NAVIGANT
A Guidehouse Company

Sustainable Urban Mobility: A Global Perspective on The Future of Electric Public Transportation

Prepared with the Scientific Contribution of:

enel
Foundation

By:

Sagie Evbenata, Scott Shepard, Ryan Citron, Ajay Chawan, Korinna Joerling, and Sam Abuelsamid from Navigant, a Guidehouse company

Mirko Armiento, and João Duarte from Enel Foundation

Navigant, A Guidehouse Company
Woolgate Exchange
25 Basinghall Street
London, EC2V 5HA

+44 (0) 203 880 0800
guidehouse.com

February 2020

TABLE OF CONTENTS

DISCLAIMER

This report was prepared by Navigant Consulting, Inc., n/k/a Guidehouse Inc. ("Navigant"),[1] with the scientific contribution of Enel Foundation. The work presented in this report represents Navigant's professional judgment based on the information available at the time this report was prepared. Navigant is not responsible for the reader's use of, or reliance upon, the report, nor any decisions based on the report. NAVIGANT MAKES NO REPRESENTATIONS OR WARRANTIES, EXPRESSED OR IMPLIED. Readers of the report are advised that they assume all liabilities incurred by them, or third parties, as a result of their reliance on the report, or the data, information, findings and opinions contained in the report.

Enel Foundation is a non-profit organization focusing on the crucial role of clean energy to ensure a sustainable future for all. By developing partnerships with pre-eminent experts and institution across the globe, leveraging on the vast knowledge of its Founders, Enel Foundation conducts research to explore the implications of global challenges in the energy domain and offers education programs to the benefit of talents in the scientific, business, and institutional realms. More information can be found at www.enelfoundation.org

[1] On October 11, 2019, Guidehouse LLP completed its previously announced acquisition of Navigant Consulting, Inc. In the months ahead, we will be working to integrate the Guidehouse and Navigant businesses. In furtherance of that effort, we recently renamed Navigant Consulting, Inc. as Guidehouse, Inc.

EXECUTIVE SUMMARY

Cities are in urgent need of decarbonised transport. Urban areas are disproportionately contributing to global transport emissions. Growing global urban populations and their high population densities result in a significant share of total passenger journeys and goods deliveries. Therefore, a substantial positive environmental impact can be made by decarbonising urban transport emissions globally.

In a joint effort with Enel Foundation, Navigant, a Guidehouse company, investigates the opportunities offered by the electrification of public transport in this paper. It envisages several important co-benefits and positive externalities for the residents of large urban areas in all global regions.

We explore selected case studies from cities around the globe to examine how different cities approach the problem of transport decarbonisation. Each city faces a unique set of challenges resulting from not only local environmental problems, but also its own transportation, technological, economic, and societal contexts. Consequently, a diverse range of solutions have been deployed, which can provide valuable insights and learnings from cities around the world.

1. THE NEED TO ACCELERATE TRANSPORT DECARBONISATION

The need to decarbonise the urban environment is urgent. The United Nations (UN) estimates that 68% of the world's population will live in cities by 2050, compared to only 55% in 2018.[2] As the world's population growth drives an increasing level of urbanisation, cities should lead the way on curbing carbon emissions. Although the world's cities occupy just 3% of the Earth's land, they account for two-thirds of the world's energy demand and are responsible for about 70% of CO_2 emissions. Fossil fuel-based urban transportation has been a major contributor to climate change.

1.1 Rethinking Transportation Aids Public Health in Major Cities

In addition to the climate impact of CO_2 emissions, local air pollution has a strong and direct effect on citizens lives and well-being and is a public health priority in most major cities. Multiple challenges result from increasing urbanisation. There is the need to modernize existing infrastructure or to develop new infrastructure to meet ever-increasing transportation demands and new lifestyles. Cities such as Shenzhen, Tokyo, New York, Santiago, Paris, London, Amsterdam, and Barcelona lead the transition towards a more sustainable society and have implemented policy and other significant measures to reduce air pollution. The progressive electrification of public transportation systems and a push for last-mile mobility alternatives and electric carsharing help to improve the quality of life for citizens. Several cities are also implementing ultra-low emissions zones and, in many cases, establishing a date to completely ban the use of internal combustion engine (ICE) vehicles.

1.2 Planes, Trains, and Automobiles Can Go Electric

1.2.1 Private Vehicles

Within the transport sector, road vehicles principally contribute to air pollution. According to the European Environment Agency, ground transport is responsible for about 10%-20% of total carbon emissions, particulate matter (PM2.5 and PM10), non-methane volatile organic compounds (NMVOCs), and for almost 30% of nitrogen oxide (NOx) global emissions.[3]

EVs play a key role in the energy transition and are already helping to shape the future. In 2018, the global stock of EVs and plug-in hybrid EVs (PEVs) passed 5.1 million, a 63% increase from 2017. Around 2.3 million (45%) of these vehicles are in China, 1.2 million (24%) in Europe, and 1.1 million (22%) in the US. Annual PEV sales are projected to grow to 24.9 million annually by 2030, and the global stock of PEVs could exceed 123 million by 2030.[4]

[2] "68% of the world population projected to live in urban areas by 2050, says UN," United Nations, Department of Economic and Social Affairs, 16 May 2018.
https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

[3] European Environment Agency, *Emissions of air pollutants from transport*, 22 November 2018.
https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-air-pollutants-8/transport-emissions-of-air-pollutants-8

[4] Navigant Research, *Market Data: EV Market Forecasts*, 1Q 2019.
https://www.navigantresearch.com/reports/market-data-ev-market-forecasts

By the end of 2018, the global stock of electric two-wheelers was 260 million with more than 250,000 light commercial vehicles.[5] Most are electric bikes (e-bikes) operating in the Asia Pacific. However, growth in North America and Europe to 2030 is expected to be significant, with sales projected to more than triple and double respectively.[6]

1.2.2 Ground Transportation

While private vehicles are an important part of the energy transition, public transportation represents the most effective way to move large amounts of people to their destinations. Public transport helps minimise congestion and the related pollution and time lost in commuting. Cities with low levels of public transportation development tend to have higher levels of congestion. This is reflected in TomTom's global traffic index,[7] which highlights that many of the top 10 most congested megacities have relatively low levels of public transport development. In the US, the average cost of congestion was estimated to be to almost 97 hours lost per year,[8] at a monetary value of $1,348 for each citizen.

