ZEBRA

ZERO EMISSION BUS

RAPID-DEPLOYMENT ACCELERATOR

From pilots to scale

Lessons from electric bus deployments in Santiago de Chile

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ZEBRA: The ZEBRA (Zero Emission Bus Rapid-deployment Accelerator) partnership works to accelerate the deployment of zero emission buses in Latin American cities, with the final aim to achieve climate goals, improve urban air quality, and the overall standard of public transport. ZEBRA is a P4G funded partnership led by the ICCT and C40 Cities, and supported by CMM-Chile and WRI.

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CONTENT

I. INTRODUCTION

Santiago de Chile is one of the largest metropolitan areas in South America. Located in the valley of the Mapocho river surrounded by the Andes and the coastal mountain ranges of Chile's central valley, it is home to over 7 million—more than 40% of Chile's population—and South America's highest skyscraper. Additionally, since the beginning of 2019, Santiago is home to the largest fleet of electric buses outside of China. How did the city become a global leader in the adoption of electric public transport? What lessons can we learn from Santiago and what does the future of public transit in Chile look like? We seek to answer these and other questions in this case study.

II. TACKLING TRANSPORTATION EMISSIONS THROUGH REGULATION AND IMPROVED VEHICLE TECHNOLOGY

Santiago de Chile is not dissimilar from other megacities in so-called emerging economies. The latter half of the 20th century brought economic growth, urban sprawl, and an exponential growth in the number of private vehicles, and with this came higher levels of congestion and air pollution. By the early 1990s, the city was one of the most polluted capital cities in all of Latin America. As a result, Chile began to monitor air pollution, regulate emissions from the transportation sector, and integrate Santiago's public transportation operators into a unified system under the purview of a public transportation authority. Since then, Chile has played a pioneering role in the region in the adoption of vehicle emission standards, as reflected in the composition of its urban bus fleet (see Figure 1). In 2018, Santiago became the first city in Latin America to adopt Euro VI emission standards for its public transportation system, and this helped set the stage for electric bus deployments in subsequent years. By March 2020, Santiago had already deployed close to 600 Euro VI buses and more than 400 electric buses—the latter making up approximately 6% of the fleet. This city has set a target of full electrification by 2035.[1] This is an effort to reduce exposure to local pollutants from the transportation network and, in particular, to reduce CO_2 emissions, which have increased over time (see Table 1).

