core element of planning the implementation of e-buses is the building of a cooperative partnership between private companies and the public sector. Private companies include bus operators, bus manufacturers, and financiers. The financing, which in this case is for bus acquisition and electric infrastructure, could come from traditional sources such as banks, but also other companies with an incentive to invest in this business, and with sufficient knowledge of the related risks and competitive loans or leasing rates. With this type of a financial model, a significant financial contribution from the government is not necessary, but it must be involved in policy making and regulation.
- The government's efforts in easing the transition to e-mobility is a key facilitator of the other stakeholders' actions. Government support can occur through various means. The generation of policies (such as environmental agreements, the e-mobility strategy, and decarbonization initiatives in the case of Chile) encourages a series of actions than can have a direct

impact on e-mobility. The state should also play the role of a facilitator by giving guarantees for leasing contracts, and ideally reducing the nonpayment risk perceived by the financier. The government should also accelerate some processes in order to shorten approval periods for quicker implementation of this initiative.

- The timing of the construction of the electric infrastructure have been explicitly mentioned in the report as critical to the implementation of an e-fleet. The efficient timing seen in Chile was made possible by the support of the different actors involved in the process. As experience shows, successful planning involves designing a map of electric capacity by zone/depot location, and estimating electricity requirements and requisite dates for authorization, construction, and installation.
- When estimating the number of chargers required within e-depots, it is necessary to consider when the buses will be charged (with the use of charging management technologies). This, in turn, requires due diligence from electricity companies and regulating authorities. Also, the planning phase includes the preparation of charging devices and their adaptation to the arriving fleet. In this sense, the standardization of chargers is desirable as a next step.
- Additionally, planning should consider the selection of bus routes suitable for e-buses, in terms of slope and length, followed by the possible adjustments of buses for operating on that route. Thus, it would be relevant to measure, with a certification process, how the buses will adapt to local characteristics for the future operation of the fleet. In Chile, the 3CV state agency, which operates under the MTT, constructed its own certification process for the inclusion of e-buses in the streets of Santiago after being tested in terms of performance, range, and consumption under average operational conditions in the city.
- Technical adjustments of the operational plan for demand and supply should be considered within the planning stage. Replacing the existing buses with e-buses has an impact on frequencies and fleet volume (and therefore on the costs of the system). It is important to take into consideration that e-buses, at least those introduced so far in Chile, have less passenger capacity per vehicle than the regular buses (with internal combustion engines). For nonarticulated buses, the relation in terms of capacity is not 1:1, so to achieve the same level of supply, more buses are necessary, increasing the service fleet. In parallel, frequencies for this new bus capacity need to be adjusted. If articulated buses, which are very common in Santiago, are replaced by nonarticulated e-buses because of the high cost of the electric technology of articulated e-buses, the operational modifications become even more important, and may restrain fleet renewal when frequencies are already too high.

Implementation

- **Pilots are an essential element** to consider when implementing e-bus fleets. Testing the actual battery range and the capabilities of a bus under real conditions in the city is key to estimating performance indicators such as autonomy and efficiency. In addition, initiating the adoption of e-buses using pilots allows for the testing of the different brands of buses in order to check manufacturing data and simulations. To maximize the benefit of these pilots, the authority must ensure that the results and learning are made public.
- **Training is a priority.** Training e-bus drivers, maintenance technicians, and personnel in charge of electrical infrastructure use is essential for the adequate operation of buses, since many performance indicators rely on their work. Here, the role of academia is relevant in transforming current courses and careers to adapt to the future challenges of e-mobility, and in preparing future professionals for the associated tasks.

Management

- The management and monitoring of e-buses' operation is **mainly the responsibility of the bus operator** but depends on the contractual agreements between the different actors, especially regarding maintenance of the fleet and the electric infrastructure, in addition to charging management issues.
- The **performance of the bus should be monitored** from the first moment of operation. Real autonomies, average consumption, battery wear, among others, are important elements to have in mind when evaluating the implementation of e-buses in the streets. Understanding performance is key for bus operators, especially due to the monetary benefit associated with low operational costs.
- **Maintenance** is an important issue to guarantee the availability of the e-fleet, and thus the proper operation of e-buses. Also, the management and control of the maintenance processes are relevant for the operator because the cost of maintenance of e-buses is less than that of diesel buses, giving the operators a comparative advantage that needs to be well monitored.
- Likewise, the **management of charging processes, commonly known as smart charging**, is relevant to ensure the availability of buses for operations. Charging management also balances demand if the charging process is well planned, allowing the charging of more bus batteries than feasible with the power of the plant. This issue still remains a challenge for the future implementation of e-mobility in Chile.