The ease of use for first mile/last-mile transportation options saves commuters time and money and encourages behaviour changes. The improved user experience is a result of the combination of public transport with shared mobility and the Internet of Things (IoT) solutions. This combination allows for multiplatform data coordination, applications, and services such as platforms for traffic management and shared mobility. The growing adoption of IoT solutions and the increased competition of multiplatform offerings is quickly lowering transportation costs and increasing affordability.

The International Energy Agency's *Global EV Outlook 2019* estimates there are over 460,000 electric public buses worldwide. China has led the deployment of e-bus fleets with almost 99% of the market. By 2030, e-buses should make up over 80% of the new transit bus market.[9] In Europe, e-buses have steadily increased. In 2018 there were estimated to be over 1,200 e-buses, roughly double the amount in 2015. By 2026 e-buses are expected to reach over the 40% of the market.[10] The European Commission Clean Bus Expert Group estimates that "e-buses with daily duty cycles of less than 165 km are already cost-competitive with diesel on a total cost of ownership basis. Falling battery costs mean that this will apply to duty cycles above 165 km per day, within 2-3 years."[11]

The rail sector (both urban and regional/national rail systems) is progressing with electrification. High speed ground transport (HSGT) technologies are leading to reductions in short-haul air traffic, vehicle miles travelled, and oil consumption. HSGT include high speed

---

[5] International Energy Agency, *Global EV Outlook 2019*, May 2019. www.iea.org/publications/reports/globalevoutlook2019/

[6] Navigant Research, *Market Focus: Electric Two-Wheel Vehicles*, 4Q 2019. https://www.navigantresearch.com/reports/electric-two-wheel-vehicles

[7] TomTom, *Traffic Index 2019*, 2019.
https://www.tomtom.com/en_gb/traffic-index/ranking

[8] Inrix, *INRIX: Congestion Costs Each American 97 hours, $1,348 A Year,* February 2019.
http://inrix.com/press-releases/scorecard-2018-us/

[9] Navigant Research, *Market Focus: Electric Buses*, 3Q 2019. Sustainable Bus, *Electric buses market will grow faster than electric cars, according to BloombergNEF,* June 2018.
https://www.navigantresearch.com/reports/electric-buses

[10] World Bank; International Association of Public Transport, *Electric Mobility and Development,* 2018.
https://openknowledge.worldbank.org/handle/10986/30922

[11] World Bank; International Association of Public Transport, *Electric Mobility and Development,* 2018.
https://openknowledge.worldbank.org/handle/10986/30922

rail (HSR), maglev trains (efficient and quiet trains magnetically suspended over the track), and hyperloops (efficient high speed trains running in sealed low pressure tunnels). HSGT has major sustainability advantages over other transportation modes since it is generally electrically powered and can potentially use 100% renewable energy. HSR for example, is on average two to five times more energy efficient than car or air travel.[12]

1.2.3 Aviation

By comparison, the electrification of aviation is in its infancy. There are only a few electric aircraft prototypes for short-distance flights, while electric and hybrid propulsion systems are still in testing phases.[13] Aircraft systems such as climate and flight control are progressively switching from hydraulic and engine bleed air systems to electric, increasing their overall efficiency. Major aircraft players are making significant investments in urban air mobility and aerial ridesharing. In particular, companies like Uber plan to offer riders an affordable option for shared electric vertical take-off and landing (VTOLs) in 3-4 years. These aircraft would shuttle passengers over urban congestion, saving valuable commuting time. Overall, the progress of electric VTOL aircraft is well behind other transportation modes, primarily due to the high cost of this technology and its development.

1.2.4 Marine Transport

The marine transport sector can also contribute to this transformation. The opportunity exists to leverage the higher efficiency and lower emissions of electric motors compared with ICEs. Ships have a strong effect on the environment, especially near coastal areas, and efforts for cleaner solutions are needed. For instance, according to a study conducted by Transport and Environment,[14] 203 cruise ships emitted about 20 times more sulphur oxides (SO_x) along European coasts than all of Europe's 260 plus million passenger vehicles in 2017.

Marine transport also has a significant impact on climate change. The International Maritime Organization[15] estimates that the marine sector is responsible for roughly 3% of global CO_2 and greenhouse gas emissions per year; however, the maritime battery certifier, DNV GL, estimates that one container ship emits as much CO_2 as 75,000 cars and as much particulate matter as 2.5 million cars.[16]

Without the significant technological advances that can drive economies of scale and substantial cost reductions, the electrification of sea transportation is uncertain and faces development challenges. In 2018, there were just 8,000 recreational hybrid and electric vessels (watercraft typically under 25 meters for short-distance journeys) globally, and only a low number of electric fishing boats and ferries.[17]

---

[12] A. Jehanno, D. Palmer, C. James, International Union of Railways, *High Speed Rail and Sustainability*, 2011. https://www.fra.dot.gov/Elib/Document/15010

[13] Airbus, *Future technology Leveraging the Technologies That Will Revolutionise Our World*, 2019. https://www.airbus.com/innovation/future-technology.html