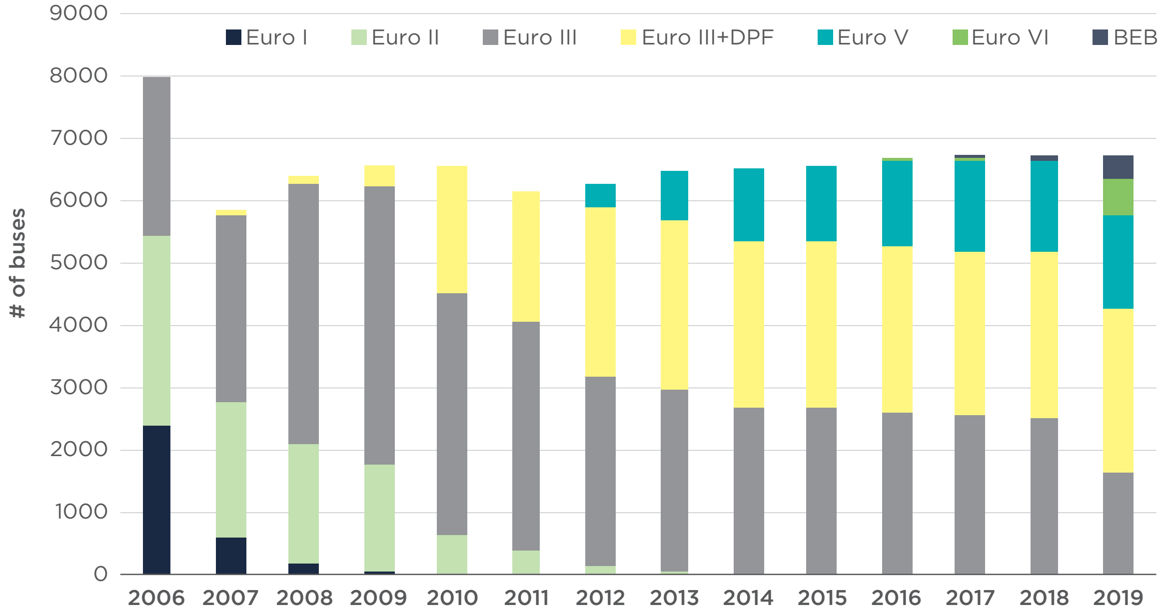

Figure 1. Evolution of urban bus emission control technologies in Santiago (Directorio de Transporte Público Metropolitano, 2011, 2012 & 2018).[2]

Table 1. Emissions from Transantiago, 2012–2018 (tonnes)[3]

Emissions	MP_{10}	$MP_{2.5}$	NO_x	CO	HC	CO_2
2012	96.7	84.9	4,518.4	1,201.6	227	447,287
2018	73.7	61.5	4,122.6	1,222.8	179.6	460,786
% Change	-23.8%	-27.6%	-8.8%	1.8%	-20.9%	3.0%

III. ELECTRIC BUS DEPLOYMENTS IN SANTIAGO DE CHILE

In 2007, after an ambitious transportation reform, Santiago launched its restructured public transport system, Transantiago (now known as Red Metropolitana de Movilidad, or RED). Today RED is made up of 380 routes operated by six private operators; it has the capacity to move 690,954 passengers with its fleet of 6,756 buses on a network that spans more than 2,946 kilometers (see Table 2 for additional statistics.) The operators have to meet performance requirements as part of their obligations to the local transport authority.[4] The system has been criticized and is currently being reformed to correct many of its structural failures; these reforms include, among others, disaggregating fleet provision from operation, smaller business units, shorter contracts, and incentives for electric bus operations. All the same, Santiago has been at the forefront of large-scale new vehicle technology deployments in Latin America, including electric vehicles. Santiago's electric bus journey began with early demonstration projects in 2011 and 2013 and continued through 2017, a pivotal year in terms of electric bus pilot projects.[5]

Table 2. Transantiago network statistics, 2012–2018[6]

	2012	2013	2014	2015	2016	2017	2018
Number of buses	6,298	6,493	6,513	6,550	6,646	6,681	6,756
Number of routes	374	368	371	379	378	377	380
Passenger capacity	642,964	665,980	674,391	676,685	682,642	685,257	690,954
Distance traveled (million km)	469	464	460	460	459	453	449
Length of bus network (km)	2,766	2,770	2,790	2,817	2,821	2,834	2,946

In November 2017, Metbus, one of Santiago's private bus operators, partnered with Enel, an Italian utility company, and BYD to bring two electric 12 meter (m) BYD K9FE buses to operate under regular service in Santiago. The two buses ran for a year with five trained drivers on route 516, which takes approximately 4–4.5 hours to complete. Over the year, they covered 105,981 km and moved more than 350,000 passengers with an availability ratio of 99.23% (1,665 return legs were completed, 13 return legs were not). Operating costs were calculated at $0.10/km, based on a $0.10/kilowatt hour (kWh) price and an energy consumption of 1.006 kWh/km. In comparison, a diesel reference bus with an energy consumption of 0.5 liters/km operates at a cost of $0.86 per liter.[7]

As a result of this pilot, Metbus worked with BYD and Enel X, an Enel subsidiary, to scale the operation by adding an additional 100 BYD K9FE units in 2019. Enel X acted as the financial agent and energy provider, and leased the buses to Metbus for 10 years; Metbus, in turn, operates the buses and provides basic maintenance, while BYD is in charge of more important maintenance operations including battery packs and electric drive trains. For the latter, Metbus negotiated a fixed maintenance rate of $0.09/km with BYD and there is an availability clause whereby the manufacturer is responsible for any fines incurred by buses that do not meet frequency requirements.[8]

