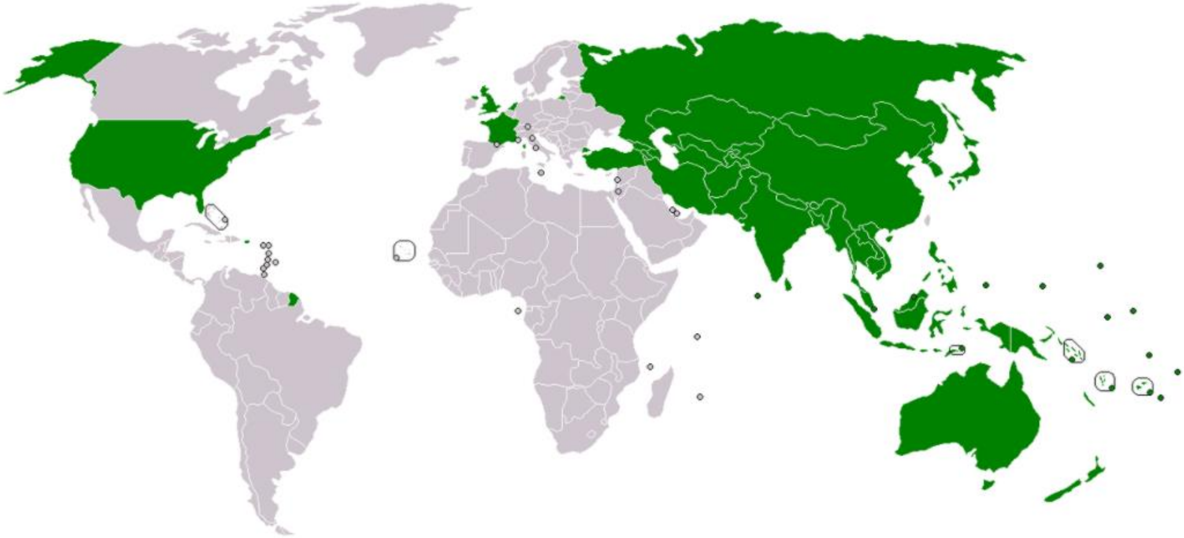
ELECTRIC MOBILITY IN PUBLIC TRANSPORT

A Guidebook for Asia-Pacific Countries

ESCAP

Economic and Social Commission
for Asia and the Pacific

2023



*The shaded areas of the map indicate ESCAP members and associate members**

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About the ESCAP E-Mobility in Asia and the Pacific Series

The Paris Declaration on Electro-Mobility and Climate Change & Call to Action highlighted fact that greenhouse gas emissions from the transport sector are set to rise by almost 50 per cent by 2050 unless major action is taken. It further states that limiting the global temperature increase to below 2 degrees Celsius requires *“changing the transport emissions trajectory through an integrated electromobility ecosystem encompassing various transport modes, coupled with the low-carbon production of electricity and hydrogen…”,* and that this transition will require “*at least 20 percent of all road transport vehicles globally to be electrically driven by 2030”*. Electric mobility, or e-mobility, is therefore at the centre of the fight against climate change.

While the number of electric vehicles is growing around the world, Asia is leading the global e-mobility revolution. Within Asia and the Pacific, several countries like China are ahead in EV adoption, while others are in the preliminary stages of the transition. The barriers for smaller countries, such as high import costs, the need for new safety and technical standards, and costs for developing charging infrastructure, seem particularly high. However, the e-mobility revolution also offers huge opportunities to reduce air pollution and raise the quality of public transport in the region.

Under ESCAP’s Regional Action Program for Sustainable Transport Development in Asia and the Pacific (2022–2026), governments agreed to establish *“a regional cooperation mechanism to promote low-carbon transport, including a shift to electric mobility and clean energy technologies to contribute to transport emissions reductions”* at the Fourth Ministerial Conference on Transport held at Bangkok in December 2021. ESCAP launched the Asia-Pacific Initiative on Electric Mobility in August 2022 to promote acceleration to the transition to electric mobility in public transport with the aim to reduce GHG emissions from the transport sector and support the implementation of the Paris Agreement. To support these efforts, ESCAP commissioned a series of policy-oriented reports on e-mobility in Asia and the Pacific. They include:

- *Electric Mobility in Public Transport: A Guidebook for Asia-Pacific Countries (2023)*
- *New Energy Vehicle Policies and Promotion in China (2023)*
- *Case Studies on E-Bus Development and Operation in China (2023)*

It is hoped that these reports will stimulate further exchange of information, knowledge and experiences between countries in the Asia and Pacific region. The support of the Government of China through the China-ESCAP Cooperation Fund is gratefully acknowledged.