[14] Transport & Environment, *One Corporation to Pollute Them All*, June 2019. https://www.transportenvironment.org/sites/te/files/publications/One%20Corporation%20to%20Pollute%20Them%20All_English.pdf

[15] International Maritime Organization, *Third IMO Greenhouse Gas Study*, 2014. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf

[16] L. Gear, *Electric and Hybrid Boats and Ships 2019-2029*, IDTechEx, 2019

[17] L. Gear, *Electric and Hybrid Boats and Ships 2019-2029*, IDTechEx, 2019

There are some encouraging developments, however. Cold ironing, also known as shore connection, shore-to-ship power, or alternative maritime power, is becoming more widespread. Cold ironing provides ships with shore power (power requirements while a ship is stationary) using heavy-duty cables to connect to a power supply on the port or harbour, eliminating the undesired air pollutants, which are produced by diesel-fuelled power generators. To speed up the spread of this technology, ships, terminals, and ports must be transformed and equipped with additional electrical capacity, conduits, facilities, and necessary infrastructure.

1.3 The Global Challenge of Decarbonising Transport

Cities around the world face different challenges depending on if they are located in highly industrialized or less developed countries. Regardless of their location and development status, cities can learn from each other. This white paper focuses not only on environmental benefits such as noise and air pollution, but also on the technological advantages. For example, the electrification of public transport can be an effective method to stabilize the grid.

2. ADDRESSING THE IMPACT OF CLIMATE CHANGE AND RESILIENCY

Global warming seriously damaging not only the natural environment, such as fauna and mankind, but also to critical infrastructure and physical assets, such as power grids. It is crucial to examine how climate change affects infrastructure and urban areas with projected high levels of energy consumption. Investments in resilience are increasingly vital in the energy sector and should not be postponed, as demonstrated by the increasing number of recent climatic disasters. For instance, Pacific Gas and Electric Company, one of the largest utilities in the US, filed for bankruptcy protection in January 2019 after being devastated by several wildfires in Northern California. It switches off the electrical grid during times of severe fire risk to stop the spread of wildfires.

Cities are implementing measures to reduce emissions across transportation systems while also considering the impact of a changing climate, which will occur over the lifetime of transportation infrastructure. The effects of climate change can include increased frequency of cloudbursts combined with more frequent and longer heatwaves, leading to increased incidence of surface water flooding (as seen in Berlin, Germany), increased risk of mortality at low water transportation crossings (as seen in San Antonio, Texas) and the associated disruptions to the transportation network.

Furthermore, rising sea levels can increase the risk of coastal flooding, saline ingress, and infrastructure damage. Cities tackle adaptation and mitigation with an integrated approach to ensure transportation infrastructure is both low carbon and climate change resilient. Examples include cities integrating ecosystem-based adaptation (EbA) measures to remove concrete and hard surfaces. Cities replace them with porous surfaces and green spaces to improve surface water draining along tramways (as seen in Bordeaux, France) and on a wider city scale (Berlin, Germany). Using EbA measures such as urban planting, urban forests, greenspace, and waterways alongside transportation routes, cities create integrated cooling corridors. These measures reduce air temperature, improve air quality, and reduce heat-related mortality, which is a severe risk during heatwaves. Floating roads are being built to reduce disruption from rising sea levels. After extreme weather events, cities use technology focused on improving transit information regarding disrupted or closed routes and provide alternative route options ahead of time for users to minimise disruption.

Morocco is an example of a country strengthening its climate resiliency. Several strategies have been implemented to integrate climate change resiliency into key sectors of the national economy including energy, transport, agriculture, tourism, and others. In 2010, Morocco implemented an engineering approach to assessment and resiliency planning. This was based on a study conducted by The World Bank that classified road sections according to four types of vulnerability and a set of characteristic indicators of observed risk. The decision tool created from this assessment allowed road managers to prioritise investments to improve the road network and determine vulnerabilities. The study concluded, amongst other things, that current road design and construction practice had shortcomings for climate conditions.

3. CHALLENGES AND OPPORTUNITIES TO FUTURE-PROOF ELECTRIFIED PUBLIC TRANSPORTATION

The World Health Organization (WHO) lists air quality as the greatest environmental risk to health at a global level and estimates that outdoor air pollution exposure is responsible for almost 7 million deaths every year.[18] While much of this happens in developing nations, back in 2014, about 92% of the world's population resided where air quality levels exceed WHO limits. The following air pollutants damage human health: PM2.5 and PM10, Black Carbon, SOx, NOx, Ammonia, Carbon Monoxide, Ozone, Methane, NMVOCs. Electrifying transport can be a great opportunity to improve air quality and to reduce CO_2 emissions, especially if the electricity is generated from renewable energy sources (RESs).

There are several co-benefits and positive externalities, including reduced noise pollution. A study conducted by Enel Foundation, European Climate Foundation, and Transport & Environment (2018),[19] estimated that in 2030 air quality improvement caused by the reduction of tailpipe emissions from cars could amount to cumulative savings of €10.5 billion in Italy. This figure was reached by considering the benefits in productivity, healthcare costs, and saved lives. Another recent study[20] assessed the impact of the energy transition on air quality by considering emissions from transport and residential sectors. In a single year (2030), costs related to air pollution in the European Union could be reduced up to €2.9 billion. The total reduction of air pollutants and CO_2 emissions will depend on several factors and the power generation mix is a crucial variable.[21]

3.1 New Markets at the Intersection of Transportation and Electrification

The progressing electrification of transport creates a strong nexus between the energy and transport sectors. This interaction is both a challenge and an opportunity, creating new business models, new market participants, and different technical solutions transforming both sectors and their respective industries. Successful electrification of transport will depend on the ability of the electric system to support the energy transition. The transition to the carbon-neutral energy systems of the future poses new challenges to the electric system. On the production side, electricity generation from variable RESs is intrinsically intermittent. On the demand side, new load patterns with potentially high peak loads emerge as the transport sector is electrified. Furthermore, overall demand for electricity is rising due to global population growth and the ongoing electrification of heating with electric heat pumps. Power systems need to be prepared to address the emerging need for flexibility.