The total amount of the agreement between Metbus and Enel X is estimated to be in the range of $40 million.[9] This includes a financial lease for 100 buses and charging infrastructure for 10 years, after which the assets are transferred to the lessee, Metbus. The amount also includes the costs associated with grid upgrades in two "electroterminals"; these are estimated to have been in the range of $3 million in each depot.[10] The BYD K9FE buses cost an estimated $295,000 per unit.[11] As for the charging infrastructure, Metbus secured 100 BYD EVA 080KI AC chargers that deliver up to 80 kW and have an estimated

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charge time of 3–4 hours when connected with two charge cables under combined charging system (CCS) protocols for an additional $3,700 per unit.[12] Enel and Metbus have also signed an agreement to provide certified renewable energy at a 40% discount— approximately $0.06 per kW.[13] Furthermore, these buses have been used to create Latin America's first electric corridor: a bus route along a major axis in Santiago, Avenida Grecia, that is operated solely with electric buses. The corridor contains 40 new state-of-the-art bus stops which include free wifi, USB chargers, bus arrival time panels, solar panels to cover electricity demands, LED lighting, wheelchair access, and, in some stations, exclusive payment zones. The partnership has been so fruitful that Metbus has increased its fleet to 285 BYD K9FE and is planning to add an additional 150 of these buses during 2020.[14]

Also in 2017, a similar partnership, this time led by Engie, a French utility company with operations in Chile, and Gildemeister, a local automobile dealer, launched a Yutong E12 (also known as ZK 6128) 12-meter low-floor bus pilot in Santiago. Buses Vule, a Transantiago operator, joined the initiative and operated the bus between December 2017 and May 2018; the bus completed

1,173 trips and traveled a total of 22,055 km.[15] By June 2019, the bus had covered more than 100,000 km and had estimated operational costs of around $0.05 per km.[16]

In late 2018, as a result of this successful pilot program, Engie announced that it would finance an additional 100 battery electric buses and work with two Transantiago operators—Buses Vule and STP. The total cost of these agreements is estimated to have been more than $30 million for the buses alone, meaning the unit price per bus was about $300,000.[17] Other estimates of the price of the Yutong E12 buses have been between $320,000 and $350,000 per unit.[18] In this agreement, Engie acted as the financial agent and provided charging infrastructure and certified renewable energy for both bus operators—3.3 gigawatt hours (GWh) per year for STP and 8.8 GWh per year for Buses Vule.[19] The STP terminal will have 13 150 kW DC chargers to operate 25 electric buses.[20] The Buses Vule terminal at Rinconada, which opened in March 2019, includes 37 150 kW DC chargers capable of handling the operation of 75 electric buses. The total cost per charger has not been released, but it is estimated to be in the range of $20,000 to $40,000 per unit. The total energy demand for the terminal is estimated to be 6 megawatt (MW) and includes a 2.1 MW backup system.[21] In April 2019, these buses were integrated into regular operations.

Most recently, in March 2020, NEoT Green Mobility, an investment platform dedicated to financing zero-emission mobility, financed 25 King Long DM2800 electric 12 m buses to be used in Redbus' (a Transdev company) operations. Details regarding the financial agreement are limited, but they mirror the Engie/Enel business model of providing separate asset ownership for infrastructure and buses to a local transport operator. STP is also seeking to add 215 electric buses to its fleet, this time in conjunction with Foton, represented by Andes Motors in Chile, and COPEC, a local fuel distribution company. Details of this are still scarce, but contracts have been finalized.[22] Importantly, this not only brings new financial actors to the sector but also incorporates new electric bus manufacturers within Santiago's transport operations. At the time of writing, there are 11 type-approved electric buses for Chile, including two A1 buses (8–11 m) and one C2 bus (18 m) from five different Chinese manufacturers (see Table 3). Articulated buses (18 m) have been tested in Santiago from at least two different manufacturers, BYD and Sunwin, but have not been incorporated into any fleets thus far.[23]