CONTENTS

ABBREVIATIONS

2W	2-wheeler
3W	3-wheeler
4W	4-wheeler
AC	alternating current
ACEA	European Automobile Manufacturers Association
AMC	annual maintenance contract
BAU	business-as-usual
bcm	billion cubic meters of natural gas
BEV	battery electric vehicle
BMS	battery management system
CAPEX	capital expenditure
CCS	combine charging system
CHAdeMO	CHArge de MOve
CI	charging infrastructure
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DC	direct current
e-bus	electric bus
e-mobility	electric mobility
EC	European Commission
EP	Equator Principles
ESG	Environmental, Social, and Governance
ESP	energy service provider
EU	European Union
EV	electric vehicle
FAME	Faster Adoption and Manufacturing of Electric and Hybrid Vehicles in India
GCC	gross cost contract
GCF	Green Climate Fund
GEF	Global Environment Facility
GHG	greenhouse gas
GVW	gross vehicle weight
HT Lines	high tension lines
ICE	internal combustion engine
IEC	International Electrotechnical Commission
IPT	intermediate public transport
ISO	International Organization for Standardization
ITMS	Intelligent Traffic Management System
ITS	Intelligent Transportation System

km	kilometre
kWh	kilowatt-hour
Lao PDR	Lao People's Democratic Republic
LDV	light duty vehicle
LFP	lithium-ion phosphate
LPG	liquified petroleum gas
LTO	lithium titanate
MIS	management information system
Mt	megatonne
MW	megawatt
NDC	Nationally Determined Contributions
NEV	new energy vehicle
NMC	nickel manganese cobalt
NO_2	nitrogen dioxide
O&M	operations and maintenance
OEM	original equipment manufacturer
opex	operational expenditure
OPM	outright purchase model
PHEV	plug-in hybrid electric vehicle
PLI	production linked incentive
PRI	Principles for Responsible Investment
PT	public transport
PTA	public transport agency
RCS	regulations, codes and standards
SDGs	Sustainable Development Goals
SDO	standard development organizations
TCO	total cost of ownership
TOSA	Trolleybus Optimisation Système Alimentation
UN	United Nations
UN ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
ZEV	zero emission vehicles

Glossary

bus operator	Private / public sector entities who are legally or contractually obligated to operate Public Transport (PT) buses.
business model	Business model in the context of PT indicates an arrangement between different stakeholders involved in the provision, operation and maintenance of PT and its infrastructure.
energy service providers (ESP)	ESPs in the context of PT are entities, usually private, who provide services relating to energy needs of electric vehicles, such as battery charging and creation of charging infrastructure.
EV drivetrain	The system responsible for delivering power from the battery to the wheels in an EV, made up principally of three main components: the electric motor, drive shafts, and transmission.
fleet operators	Entities who operate large fleets of vehicles for purposes of transporting either people or freight.
gross cost contract (GCC)	Type of PT operator contract where the Operator is responsible for operating buses against pre-determined per km (and/or per bus hour) payments. Fares are collected and retained by the PT Agency.
low-carbon transport	Transport system that prioritizes lower carbon emitting systems over others, thus encouraging use of cleaner and efficient energy sources.
net cost contract (NCC)	The type of PT operator contract where the Operator which runs the buses also collects fares to pay for its operational costs. Unlike in GCC, the risk of any revenue shortfall to meet operating costs lies with the Operator.
outright purchase model (OPM)	The traditional procurement arrangement used by PT agencies where they purchase the fleet rather than leasing it or hiring an operator who owns and operates the fleet.
public transport agency (PTA)	An entity or organization that is legally or contractually mandated to provide PT services in a particular jurisdiction.
public transport operators (PTO)	A public or private sector entity providing and operating PT services.
total cost of ownership (TCO)	In the context of an EV, the total cost of ownership is the total cost for owning and operating an electric vehicle over its lifecycle, and includes both its capital and operating costs.