One way to tackle these new challenges and improve the overall power system stability is with demand response. By shifting the times of electricity demand, peak loads could be adjusted to the available supply, reducing congestions and the amount of reserve needed to balance the grid. This form of ancillary service is successfully in use by large industrial consumers such as cement manufacturing, chemical processing, or aluminium plants, which

[18] World Health Organization, *Ten Threats to Global Health in 2019*, 2019. https://www.who.int/emergencies/ten-threats-to-global-health-in-2019

[19] Enel Foundation, *Fuelling Italy's Future How the Transition to Low-Carbon Mobility Strengthens The Economy*, 2018. https://www.enelfoundation.org/content/dam/enel-found/news-pdf/news-pdf-2018/Fuelling_Italys_Future.pdf

[20] The European House Ambrosetti and Enel Foundation, *Just E-Volution 2030 - The Socio-Economic Impacts of Energy Transition in Europe*, 2019.

[21] While emissions reductions by vehicles are often measured from tank-to-wheel, the total emissions also depend on the well-to-tank emissions.

offer demand response services to the grid by adjusting production peaks to periods of high availability of electricity.[22] This mechanism can be compared to a virtual battery.

As EV batteries become less costly and more durable each year, their potential to offer demand response services increases. R&D of new battery chemistries and formats are increasing both energy density[23] and durability.[24] These developments reduce the risks tied to premature battery degradation resulting from increased battery use for non-motive purposes. These developments are critical to improving mass-market adoption of EVs and enabling EVs as grid energy storage assets.

A recent study[25] analysed the impact of EVs and storage on the electric system of four European countries in 2040. It estimated that smart charging would deliver net cumulative benefits in France, UK, Spain, and Italy for about €4.3 billion per year. On one hand, smart charging of EVs would increase the system flexibility, reducing the investments required to balance the grid. On the other hand, overnight charging will consume energy generated by wind plants that would otherwise be curtailed. The synergy between EVs and variable RESs is strong in the case of e-buses, which can act as giant batteries on wheels with predictable demand patterns. Electrified bus fleets could be instrumental in supporting system integration and reducing future grid reliability problems as EVs penetrate the vehicle market.[26]

Bidirectional charging of electric vehicles enables vehicle-to-grid (V2G), vehicle-to-home, and other potential vehicle-to-X applications. It represents another recent technological advancement that can play a major role in the future energy system, increasing the share of renewables in the mix and the number of prosumers. By means of a bidirectional charging station, it is possible to consider an EV not only as an electric appliance, but also as an innovative means to store energy and provide balancing services.

V2G technology potentially enables all vehicles to offer ancillary services. Unlike private vehicles, public transport typically follows a regular and predetermined timetable that facilitates the scheduling of both charging and discharging to the grid. For this reason, new e-mobility offerings provide a better consumer experience compared with ICE vehicles and they can also help to balance the grid. With extensive application of V2G and vehicle-to-home solutions, it is possible to aggregate a critical mass to enable power grid stabilization solutions, shaping the future of energy management.

---

[22] Aluminium Insider, *Why Trimet Aluminium Is Betting On Enpot's Virtual Battery*, October 2017. https://aluminiuminsider.com/trimet-aluminium-betting-enpots-virtual-battery/

[23] The Verge, *The New Chevy Bolt Gained 21 Miles of Range Thanks To A Battery Chemistry Tweak*, August 2019.
https://www.theverge.com/2019/8/22/20828821/2020-chevy-bolt-259-miles-battery-upgrade

[24] Wired, *Tesla Has Created A Battery That Could Last One Million Miles*, September 2019
https://www.wired.co.uk/article/tesla-batteries-electric-vehicles

[25] Transport & Environment, *Batteries on Wheels: The Role of Battery Electric Cars In The EU Power System And Beyond*, 2019
https://www.transportenvironment.org/sites/te/files/publications/2019_06_Element_Energy_Batteries_on_wheels_Public_report.pdf

[26] European Association for Storage Energy, *Energy Storage: A Key Enabler for The Decarbonisation Of The Transport Sector*, February 2019
http://ease-storage.eu/wp-content/uploads/2019/02/2019.02.EASE-Energy-Storage-and-Mobility-Paper.pdf

3.2 Case Studies

3.2.1 Shenzhen, China's E-Buses Inspire Mass Electrification Adoption

Shenzhen is a young, fast-growing, industrial Chinese megacity with severe air quality problems. The city focused its mobility strategy around electrified city and fleet vehicles (e.g., buses, taxis) and extensive charging infrastructure. In late 2017 it completed a transition and converted its entire bus fleet (16,359 vehicles) to e-buses. As of mid-2019, nearly 100% of the city's 21,000 taxis are electric.

Buses and taxis consume large amounts of fuel and have high maintenance costs due to how often and how long these vehicles are typically used. These characteristics act in favour of the economics of electrification, since the higher upfront cost of EVs can be recovered through lower operating costs (e.g., electricity is roughly one-third the cost of diesel in Shenzhen) and fewer maintenance requirements.