Table 3. Electric buses approved for RED operations (MTT 06/2020)[30]

Vehicle Class	Brand	Bus model	Power [kW]	Battery capacity [kWh]	Passenger capacity	Energy consumption[31] [kWh/km]	Range [km/ charge]	Operation [# of buses]	Operator	Routes	Charger	Charging strategy
B2	BYD	K9 FE	300	276.5	81	1.57	176.1	285 + 150 (Expected Q2-Q3 2020)	Metbus	507c, 516, 519	BYD EVA 080KI charger, AC 80kW, CCS 1 standard	Overnight, 4-4.5 hours at depot
B2	YUTONG	ZK6128BEVG	215	324.4	87	1.48	219.7	101	Buses Vule, STP	213e, I09, I09c, I09e	150kW DC chargers, GB/T standard	Overnight, 2.5-3 hours at depot
B2	FOTON	eBus U12 QC	350	151.55	90	1.67	90.9	N.A.	N.A.	N.A.	N.A.	N.A.
A1	BYD	K7	180	156.6	45	1.13	138.6	N.A.	N.A.	N.A.	N.A.	N.A.
A1	FOTON	EBus U8,5 QC	130	129	47	1.24	104.0	N.A.	N.A.	N.A.	N.A.	N.A.
B2	ZHONGTONG	LCK6122EVG	350	351.237	88	1.58	222.3	N.A.	N.A.	N.A.	N.A.	N.A.
B2	KING LONG	XMQ 6127G PLUS	280	374.65	90	1.74	215.0	25	Redbus	CO2, CO2c, C06, C14	ABB HVC 150C, 150kW Depot box, CCS 2 standard	Overnight, 2.5-3 hours at depot
A1	KING LONG	XMQ 6900G	200	210.56	45	1.13	186	N.A.	N.A.	N.A.	Unknown, CCS 2 standard	N.A.
C2	ZHONGTONG	LCK6180EVG	300	525.11	141	2.67	196	N.A.	N.A.	N.A.	Unknown, CCS 2 standard	N.A.
A2	ZHONGTONG	LCK6106EVG	200	315.07	74	1.46	216	N.A.	N.A.	N.A.	Unknown, CCS 2 standard	N.A.
B2	FOTON	eBus U12 SC	350	385.08	90	1.63	237	215 (expected Q2-Q3 2020)	STP (expected)	N.A.	Unknown, CCS 2 standard	N.A.

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IV. LESSONS LEARNED

The notable growth in the number of electric buses on Santiago's streets in the past couple of years has generated positive outcomes. Preliminary calculations show emissions reductions on the order of 2,561.1 tonnes of CO_2e from 3,658,388 km operated with 100 electric buses from Metbus.[24] Extrapolating this to the current fleet of 411 battery electric buses, these have reduced close to 20,630 tonnes of CO_2e, or around a 5% reduction in CO_2 emissions from 2018 levels.[25] Public transit users also view electric buses in a favorable light, and gave them a score of 6.3 out of 7; that is higher than Euro VI buses, which received a score of 5.8, and the public transportation system as a whole, which received a 4.3.[26] Based on frequency and availability metrics provided by operators, the reliability of operations with electric buses is in line with or superior to those from conventional buses.

The economic impact of electric bus deployment is still unclear. However, operational costs released by operators show substantial reductions vis-à-vis conventional buses. Moreover, the continued incorporation (at scale) of electric buses into the fleet, which is expected to increase to more than 800 in 2020, sends a strong market signal.

It is important to note that this deployment in Santiago was accomplished outside of fleet renewal tenders and by taking advantage of contract extensions to current operators. It was not through competitive bidding. Overall, Santiago has struggled, as have many other cities in South America, to renew its transport fleet over the past few years. Tenders have been deserted and modified. At the time of writing, there is an open tender to renew more than 2,000 buses and also make substantial changes in the structure of the transportation system.