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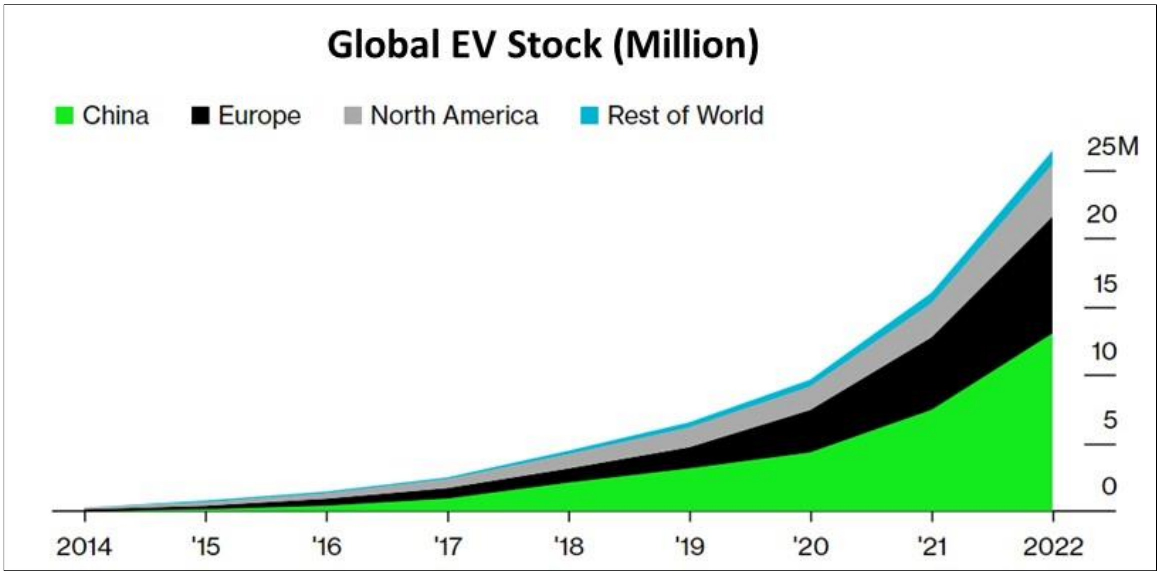
1 INTRODUCTION TO THIS GUIDE

The transport sector plays a vital role in the economic and social development of countries by providing access to activities and services. However, it is also responsible for negative externalities which affect the environment. Currently, the transport sector relies heavily on fossil fuels, contributing to over one third of total carbon dioxide emissions in 2021 (IEA, 2021). Since 2010, the transport sector's emissions have increased faster than any other end-use sector, averaging an average annual growth of 1.8 per cent. It represents the largest energy-consuming sector in 40 per cent of countries worldwide, and is the second largest in most of the remaining countries (Jaramillo et al., 2022).

Many countries in the Asia and Pacific region promote low-carbon transport through their Nationally Determined Contributions (NDCs). NDCs are primarily focused on the promotion of public bus transport, alternative energy sources, and electric mobility (mainly electric vehicles, or EVs). Indeed, EVs are becoming the fastest growing type of vehicles being sold across the world (*Figure 1*).

Figure 1. Global EV stock



Source: McKerracher (2022)

Public transport is sometimes considered to be "low-hanging fruit" for EV adoption, for three key reasons: (i) public transport vehicles cover larger distances daily, so replacing them with EVs would lead to significant reductions in GHG emissions; (ii) public transport vehicles emit more GHG on a per vehicle basis, but lower on a per passenger basis than cars; and (iii) public transport is mostly under public regulatory control, creating space for government policy interventions to shape its development. There is thus a strong case for supporting EV adoption in public transport in countries in Asia and the Pacific.

While a strong international consensus exists on the prioritization of low-carbon modes of transport, actionable policy measures are still evolving. Even where identified, implementation is challenging for some countries, particularly those which lack the necessary expertise, technological know-how, and financial means.

To assist governments towards this end, this Guidebook offers frameworks, policy goals, strategies, and instruments to accelerate the adoption of EVs in public transport systems. Public transport takes many forms, such as rail-based systems (metro systems, trams, cable cars, monorail), bus-based systems (Bus Rapid Transit, trolleybuses, normal bus systems), and intermediate public transport (IPT) (smaller vehicles such as two and three wheelers-based PT). Rail-based systems already use electric traction, so this guidebook will primarily focus on the electrification of buses and IPT fleets.