Having adequate charging infrastructure in place enabled these electrification projects to be implemented at scale. The city has 300 e-bus chargers and about 8,000 EV charging stations integrated with street light poles. Shenzhen has also implemented strong regulatory policies limiting ICE private car ownership and use in the city (while exempting EVs from these limits). Overall, aggressive EV targets, e-bus, and e-taxi subsidies, strong regulatory policies limiting private car ownership and use, and using a nearby EV factory (BYD Company Ltd.) resulted in a successful electrification transformation for the city. The success of this programme was recognised in the 2019 Union Internationale des Transports Publics (UITP) Awards for the category of Outstanding Achievement.[27]

3.2.2 Santiago, Chile, Decarbonises with Zero-Emissions Public Transport

Inspired by Shenzhen's complete public bus electrification programme, Santiago is now Latin America's leading city for bus fleet electrification, boasting the highest number of electric, zero-emissions buses for the region. Santiago is one of the most polluted cities in Latin America,[28] frequently experiencing dangerous levels of air pollution. The Chilean government has actively addressed this by looking to decarbonise the city with zero-emissions public transport. Schemes include the deployment of e-scooters, cars, taxis, and trucks to increase the number of EVs tenfold by 2022 and the full electrification of public transport by 2050.[29] Switching a diesel bus to electric can accrue annual savings of up to 60 tonnes of carbon emissions.[30] One 2017 study by the UN Environment Programme

[27] UITP, *UITP AWARDS: Shenzhen Bus Group, World's First Bus Company to Achieve Full Electrification*, July 2019.
https://www.uitp.org/news/uitp-awards-shenzhen-bus-group-worlds-first-bus-company-achieve-full-electrification

[28] AirVisual, *Air Quality and Pollution City Ranking*, January 2020.
https://www.airvisual.com/world-air-quality-ranking

[29] Reuters, *Enel-BYD Say Chile Electric Bus Roll-Out Heralds More for Region*, December 2018.
https://uk.reuters.com/article/us-chile-environment-electricvehicles/enel-byd-say-chile-electric-bus-roll-out-heralds-more-for-region-idUKKBN1OC2M9

[30] Asia Times, *Chinese E-Buses Reducing Emissions in Chile*, June 2019.
https://www.asiatimes.com/2019/06/article/chinese-e-buses-reducing-emissions-in-chile/

estimated that the transition to a full e-taxi and bus fleet in Santiago would avoid 1,379 premature deaths by 2030.[31]

Following relevant success from a pilot test with two e-buses promoted by Enel X in 2016, the first lot of 100 e-buses were commissioned in Santiago in December 2018. This resulted from a tender launched by the Chilean public transport company, Metbus, that Enel X won.[32] [33] [34] Leveraging the success the first phase of fleet electrification, Enel X will supply an additional 183 e-buses to Metbus and 70 additional charging stations at the depots. The 285 e-buses in Santiago are the largest fully electric public transportation fleet in operation across Latin America, amongst the largest globally outside China.

The supply of this electric fleet came with the construction and management of two fully electric terminals (bus depots) designed, built, and operated by Enel X. They are equipped with 100 charging points. The electricity feeding the e-bus is provided by Enel from 100% renewable source and moreover solar panels have been installed at bus depots to serve the auxiliary consumption of the buildings. The e-bus depots can also leverage smart charging technology that intelligently optimise consumptions and power demand when the buses are charged. This results in a reduction of peak power consumption by 40% and a reduction of 50% in cost savings while ensuring that the buses are fully available for dispatch. In addition to the reduction in pollution and costs, the e-buses benefit travellers and the citizens of Santiago with substantially lower noise levels. High levels of passenger satisfaction have been reported about the e-buses. This is due to benefits such as the air conditioning system, the relative spaciousness, seat comfort, low noise, and reduction in pollution.

In addition to the technical and product innovations, this programme has been recognised for its innovative business model and funding scheme. It received a UITP 2019 award for Smart Funding, Financing, and Business Models.[35] Metbus coordinated deeper integration of the entire supply chain, partnering with Enel to supply the buses, charging infrastructure, and programme finance. It also partnered with BYD to provide a high performance maintenance agreement. The success of this initiative has inspired three other Latin American countries to adopt similar programmes.[36,37] The initiative is expected to be a catalyst for more widespread decarbonisation of public transportation in Santiago.

---

[31] Movilidad Eléctrica en Latinoamérica, *¿Te Imaginas Tu Ciudad Con Un Transporte Público 100% Eléctrico Al 2030? (Can you imagine your city with 100% electric public transport by 2030?),* November 2017.

http://movelatam.org/wp-content/uploads/2017/11/MOVE_28.11.2017_eMobility-City-Assessments_CHI_SANTIAGO.pdf

[32] Enel X, *Electric Buses, The Green Revolution On The Streets Of Santiago*, 2018.

https://www.enelx.com/it/en/news-media/news/2018/12/electric-buses-santiago-chile

[33] Enel, *An E-Bus Named Desire*, January 2019.

https://www.enel.com/stories/a/2019/01/enel-focus-on-santiago-chile-emobility-public-transport

[34] BYD, *Chile Incorporates 100 New BYD Electric Buses, Consolidating Its Commitment To Electromobility*, August 2019.

http://www.byd.com/en/news/2019-08-02/Chile-Incorporates-100-New-BYD-Electric-Buses%2C-Consolidating-Its-Commitment-To-Electromobility

[35] UITP, *UITP Awards: Metbus, Enel X And The City Of Santiago Overcome Barriers To Electromobility*, July 2019.

https://www.uitp.org/news/uitp-awards-metbus-enel-x-and-city-santiago-overcome-barriers-electromobility

[36] Reuters, Enel-*BYD Say Chile Electric Bus Roll-Out Heralds More For Region*, December 2018.

https://www.reuters.com/article/us-chile-environment-electricvehicles/enel-byd-say-chile-electric-bus-roll-out-heralds-more-for-region-idUSKBN1OC2M9

[37] Electrek, *Electric Buses Surging In Latin America, Chile Adding To Fleet As It Aims For All-Electric By 2040*, May 2019.