The new system seeks to split the ownership and operation of assets by having fleet suppliers and bus operators, while the transport authority manages depots. Embedded in the current tender are several incentives for electric buses. Fleet suppliers can obtain fleet contracts for 10 years for internal combustion engines and for electric buses, it is extended to 14 years. Operators, which will lease buses from suppliers, will be granted 5-year contracts that are extendable for up to an additional 5 years based on performance factors. Importantly, if the base operational fleet of these operators is made up primarily of electric buses, i.e., more than 50%, than these contracts are granted for 7 years, and are extendable for another 7 based on performance indicators. A sliding scale point system is also included based on energy consumption (megajoules/km) that is calculated based on performance on the TS-STGO drive cycle.[27] Santiago is the first city in Latin America to develop its own drive cycle for urban buses type approval.[28] Importantly, this is the first tender in Santiago where we will see diesel buses compete alongside electric buses. Other tenders have been technology specific. While it is unclear how many of the new buses will be electric, recall that there is a mandate to fully electrify by 2035.

Further challenges to the advancement of electric public transport remain. The exponential growth of this vehicle segment preceded many regulatory considerations, particularly regarding charging standards and interoperability requirements. The economic viability of substantially increasing the number of electric buses is also unclear, given the current economic and social pressures currently weighing on the heavily subsidized system in Santiago. However, the arrival of new actors and business models adds a new impetus for these technologies. Infrastructure challenges also remain. These include ensuring more dedicated bus lanes to increase passenger uptake and improve frequencies for the bus network as a whole, and also grid upgrades at depots that are necessary to handle peak loads. Currently, there are already 10 electric bus depots with over 22 MW of installed capacity (see Table 4) to operate 411 electric buses out of a total fleet of just under 6,800 buses. Although many of these lessons are transferable to other cities in emerging economies, structural challenges, particularly the formalization of urban bus operators, remains a key building block for these large-scale deployments, and that process is not dependent on technology but rather on political will. This is the case in most cities in Chile outside of Santiago, which have the challenge of electrifying their entire fleets by 2040—a goal set by the central government.[29]

Table 4. RED electric bus depots, chargers and installed capacity

Depot Name	Chargers	Installed capacity (MW)
Peñalolén	65 (1x80kWAC)	5.2
Los Acacios	37 (1x80kWAC)	2.4
Los Pinos	37 (1x80kWAC)	3
Las Palmas	13 (1x80kWAC)	1.25
El Salto	5 (3x50kWDC)	0.75
Nueva Bilbao (1)	3 (3x50kWDC)	0.5
Nueva Bilbao (2)	3 (4x40kWDC)	0.5
I+D Peñalolén	1 (350kW + Pantograph)	0.4
Rinconada	37(1x150kWDC)	6.0
Juanita	13(1x150kWDC)	2.1
10 Depots	214 Chargers	22.1 MW total installed capacity