Despite the sufficient process of charging management within the existing e-depots, there is emerging technology in the field of smart charging that could be applied in both existing and projected new e-depots of Santiago's public transport system.

- The adoption of e-buses is a novelty in most cities in the world. The planning, implementation, and managing of e-fleets present new challenges to be addressed by both the companies involved and the regulator. Thus, the growing adoption of e-buses in different cities of Latin America and the world offers a **continuous learning process** as transport systems adapt to include this new, cleaner, and maybe even cheaper technology.

These findings are relevant inputs for structuring public transport systems, particularly those in the process of the renewal of bus fleets. Future tendering processes with technological improvements, in Chile and abroad, may use aspects of the Chilean experience with e-mobility in their required analyses, to help with the design, planning, and implementation of public transport systems, as well as the reduction of associated risks. Sustainable transport systems are the future of mobility worldwide. E-mobility has presented itself as an affordable and effective alternative to replace old business models and move toward cleaner and more efficient technologies.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SWL - UNDER TWIN LIFT TELESCOPIC SPREADER
SWL - SINGLE LIFT MODE - 50 TONNES
SWL - TWIN LIFT MODE - 65 TONNES
SWL - UNDER HOOK BEAM - 75 TONNES
SWL - RESTRICTED HOOK TRAVEL - 100 TONNES
4
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07

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Appendix A

Data gathering

The initial task was the collection of relevant data to better understand e-mobility in Santiago. For this activity, existing and available public data sources were identified and analyzed. Interviews with key stakeholders provided further local insight and relevant information on existing initiatives, providing information on the progress and issues that had been addressed politically at the local level. Once all data were collected, they were analyzed and used as key information in developing the present report.

A user perception survey was also part of the data collection task, conducted with the main objective of understanding passengers' preferences regarding e-buses.

Desk research

The literature review was comprehensive (see the references section of this report); the following studies were especially useful:

- Sustainable Transport Solutions: Low Carbon Buses in the People's Republic of China (ADB, 2018)
- Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO_2 (Bloomberg New Energy Finance, 2018)
- "Low Carbon Technologies Can Transform Latin America's Bus Fleets" (C40 Cities, 2013)
- "Oportunidades para el Desarrollo de la movilidad eléctrica en la ciudad de Santiago: Propuesta para el Transporte Público" (Centro Mario Molina, 2014)
- "Electric Buses in America: Lessons from Cities Pioneering Clean Transportation" (Frontier Group, 2019)
- Green Your Bus Ride: Clean Buses in Latin America (World Bank, 2019)
- "United Nations Framework Convention on Climate Change" (United Nations, 2019)

Interviews

To define the actors involved in the process of introducing e-buses to Santiago, one of the first steps was to map the relevant stakeholders who could influence decision-making, enable the adoption process, or provide support and knowledge. Figure A-1 summarizes the actors mapped, grouped by their role.

Figure A-1: Actors involved in the introduction of e-buses

(1) Government Authorities

(2) Technical Government Teams

(3) Energy companies or other investors

(4) Private sector bus operators

(5) Bus manufacturers

Representatives from each group of stakeholders provided valuable insight into the process of adoption of e-buses. The interviews conducted for the present report are listed in table A-1.