3.2.3 Bogotá, Colombia, Embraces Smart Infrastructure

Following Santiago, Bogotá also decided to move forward with the operation of 379 Integrated Transportation System e-buses. Through its advanced energy services business line, Enel X will be responsible for the design, construction, and supply of three terminals where the e-buses will be charged. Construction of the three terminals, started in November 2019 and are due to be delivered in the second half of 2020. The terminals will have an installed capacity between 8 MW and 10 MW and can simultaneously charge all buses through connected fast chargers.

As a complementary service, Enel X will build and manage three smart bus shelters adjacent to the three terminals where smart city services such as video surveillance, digital signage, and smart lighting will be offered to the passengers waiting to board e-buses. The company will also install 177 smart charging points and related infrastructure to ensure charging for the city's fleet. The integration of this fleet into the city's public transport system will place Bogotá amongst the cities with the largest e-bus fleet in the Latin American region.

---

https://electrek.co/2019/05/24/electric-buses-latin-america/

4. SUSTAINABLE SMART MOBILITY AND SOCIETAL BENEFITS

Cities and public agencies continue to invest in technologies focused on improving transit information delivery such as real-time arrival and departure times, local station maps, and service alerts. Transit companies are partnering with major ride-hailing service providers, such as Uber and Lyft, to let users view and purchase public transit rides through their apps. Uber is offering this service in Denver, Colorado, in partnership with the Regional Transportation District, and Lyft has partnered with over 25 transit agencies.

The availability of multimodal mobility options is prevalent in several major cities and its strong growth is expected to continue. The integration of several transport options into a simple transaction provides a pain-free user experience. Data collected on individual journeys is an essential tool in optimising the planning of transport services. Transport for London's (TfL's) multimodal public transport system, with the benefits of its advanced Oyster contactless payment system, provides a rich dataset to improve the service, safety, and to manage essential upgrades.[38]

Multimodal apps leverage data from transportation authorities and can combine this information with private mobility providers. For example, in London, Citymapper's journey planning app integrates the following to provide several optimised journey options:

- Public transportation modes: Bus, tube, train, ferry, tram
- Ridehailing services: Uber and other taxis
- Carsharing services: Zipcar
- Micro-mobility options: e-scooters, bicycle sharing schemes, walking

The quality of these multimodal apps is highly dependent on the data provided by the integrated transport services. TfL has an open data policy and provides a free application programming interface (API) to enable third-party developers to develop new applications. It is estimated that the economic benefits of this policy are up to £130 million per year,[39] which benefits customers, road users, London and TfL itself. This economic value is primarily derived from the time saved by travellers, the provision of quality data enabling travellers to travel more easily and make more journeys, and from the creation of commercial opportunities for third parties using open source data and API.

4.1 Public and Private Collaboration Streamlines Mobility

Improvements in transit system connectivity can improve operational efficiency and performance. Sensors can inform transit agencies in advance of diagnostic issues, enabling proactive maintenance and routes can be optimised based on passenger loading data. Some examples of this include:

[38] Intelligent Transport, *How TfL Uses 'Big Data' to Plan Transport Services*, June 2016. https://www.intelligenttransport.com/transport-articles/19635/tfl-big-data-transport-services/

[39] Transport for London, *TfL's Free Open Data Boosts London's Economy,* October 2017. https://tfl.gov.uk/info-for/media/press-releases/2017/october/tfl-s-free-open-data-boosts-london-s-economy

- **Linz, Austria:** City officials used a connected mass transit solution from Cisco Systems, Inc. and increased tram efficiency and performance while reducing energy consumption by 10%.

- **New York City, New York:** 11 of the 317 public bus routes in the city have been equipped with a system that enables buses to communicate with traffic lights to optimise journeys through city traffic.

Contactless payment systems contribute to the speed and efficiency of transit systems, bringing down costs and improving the passenger experience. According to Business Insider, over 100 contactless payment transit systems are in use around the world including major cities such as London, Toronto, and Sydney.[40] Smart cards (or contactless bank cards, Apple Pay, or Android Pay) eliminate the cost of printing tickets and maintaining fare equipment and reduce the overall cost of fare collection up to 30%.

Autonomous driving technologies have significant potential to benefit public transportation—the elimination of human drivers can substantially reduce the costs of travel. Driverless rail and metro are proven technologies in Singapore, Vancouver, Canada, and Dubai, United Arab Emirates. Trials of self-driving buses are also on the rise. For example, Stockholm, Sweden is working with Ericsson to conduct 6-month trials of two electric self-driving shuttle buses on public roads. A similar program is being deployed in Shenzhen. As autonomous driving technology for passenger vehicles matures, one of the prime applications for this technology will likely be for ride-hailing fleets. Several automakers including Daimler AG, Volkswagen, and Tesla, and ride-hailing companies such as Uber and Lyft are developing robotaxis to provide mobility as a service offerings.

Intelligent transportation systems (ITS) can utilise real-time traffic data and streaming analytics to help transport authorities make data-driven planning decisions to manage congestion. This could include where to install dedicated bus lanes, where to re-route vehicles in case of accidents or an emergency, and how to re-time traffic signals to better smooth traffic flow. For example, in early 2018, Dallas, Texas, partnered with Ericsson to upgrade its traffic management system. In addition to adjusting traffic signals across hundreds of intersections in real time, the system will also be connected to local transit systems. This will enable a bus rapid transit route to be prioritised through targeted green light timing. Some adaptive traffic control technologies, such as Trafitek's UTOPIA, are specifically designed for prioritising public transit at traffic lights.