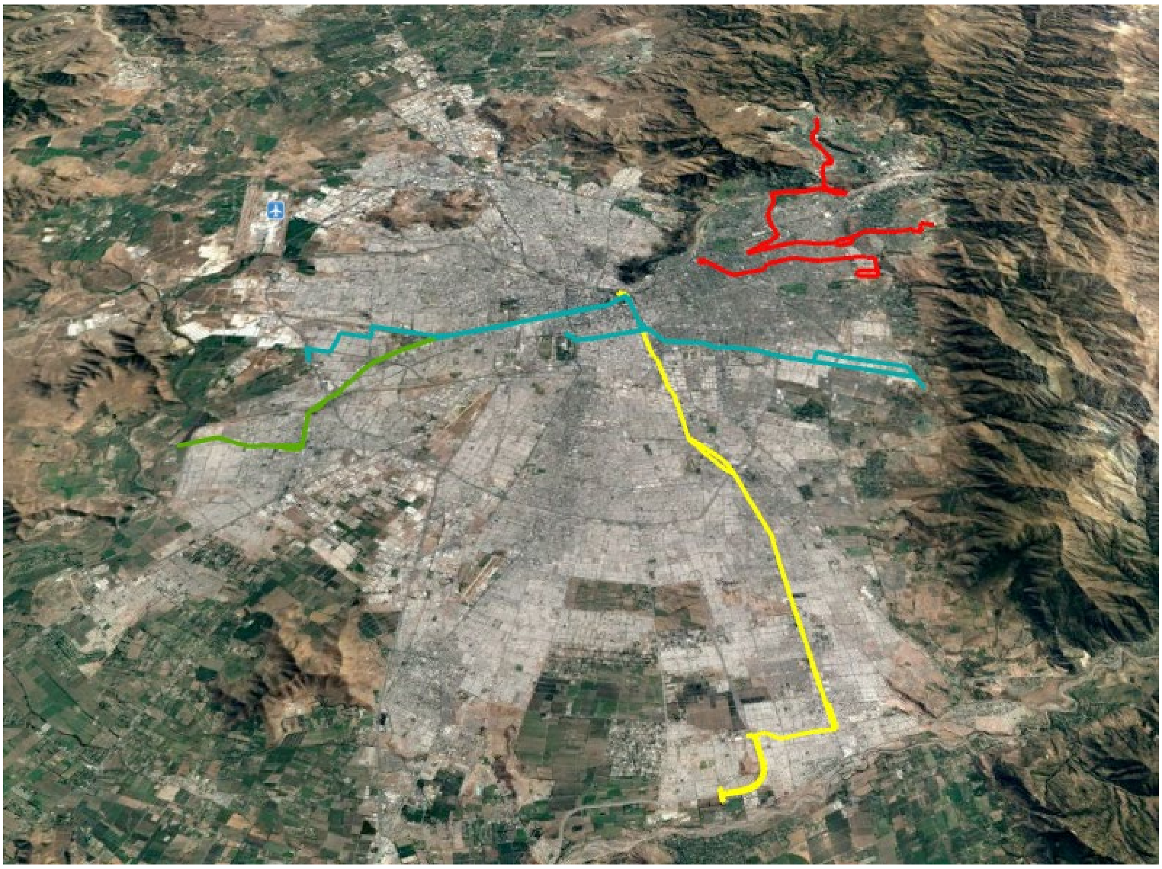

Figure 2. Electric bus routes in Santiago de Chile. Buses Vule (I09, I09c, I09e) is shown in green, Metbus (507c, 516, 519) is shown in cyan, Redbus (CO2, CO2c, C06, C14), and STP (213e) is shown in yellow.

1 See https://secureservercdn.net/198.71.233.13/fd4.9c7.myftpupload.com/wp-content/uploads/2019/10/Electromovilidad-en-el-Transporte-Pu%CC%81blico-de-Santiago.pdf

2 See http://www.dtpm.cl/descargas/archivos/Informe%20de%20Gesti%C3%B3n%2020%20%20DE%20NOV.pdf http://www.dtpm.cl/archivos/Informe_de_gestión_2012_4_de_Septiembre.pdf and http://www.dtpm.cl/descargas/memoria/Informe_Gestion_2018_DTPM.pdf

3 See http://www.dtpm.cl/descargas/memoria/Informe_Gestion_2018_DTPM.pdf

4 Previously seven but Alsacia S.A declared bankruptcy in 2014 and was removed from the system in 2018. See https://www.latercera.com/nacional/noticia/transantiago-finalizan-operaciones-alsacia-nuevos-operadores-tienen-mejoras-23-indices-calidad/549980/

5 Hybrid and Electric Bus Test Program, conceived by C40 and the Clinton Climate Initiative, and supported by the Inter-American Development Bank with a financial contribution of $1.49 million. Also, See http://www.innovacion.cl/2013/08/inauguran-recorrido-del-primer-bus-electrico-que-operara-en-chile/