Table A-1: Interviews conducted for the study

Type	Role	Stakeholder	Name	Position	Relevance to the study				
					Technical capacity	Regulation	Financial	Energy	Policy
Public sector	1	Metropolitan Public Transport Board (DTPM)	Fernando Saka	Executive Director	✔	✔	✔		✔
	2		Diego Puga	Head of Finance and Management Control		✔	✔		✔
			Ignacio Abud	Coordinator of the Bidding Process for Bus Operations	✔	✔	✔		✔
			Santiago Larraín	Coordinator of the Bidding Process for Bus Provision	✔	✔	✔		✔
			Nathalia Maira	Head of Planning	✔	✔			✔
			Loreto Porras	Users' Experience Manager					✔
		Ministry of Transport and Telecommunications (MTT)	Mauricio Funes	National Coordinator of Electromobility	✔	✔	✔		✔
			Manuel Valencia	Head of Press					✔
		Ministry of Energy	Armando Pérez	Professional at Sustainable Energy Department	✔	✔		✔	
		National Energy Commission (CNE)	Jerson Reyes	Head of Research Innovation Unit	✔	✔		✔	
Private sector	3	Enel X	Fabián Acuña	B2B Enel X	✔		✔	✔	
			Rodrigo Carrau	Head of E-Mobility Chile	✔		✔	✔	
			Jean Paul Zalaquett	Head of E-Mobility South America	✔		✔	✔	
		Engie	Carlos Arias	B2B Engie Chile	✔		✔	✔	
			Laurent Furedi	Costumer Solutions Green Mobility	✔		✔	✔	
		COPEC	Francisco Larrondo	Mobility Head at COPEC	✔		✔	✔	
		NeoT Capital	Víctor Cabanes	Investment Director			✔		
	4	Buses Vule	Pablo Dosque	Head of e-Bus Projects	✔		✔	✔	✔
		Metbus	Héctor Moya	Director	✔		✔	✔	✔
		RedBus (Transdev)	Henri Rohard	Head of Commercial Business	✔		✔	✔	✔
	5	Yutong (Gildemeister)	Cristian Pérez	Head of Buses Division	✔		✔	✔	
		BYD Chile	Tamara Berríos[a]	Country Manager	✔		✔	✔	
Other	-	Superintendence of Electricity and Fuel (SEC)	Julio Clavijo	Head of Renewable Energies and Electromobility	✔	✔		✔	
			Gustavo Hunter	Electromobility Professional	✔	✔		✔	

Source: Fieldwork conducted for the present study in 2019.
Note: Role 1–5 are designated as 1 = government authorities; 2 = private sector bus operators; 3 = bus manufacturers; 4 = technical government teams; 5 = energy companies and investors.
[a] Presentation at UITP.

User experience surveys

To complement the information collected through literature reviews and interviews, a user experience survey was conducted to identify the preferences of passengers in the Santiago public transport system. Specifically, they were asked to evaluate the e-buses operating in the Grecia corridor.

The survey had four categories of questions: (i) characterization of the trip, (ii) valuation of the attributes of the e-bus, (iii) willingness to wait for an e-bus versus a traditional diesel bus (with the same fare), and (iv) the unique characteristics of the individual respondents, in addition to an open-ended comment form. More details on the methodology used are given below.

Figure A-2: Questionnaire's structure

Trip characteristics section

- Type of bus used
- Purpose of the trip
- Trip frequency
- Travel time
- Timing of the trip
- Frequency of use of e-buses

Valuation of the attributes of the e-bus

- Ranking of 5 best e-bus attributes (among a list of 13 attributes)
- Evaluation (with a rating scale from 1 to 7) of aspects of the electric bus
- Evaluation (with a rating scale from 1 to 7) of the different types of buses
- Degree of agreement with statements regarding the electric bus

Exercise of willingness to wait for an e-bus

- Choice of a trip on a nonelectric bus vs waiting extra time for an e-bus (with all other factors held constant)

Characteristics of the individual and open-ended comment section

- Questions on the age and gender of the people surveyed
- Open-ended comment

Source: Fieldwork conducted for the present study in 2019

User experience surveys' methodology

The objective of the user survey of the Santiago public transport system was to determine the valuation and evaluation of the Red e-buses.

The survey was conducted online, and a specific website was created for the purpose. To encourage participation, 5,000 flyers were distributed in different areas of the Avenida Grecia bus corridor, in which electrical and diesel bus services operated simultaneously. In addition to displaying the website (www.buselectrico.cl), the flyers give instructions on how to access the questionnaire.

Figure A-3 shows the two sides of the flyer.

Figure A-3: Flyer's content

Source: Fieldwork conducted for the present study in 2019

The flyers were distributed at four bus stops of the corridor, during morning rush hours (7:00–9:30) and off-peak hours (9:30–14:00), and in the direction of the city center. This work was carried out on October 3 and 4, 2019.