4.2 Case Studies

4.2.1 Tokyo, Japan, Will Showcase Mobility Services During 2020 Olympics

Tokyo's highly developed and mature public transportation infrastructure serves the world's largest urban population of 38 million people. The transportation infrastructure is renowned for high levels of reliability, safety, cleanliness, and efficiency. Tokyo boasts the world's largest urban rail network, with 4,714 km of track and 2,210 stations, supporting a

---

[40] Business Insider, *Here's How Contactless Payments Are Revolutionizing Transit Around the World*, January 2019.
https://www.businessinsider.com/sc/contactless-payments-make-transit-easier-2019-1?r=US&IR=T

commuting workforce that makes 40 million daily train rides.[41] [42] Additionally, Tokyo's 320 km metro system has the world's highest daily metro usage of 8.5 million passengers. Only 14% of journeys were made by private car in 2008.[43] Furthermore, passenger journeys by taxi are steadily declining and ride-hailing services have yet to make a significant effect. Despite falling road transportation usage, Tokyo demonstrates advanced traffic management systems, using connected vehicle data and integration into ITS to minimise congestion and its environmental impact.

Tokyo is an exception to Japan's declining population trend, mainly due to strong internal migration.[44] Moreover, Tokyo will be most affected by a rapid increase in tourism (250% growth in from 2012-2017)[45] that will increase passenger journeys around the city. Tokyo will host the 2020 Olympics and Paralympics. This will provide opportunities to test the public transportation system under the heavy strain of millions of additional visitors, gain unique insights through trialling the technologies, and showcase its mobility services to the world.

Several mobility service initiatives are underway, such as Toyota Motor Corporation's e-Palette multipurpose autonomous EV, which can provide a variety of services depending on local demand. For example, it can bring services to those with limited mobility, but also can be purposed for mobile healthcare, delivery services, mobile office space, or conventional mobility services. This vehicle will be demonstrated while transporting athletes around the Olympic Village and between sporting venues.[46] Toyota Motor Corporation has also developed the Sora, a zero-emission hydrogen fuel cell bus that can provide a 9 kW supply for emergency power following disasters.[47] 100 of these buses will be deployed for public transportation in advance of the Olympics. Tokyo's metropolitan government will install a hydrogen station at the Olympic Village for these vehicles. Japan has a high proportion of elderly citizens; However, its public transportation is highly adapted to meet the accessibility demands of elderly passengers and those with disabilities. Another mobility initiative to further advance transportation for the disabled are autonomous electric wheelchairs developed by Panasonic. They have been trialled at Haneda Airport for eventual deployment at major airports during the Olympics.[48] These app-controlled wheelchairs are optimised for crowded spaces and can navigate to specific locations such as shops or boarding gates.

The Olympics will be an excellent opportunity to demonstrate leadership in sustainable and accessible urban mobility and share valuable lessons that can be applied elsewhere. The

---

[41] Wikipedia, *Transport in Greater Tokyo*, retrieved 31-01-2020.
https://en.wikipedia.org/wiki/Transport_in_Greater_Tokyo

[42] Ministry of Land, Infrastructure, Transport and Tourism, *Tokyo Metropolitan Area.*
http://www.mlit.go.jp/kisha/kisha07/01/010330_3/01.pdf

[43] Land Transport Authority. *Passenger Transport Mode Share in World Cities,* November 2011.

[44] Nippon.com, *Population Inflow to Tokyo Continues as Japanese Seek Commuting Convenience,* February 2019.
https://www.nippon.com/en/japan-data/h00385/population-inflow-to-tokyo-continues-as-japanese-seek-commuting-convenience.html

[45] Quartz, *The Rise in Tourists Visiting Japan Is Statistically Off the Charts*, May 2018.
https://qz.com/1283090/going-to-japan-youre-not-alone-tourism-is-booming-at-unprecedented-levels/

[46] Toyota, *Toyota Provides Diverse Mobility for Tokyo 2020, including a Full Line-up of Electrified Vehicles*, August 2019.
https://global.toyota/en/newsroom/corporate/29232815.html

[47] Toyota, *Toyota Launches Production Model "Sora" FC Bus*, March 2018.
https://global.toyota/en/newsroom/corporate/21863761.html

[48] Access and Mobility Professional, *Panasonic Trials Begin for Autonomous WHILL 'Smartchair'*, August 2017.
https://www.accessandmobilityprofessional.com/panasonic-trials-begin-autonomous-whill-smartchair/

1964 Tokyo Olympics showcased the launch of the Shinkansen bullet train, which still influences HSR transport around the world today.

4.2.2 New York, New York's Police Department Embraces Smart Cars

New York City (NYC) has a population over 8.6 million people. It is home to the New York City Police Department (NYPD), which consists of 36,000 officers and 19,000 civilian employees.[49] While on patrol, NYPD officers have used a variety of vehicles, including horses, scooters, and the iconic Ford Crown Victoria. In 2016, a new vehicle option joined the stable: the all-electric smart fortwo, manufactured by German carmaker Daimler AG (although now discontinued in the US).[50] Its introduction was aimed at replacing the three-wheel scooters commonly used by parking enforcement officers and others responding to incidents in areas difficult to access by conventional vehicles, such as Central Park.

Compared to the old three-wheel scooter previously used for certain enforcement duties, the smart fortwo safely and comfortably fits two patrol officers. Its climate control improves officer comfort and morale during hot summers and cold winters. For residents and visitors, the less-menacing appearance of the small two-seater cars promotes engagement with officers, who might otherwise be intimidating. Miss-branded a clown car by the media and midget car by a previous police commissioner,[51] a member of the 76th Precinct posted a photo showing its tallest officer, standing at 198 cm (6 feet 6 inches) tall, comfortably behind the wheel of his smart cruiser. After overcoming the somewhat comical appearance of this small car donning traditional NYPD Police cruiser markings, the vehicle is appreciated by officers, residents, and visitors.