6 See http://www.dtpm.cl/descargas/memoria/Informe_Gestion_2018_DTPM.pdf

7 See https://www.revistacolectibondi.com.ar/2018/12/09/chile-los-primeros-buses-electricos-cumplieron-un-ano-de-operacion-y-estos-fueron-los-resultados-de-la-prueba/

8 Maintenance costs per/km for diesel buses run at around $0.27, as estimated by METBUS. See http://movelatam.org/portfolio-item/experiencias-de-un-operador-de-transporte-publico-en-la-introduccion-de-buses-electricos-en-santiago-chile/

9 See http://www.economiaynegocios.cl/noticias/noticias.asp?id=522475

10 It is unclear if these costs were included in the financial lease or rather in a separate agreement between both parties.

11 See http://movelatam.org/portfolio-item/experiencias-de-un-operador-de-transporte-publico-en-la-introduccion-de-buses-electricos-en-santiago-chile/

12 *Ibid.*

13 See http://movelatam.org/portfolio-item/experiencias-de-un-operador-de-transporte-publico-en-la-introduccion-de-buses-electricos-en-santiago-chile/

14 Based on conversations with Metbus on March 2, 2020.

15 DTPM presentation at CMM-DTPM workshop (June 2018)

16 See http://www.electromov.cl/2019/07/01/crisitian-perez-de-gildemeister-detalla-la-mantencion-en-buses-electricos-de-yutong/

17 See http://www.electromov.cl/2019/01/21/nuevo-electroterminal-de-engie-para-el-transantiago-utilizara-norma-china/

18 See https://www.latercera.com/nacional/noticia/plan-busca-convertir-chile-segundo-pais-mas-buses-electricos-del-mundo/219064/

19 See http://www.electromov.cl/2019/02/15/engie-entregara-suministro-de-energia-100-renovable-para-100-buses-electricos-del-transantiago/

20 See https://www.engie.cl/engie-entregara-suministro-de-energia-100-renovable-para-100-buses-electricos-del-transantiago/

21 See http://www.revistaei.cl/2019/03/28/se-pone-marcha-electroterminal-buses-mayor-potencia-latinoamerica/

22 Based on conversations held on April 23, 2020 with Andes Motors.

23 See https://www.latercera.com/mtonline/noticia/bus-electrico-articulado/644852/ and https://www.electromov.cl/2019/02/22/presentan-bus-de-sunwin-electrico-y-articulado-para-plan-piloto-del-transantiago/

24 See https://www.energia.gob.cl/noticias/nacional/subsecretario-de-energia-y-agenciase-entregan-primeros-certificados-de-validacion-de-emisiones-de-gei-para-empresas-que-usan-electromovilidad

25 Own calculations including the use of renewable energy.

26 See http://www.dtpm.cl/descargas/estudios/Satisfacci%C3%B3n-Nuevo-Est%C3%A1ndar_vF.pdf

27 TS-STGO is a city specific drive cycle for Santiago developed by the Ministry of Transport, Centro Mario Molina, VTT, Sweden's Trafikverket among others as part of IEAs Advanced Motor Fuel's Technology Cooperation Programme's Annex 53-1 on Sustainable Bus Systems. Final report available at https://www.iea-amf.com/app/webroot/files/file/Annex%20Reports/AMF_Annex_53-1.pdf

28 Resolución Exenta N° 2.243 de 2018 del Ministerio de Transportes y Telecomunicaciones available at https://www.leychile.cl/Navegar?idNorma=1121384

29 See https://em.consumovehicular.cl/orientaciones-de-politicas-publicas

30 See MTT/3CV https://mtt.gob.cl/wp-content/uploads/2014/01/Consumo-Energetico-Buses-Electricos_WEB.xls

31 Energy consumption calculated based on TS-STGO drive cycle as per Resolución Exenta N° 2.243 de 2018 del Ministerio de Transportes y Telecomunicaciones available at https://www.leychile.cl/Navegar?idNorma=1121384

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