This Guidebook draws on ESCAP's Project for Promotion of EVs in Public Transport. Drawing on the experiences of five pilot countries, namely Georgia, Lao People's Democratic Republic (Lao PDR), Nepal, the Republic of Fiji, and Thailand, as well as the experiences of other Asian countries, the Project intends to build the capacity of governments in Asia to develop policies and strategies to electrify their public transport fleets. The Guidebook is divided into the following steps, which may be followed either in sequence, in parallel, or in a different order, depending on the context.

2. Preparing for Policy Development

Step 1: Identify the objectives and make a case for electric mobility in public transport in your country.

Step 2: Identify the barriers around EV adoption in public transport.

Step 3: Learn from the EV policies of other countries.

3. Formulating a Targeted Policy Package

Step 4: Understand the EV-based public transport ecosystem and stakeholders involved.

Step 5: Formulate targeted policy framework choosing from a standard policy and stakeholder template.

Step 6: Establish national standards for EVs.

4. Implementing the Transition

Step 7: Assess feasibility of electric bus fleets and charging infrastructure.

Step 8: Procurement, financing and business models for EVs in public transport.

Step 9: Carry out pilot projects in stages, according to promotion objectives, technical development status and operational models.

5. Manging the Transition

Step 10: Workforce skill development.

Step 11: Prepare for and manage end-of-life issues of EVs and battery disposal.

It is hoped that governments officials and policymakers, service providers, public transport and intermediate public transport agencies, operators and vehicle manufacturers will find this Guidebook useful for planning their own e-mobility transition.

2 Preparing for Policy Development

Step 1: Identify the objectives and make a case for electric mobility in public transport in your country

Step 2: Identify the barriers around EV adoption in public transport

Step 3: Appreciate the EV policies of other countries

Step 1: Identify the objectives and make a case for electric mobility in public transport in your country

As a first step, policymakers must be clear about the objectives of EV adoption in their public transport sector. Key stakeholders must understand and promote the critical advantages that low-carbon and electric mobility-based transit systems bring. Some of the common advantages are listed below, although different countries may have different priorities.

Emissions Reduction

Urban passenger transport is responsible for 40 per cent of all passenger related transport GHG emissions (ITF, 2021). Fossil fuel dependent heavy-duty vehicles like buses contribute significantly to these emissions. Emission reduction in denser urban environs with its attendant health benefits remains perhaps the most significant policy motivation for switching to EVs.

If cleaner sources of energy are used, not only tailpipe but also source emissions are eliminated. Battery Electric Vehicles (BEVs) have lower life cycle greenhouse gas emissions than internal combustion engine vehicles (ICEVs) when charged using low-carbon electricity (Gao, 2022). Stakeholders can also estimate quantities of CO_2 emissions removed from city traffic under different levels of electrification to buttress the case for policy support. If cleaner sources of energy are yet to be harnessed fully, this can become an additional argument to push the case for clean energy.

Energy Security

Using electric buses in PT could strengthen energy security. Currently, many countries are dependent on imported fossil fuels to drive transport. These imports may be reduced as the energy source is diversified away from oil. If the electricity produced is through renewable sources, or domestic sources, energy security for the country will be strongly enhanced.

Balance of Payments

Reductions in imported fossil fuels will lead to lower current account deficits and savings in foreign exchange, strengthening the country’s forex reserves. Countries such as Nepal and Lao PDR produce much of their electricity from renewable sources. Lao PDR even exports electricity to neighbouring Thailand. However, other countries spend a lot of their precious foreign exchange on fossil fuel imports for transport. A switch to electric mobility can help save foreign exchange and improve the country’s trade deficit and balance of payments.

Cost Savings

Several studies have revealed that the life cycle cost of electric buses (TCO, or total cost of ownership) is getting closer to fossil fuel-based buses, and are even comparable under certain conditions. A 2018 study (Potkány et al., 2018) set the difference at 22 per cent, thus establishing a level for governments to co-finance buses through policy measures. Meanwhile, a 2019 study for Nepal concluded that savings on fuel cost and maintenance cost of electric buses can offset the higher purchase price of an e-bus if additional local environmental benefits are taken into account or if bus life is taken at 10.7 years (Rijal et al., 2019). In countries where existing fossil fuel buses are of high quality and are expensive, equalising the TCO values is still a few years away. As prices of lithium-ion batteries plateau in the future, and advantages of scale production are harnessed, prices of EVs are expected to drop further. This will create an opportunity for public transport agencies (PTA) to reduce overall costs. Even now, if initial costs for vehicle purchase are subsidized, considerable cashflow savings could materialize as EV operational costs are lower.