EVs are quiet, relatively inexpensive to operate and maintain, and can fill a critical need of the fleet in an environmentally friendly manner.[52] [53] Small economical EVs can navigate the tight spaces found all over the greater NYC area, including the pedestrian walkway at Brooklyn Bridge Park. The NYPD has approximately 150 smart fortwos in service and scheduled another 75 for addition to the fleet.[54] NYC is protected and served by a more sustainable police force, contributing to improved air quality and health of its citizens while setting an example for the city.

4.2.3 Medellín, Colombia, Democratizes Transportation

Besides improving air quality and CO_2 emissions, the availability of public transportation can advance social inclusion by providing mobility to people unable to afford a private vehicle. This was the main motivation for the city of Medellín, Colombia, to invest in electrified public

[49] New York City Police Department, *About NYPD,* retrieved 31-01-2020.
https://www1.nyc.gov/site/nypd/about/about-nypd/about-nypd-landing.page
[50] Robert S. Martinez, The Electric Vehicle Revolution for Government Fleets, 2018.
https://www1.nyc.gov/assets/dcas/downloads/pdf/fleet/Robert_Martinez_NYPD_The_Electric_Vehicle_Revolution_for_Government_Fleets.pdf
[51] The New York Times, *Expanding Smart Car Fleet, New York Police Just Got More 'Adorable'*, December 2016.
https://www.nytimes.com/2016/12/01/nyregion/expanding-smart-car-fleet-new-york-police-just-got-more-adorable.html
[52] Government Fleet, *NYPD Replacing Scooter Fleet with Smart Cars*, February 2015.
https://www.government-fleet.com/128178/nypd-replacing-scooter-fleet-with-smart-cars
[53] New York City Police Department, *Police Vehicles*, retrieved 31-01-2020.
https://www1.nyc.gov/site/nypd/about/about-nypd/equipment-tech/police-vehicles.page
[54] Daimler, *New York City Police Department Orders 250 Smart Fortwos: Smart Forcops,* September 2016.
https://media.daimler.com/marsMediaSite/en/instance/ko/New-York-City-Police-Department-orders-250-smart-fortwos-smart-forcops.xhtml?oid=13772200

transport. With a population of around 3.9 million inhabitants, Medellín is a successful example of providing mobility to favelas and an interesting case study on social inclusion and regeneration. Until the early 2000s, the city, and especially its densely populated urban settlements, had an extraordinary track record of violence, theft and drug-related crime. The residents of these low-income hillside areas, known as barrios, on the fringes of Medellín were not well connected with the public bus transport system. Workers had to travel long times to reach their workplaces in the city centre, inhibiting development opportunities and reinforcing physical and social marginalization. The city features a steep topography and narrow streets, requiring innovative solutions to connect citizens to the city centre.

In 2004, the first line of the electric Metrocable aerial cable car was put into operation and there are now four lines in operation. Usage was high early on and the cable car helped to improve social inclusion and life quality in the barrios. The average journey from the barrios to the centre was halved. The cable car has co-benefits for the climate and the environment. It complements and partly substitutes the prior existing more emission-intense public buses. The project was registered for the UN Framework Convention on Climate Change Clean Development Mechanism (CDM). MyClimate, the monitoring agency for the CDM estimated that 121,029 tonnes of CO_2e (the CO_2 equivalent for various greenhouse gas emissions) were saved between 2010 and 2017.[55]

A key success factor for the project was the cooperation between local stakeholders in the planning process. This included the city authorities, the publicly owned Metro de Medellín company, the Proyecto Urbano Integral—an urban integration project—and residents. The majority of Medellín residents are proud of this communal transformation and feel a closer connection with their city. The successful project has been replicated in several Latin American cities.

[55] Myclimate, *Cable Cars Reduce CO2 In Medellin, Colombia*, 2012. https://www.myclimate.org/fileadmin/user_upload/myclimate_-_home/01_Information/02_News_Press/06_News_Import/Projectstory-Medellin-web.pdf

5. CONCLUSIONS

The electrification of EVs and public transportation has demonstrated a wide range of environmental and social benefits. The environmental benefits are due to the positive impact on climate change, which is especially true when electricity can be generated from RESs. Improvements to air quality have strong benefits on human health—the economic effect on healthcare costs and lost lives amounts to several billion euro per year.

Battery technology is advancing, improving durability, and reducing costs, which leads to the greater mass-market adoption of electrified transportation. The large-scale deployment of EVs can be leveraged to enable the use of their batteries as grid energy storage assets. Furthermore, the development of smart charging systems increases system flexibility, reducing the investments required to stabilize the grid. The energy for overnight charging of vehicles could be provided by wind plants, which otherwise would be wasted.

e-buses, with their significant energy capacities, can effectively behave as giant batteries on wheels and become instrumental in supporting system integration and reducing future grid reliability problems. A bus fleet has typically regular and predetermined timetables, which facilitates the scheduling of both charging and discharging to the grid. This will become increasingly important as EVs penetrate the vehicle market. Smart charging at depots significantly reduces peak power demand while enabling ancillary services that take advantage of the large battery capacity. V2G technology can provide further advantages and enables all vehicles to offer ancillary services and additional revenue for prosumers.

Electric public transportation provides considerable societal benefits. It is the most effective method to move large amounts of people to their destinations, minimising the congestion, time, and cost associated with commuting. An efficient system that meets traveller needs encourages behaviour change that lead to modal shifts.