Figure A-4 shows the delivery points.

Figure A-4: Locations of flyer delivery points

Source: Fieldwork conducted for the present study in 2019


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Appendix B

Alternative modeling techniques

MAC: Marginal abatement cost model

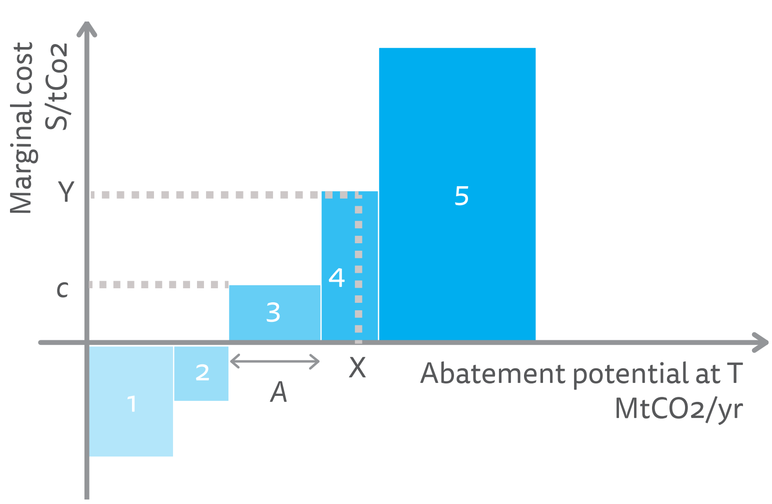
The marginal abatement cost (MAC) model is a tool mostly used in evaluating the costs and potential savings from different emission reduction technologies. This information can help governments decide on the level of ambition of their mitigation strategy and make informed domestic and international commitments.

The choice of an optimal bus technology for a particular corridor or city depends on a variety of factors, including which pollutants are of the highest concern (e.g., greenhouse gases [GHGs] or health impacts of particulate matter [PM] and others), balanced by cost and feasibility considerations, which vary significantly from city to city. A MAC curve provides information on abatement costs and abatement potentials for a set of mitigation measures expected within a particular time period (or a specific year) in the future, and ranks them according to their cost, from the least to the most expensive.

MAC graphs depict the economic costs of carbon dioxide (CO2) emission reduction measures relative to a baseline situation. The graphs show the cost of reducing one tonne of CO2 using a particular emission reduction measure as well as the magnitude of the potential CO2 savings. The inclusion of multiple emission reduction measures in one graph allows for comparison across CO2 reduction options. The World Bank develops and promotes a piece of software called MACTool (Vogt-Schilb, Hallegatte, and De Gouvello, 2014), which can produce achievable potential MAC curves.

Three basic modeling approaches are used to build MAC curves: a bottom-up individual assessment of technologies/abatement measures, a bottom-up system modeling approach, and macroeconomic modeling.

Figure B-1: A measure-explicit marginal abatement cost curve



Source: Vogt-Schilb, Hallegatte, and de Gouvello, 2014.

The general appearance of the curve suggests that measure 3, if implemented, has a potential abatement A and a marginal cost c, and the flatter and wider the graphical representation, the better the cost-effectiveness. This tool can also be used to define a set of measures to achieve the emission reduction target, that is, the "abatement demand" X should be met by implementing measures 1 to 4, possibly using the marginal cost up to carbon price Y.

Inputs

MACTool takes the key sociotechnical parameters of a set of large mitigation measures and macroeconomic variables as inputs. It can be developed using spreadsheet software. The user must also specify at least one scenario for the future macroeconomic variables of interest, such as the price of fossil fuels and the future demand for electricity. Finally, the user must provide scenarios for the future penetration of (low-carbon) technologies in both the baseline case and at least one emission-reduction scenario.

This tool can be used to conduct a cost-effectiveness analysis of the MAC of reducing a tonne of CO_2 emissions when switching from diesel buses to clean bus technologies. The analysis considered the total cost of ownership (TCO) for each technology, as well as the externality costs of air pollution (nitrogen oxide [NO_x] and PM).

In this case, the main objective is to evaluate various technologies and compare them to diesel buses (Euro V, for example) in terms of both the cost-effectiveness of emission reduction ($ per tonne of CO_2, $/t$CO_2$) and the potential CO_2 savings (tCO_2). MACs are calculated by taking the difference in TCOs between clean buses and diesel buses and dividing it by the difference in CO_2 emissions. It is important to note that the cost-effectiveness analysis is dependent on a set of factors that vary over time (e.g., as technologies evolve) and are subject to local interpretation.

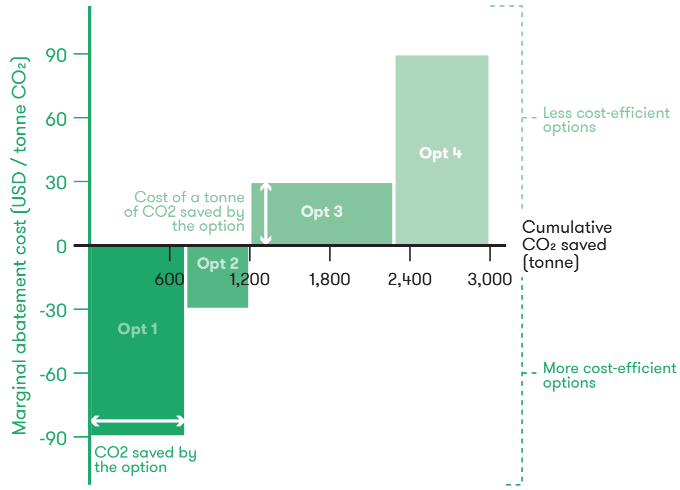
Outputs

As outputs, MACTool computes the amount of GHGs saved by each measure in the long run (in metric tonnes of carbon dioxide [MtCO_2]), and the cost of doing so (in $/t$CO_2$). This information is illustrated with two figures: an achievable potential MAC curve and an abatement wedge curve.

The MAC histograms illustrate the cost and CO_2 reduction potential of each clean bus technology as follows:

- The **vertical height** represents the cost to reduce one tonne of CO_2 emissions, with negative values (below the line) indicating net cost savings.
- The **horizontal width** of each bar indicates the cumulative CO_2 reduction potential from each bus technology over its lifetime.

Figure B-2: Interpretation of marginal abatement cost histograms

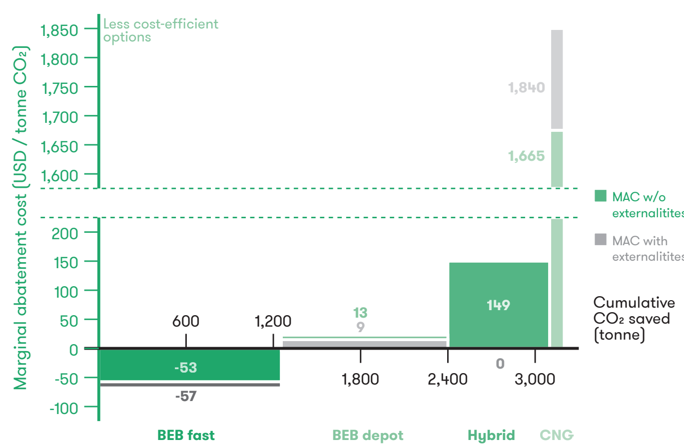


Source: World Bank, 2019

The World Bank used this methodology in the study called "Green Your Bus Ride: Clean Buses in Latin America" to evaluate different bus technologies. The MAC results for Santiago showed that fast-charging battery e-buses (BEBs) are the most cost-effective, while the depot-charging BEBs pose moderate and low costs with externalities, offering high CO_2 reduction potential. Compressed natural gas (CNG) buses are the least economically viable technology due to high CNG fuel costs in Chile and low CO_2 mitigation potential. Hybrid (HBD) buses are not cost-effective in Santiago ($149 per tonne of CO_2 reduced).

The cost-effectiveness results presented above do not represent definitive findings, but they provide initial input for local decision-makers considering which clean bus technologies may be the most powerful and cost-effective for reducing CO_2 emissions and reducing the harmful impact of air pollution.

Figure B-3: Marginal abatement cost histogram for Santiago



Source: World Bank, 2019

The MAC work derives from the analysis and modeling of all the relevant sectors in the assessment. When the MAC data from all sectors are modeled in one chart, it creates a clear and simple picture that compares green measures by costs and benefits across sectors. The previous examples show that this tool can be used as a basis to make decisions about new policies aimed at reducing emissions or to evaluate existing ones, using the cost-effectiveness approach. It can be widely used for comparing technologies, for example, e-buses compared to diesel or other clean buses.

However, there are several restrictions on its use—it is not suitable for market-based policy evaluation as it fails to capture the amount of interactions and the probabilities of the scenarios. Its curve only refers to static concepts that do not illustrate dynamic effects.

One possible solution is to use ancillary bottom-up models, with the other information needed to calibrate assumptions based on market dynamics or technology details, such as a model for measuring the TCO of e-buses. In this way it is possible to define policies and measures, and their corresponding CO_2 saving efficiency, maintaining a consistent structure.

GREET: Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model

The GREET model is an analytical tool that simulates the energy use and emissions output of various vehicles and fuel combinations. Its approach takes into account the fact that in order to get a complete picture of the energy and environmental impact of a technology, it is important to consider the full life cycle from well to wheels for fuels and from raw material mining to vehicle disposal for automobiles.

GREET has two platforms: GREET.net, software that provides the user with an easy-to-use toolbox to perform life-cycle analysis simulations; and the GREET Excel Model Platform, the traditional multidimensional spreadsheet model that includes two submodels: the Fuel Cycle Model (which contains data on fuel cycles and vehicle operations) and the Vehicle Cycle Model (which evaluates the energy and emission effects).

Additionally, GREET has four available tools:

- Well to Wheels (WTW) Calculator
- Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool
- Fleet Footprint Calculator
- Travel Carbon Calculator

The first tool summarizes the WTW results of energy use, GHG emissions, water consumption, and air pollutants emissions for different vehicle technologies.

The AFLEET tool estimates petroleum use, GHG emissions, air pollutant emissions, and cost of ownership of light- and heavy-duty vehicles.

The Fleet Footprint Calculator allows a vehicle consumption factor to be calculated by type of fuel, where the types of existing vehicles are determined and the model gives the consumption of those vehicles for natural gas, diesel, biofuel, and so on. The limitations of the model are that the bus options do not include the full variety existing in different cities (for example, it does not include biarticulated buses like those used in TransMilenio in Colombia) and that they are calibrated for US behavior only.

By using the Travel Carbon Calculator, it is possible to obtain the CO_2 emission variations including all the activities that are needed to get the fuel from its source to the car. For example, crude oil drilling, pumping, refining, and shipping contribute to the carbon footprint of gasoline, as well as the tailpipe emissions.

Inputs

The inputs for the GREET model will depend on the results the user needs. They can include fleet size, vehicle miles traveled, and fuel economy. For example, the user could compare different fuels/technologies for consideration of future purchases.

Table B-4: Example of inputs for GREET model

2. Number of Each Type of Vehicle in On-Road Fleet

	Gasoline	Diesel	Diesel HEV	Biodiesel (B20)	Biodiesel (B100)	Ethanol (E85)	Compressed Natural Gas CNG	Liquefied Natural Gas LNG	Liquefied Petroleum Gas/Propane LPG	Electricity	Gaseous Hydrogen (G.H2)	Liquid Hydrogen (L.H2)
School Bus	0	0	0	0	0	0	0	0	0	0	0	0
Transit Bus	0	0	0	0	0	0	0	0	0	0	0	0
Shuttle/Paratransit Bus	0	0	0	0	0	0	0	0	0	0	0	0
Waste Hauler	0	0	0	0	0	0	0	0	0	0	0	0
Street Sweeper	0	0	0	0	0	0	0	0	0	0	0	0
Delivery Step Van	0	0	0	0	0	0	0	0	0	0	0	0
Transport/Freight Truck	0	0	0	0	0	0	0	0	0	0	0	0
Medium/Heavy Duty Pickup Truck	0	0	0	0	0	0	0	0	0	0	0	0
Maintenance Utility Vehicle	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0	0	0

3. The Average Annual Vehicle Miles Traveled by Each Vehicle Type

	Gasoline	Diesel	Diesel HEV	Biodiesel (B20)	Biodiesel (B100)	Ethanol (E85)	Compressed Natural Gas CNG	Liquefied Natural Gas LNG	Liquefied Petroleum Gas/Propane LPG	Electricity	Gaseous Hydrogen (G.H2)	Liquid Hydro-gen (L.H2)
School Bus	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Transit Bus	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Shuttle/Paratransit Bus	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Waste Hauler	23,400	23,400	23,400	23,400	23,400	23,400	23,400	23,400	23,400	23,400	23,400	23,400
Street Sweeper	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
Delivery Step Van	16,500	16,500	16,500	16,500	16,500	16,500	16,500	16,500	16,500	16,500	16,500	16,500
Transport/Freight Truck	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000
Medium/Heavy Duty Pickup Truck	11,400	11,400	11,400	11,400	11,400	11,400	11,400	11,400	11,400	11,400	11,400	11,400
Maintenance Utility Vehicle	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Other	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000

4. The Average Fuel Economy for Each Vehicle Type in the On-Road Fleet (miles per gasoline gallon equivalent)

	Gasoline	Diesel	Diesel HEV	Biodiesel (B20)	Biodiesel (B100)	Ethanol (E85)	Compressed Natural Gas CNG	Liquefied Natural Gas LNG	Liquefied Petroleum Gas/Propane LPG	Electricity	Gaseous Hydrogen (G.H2)	Liquid Hydrogen (L.H2)
School Bus	6.0	7.0	8.5	7.0	7.0	6.0	6.0	6.0	6.0	20.5	12.0	12.0
Transit Bus	2.5	3.0	3.8	3.0	3.0	2.5	2.5	2.5	2.5	8.5	5.0	5.0
Shuttle/Paratransit Bus	7.	8.0	10.0	8.0	8.0	7.0	7.0	7.0	7.0	24.0	14.0	14.0
Waste Hauler	2.0	2.5	3.0	2.5	2.5	2.0	2.0	2.0	2.0	7.0	4.0	4.0
Street Sweeper	3.0	4.0	5.0	4.0	4.0	3.0	3.0	3.0	3.0	10.0	6.0	6.0
Delivery Step Van	12.0	15.0	18.5	15.0	15.0	12.0	12.0	12.0	12.0	41.0	24.0	24.0

4. The Average Fuel Economy for Each Vehicle Type in the On-Road Fleet (miles per gasoline gallon equivalent)

	Gasoline	Diesel	Diesel HEV	Biodiesel (B20)	Biodiesel (B100)	Ethanol (E85)	Compressed Natural Gas CNG	Liquefied Natural Gas LNG	Liquefied Petroleum Gas/Propane LPG	Electricity	Gaseous Hydrogen (G.H2)	Liquid Hydrogen (L.H2)
Transport/Freight Truck	5.0	6.0	7.5	6.0	6.0	5.0	5.0	5.0	5.0	17.0	10.0	10.0
Medium/Heavy Duty Pickup Truck	9.0	11.0	13.5	11.0	11.0	9.0	9.0	9.0	9.0	31.0	18.0	18.0
Maintenance Utility Vehicle	20.0	25.0	31.0	25.0	25.0	20.0	20.0	20.0	20.0	68.0	40.0	40.0
Other	2.5	3.0	3.8	3.0	3.0	2.5	2.5	2.5	2.5	8.5	5.0	5.0

Source: User Guide for GREET Fleet Footprint Calculator (2012).

Outputs

In terms of outputs for a given vehicle and fuel system, GREET separately calculates:

- Total energy consumption (from nonrenewable and renewable sources), fossil fuels (petroleum, fossil natural gas, and coal together), petroleum, coal, and natural gas;
- Emissions of carbon dioxide equivalent (CO_2eq) GHGs—primarily CO_2, methane (CH_4), and nitrous oxide (N_2O); and
- Emissions of six criteria pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), NOx, PM_{10} and $PM_{2.5}$, and sulfur oxide (SO_x).

GREET includes more than 100 fuel production pathways and more than 80 vehicle/fuel systems.[55]

55 https://greet.es.anl.gov.

Lessons from Chile´s Experience with E-Mobility:
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