Access to Green Funds

Governments can access “Green Funds” to help finance their e-mobility transitions. “Green Funds” are investment funds whose portfolios are mainly based on Environmental, Social, and Governance (ESG) criteria. Major flagship programs in this area exist, such as Principles for Responsible Investment (PRI), Equator Principles (EP) for financial institutions, and the UNEP (United Nations Environment Programme)’s Statement of Commitment by Financial Institutions on Sustainable Development, which suggests ways for implementing green finance among the signatories (RBI, 2021). The Environment Fund is UNEP's core source of flexible funds. Other funds include the Global Environment Facility (GEF), the Green Climate Fund (GCF) and the European Commission (EC) (UNEP, n.d.).

Alignment with Sustainable Development Goals

Both the Paris Agreement and the UN 2030 Agenda for Sustainable Development call for emission reductions through commitments to clean fuels, public transport, electric vehicles and other low-carbon modes of transport. Transport is linked to SDGs 3,7,9,11,12 and 13. Many countries have made commitments to transport in their NDCs.

Public transport is the low hanging fruit for EV adoption

While low on per-passenger basis, emissions from larger vehicles like buses are often high in terms of absolute contribution to overall emission volumes. This is because buses not only use heavy duty engines, but they also travel slower, longer and need to stop more often. Public transport is also often controlled or regulated by the government, which creates opportunities for policy interventions to shape EV development. Finally, public transport services operate in fleets which need captive charging and cannot rely on public charging networks. Creating captive charging facilities is easier than establishing a network of public charging stations and can also be more easily linked to captive renewable sources, such as solar panels on bus depots or terminal rooftops.

Given the above, public transport, and particularly buses, offer the largest emission mitigation potential, especially in dense urban areas where the adverse health impacts of emissions are the greatest. There is a huge opportunity to electrify buses and other forms of public transport, such as two-wheelers and IPT, under the “Improve” component of the Avoid-Shift-Improve framework for transport emission reduction strategies. While efforts such as land use and urban design, demand management programs, transport integration, and so on, are also relevant, e-buses represent an important opportunity with a large impact potential in relation to the costs and efforts required.

Step 2: Identify the barriers around EV adoption in public transport

The next step is to identify major barriers that inhibit successful adoption of EVs, and then develop mitigation strategies. While country contexts vary, some common barriers are described below, together with possible mitigation options.

Barrier 1: EV cost barriers

EVs relevant for public transit and commercial fleets are electric buses, electric taxis and in some countries, IPT modes like electric two- and three-wheelers. Even though these EVs can be competitive with conventional vehicles on a TCO basis (with, or in some cases without, government financial support), high upfront costs are a major barrier. While e-buses and e-taxis are priced higher compared to their fossil fuel counterparts, other IPT modes like two- and three-wheelers are less so. Evaluating the vehicle TCO to compare EVs with fossil fuel vehicles will allow the government to determine the amount of monetary incentives needed to make EVs cost competitive. When determining this, it should be kept in mind that over time, EV costs will come down, and hence incentives need to be reduced and then phased out. Hence EV cost trends should be noted and forecast. At the same time, there is an opportunity to set up disincentives for emission ridden fossil fuel vehicles to accelerate the transition.

Barrier 2: Availability and supply of EVs could be constrained.

Many countries do not have their own vehicle manufacturing industry. Small countries like Nepal, Lao PDR, and Republic of Fiji import their vehicles. Some countries, such as Thailand, are seeing this as an opportunity to manufacture their own EVs. Adoption is strongly linked to availability and supply. EV penetration is seen to be associated with availability of a larger number of models. Importing vehicles reduces design choices and is expensive and cumbersome. PTAs which purchase vehicles through complex procurement processes often have a hard time convincing suppliers to be part of their long procurement cycles.

Governments therefore need to identify policies that increase supply and choice of models. This may be done by easing import permits and documentation, reducing import tariffs, allowing foreign manufacturer sales and service presence, and permitting direct pre-purchase outreach to manufacturers in other countries.

Barrier 3: Feasibility of adopting EVs in terms of range, convenience and reliability

The principal anxieties for potential EV consumers are the range of a single charge and time to recharge. Public transport fleets have even more serious route obligations than individual owners. They travel longer distances daily, with fixed time available to refuel or recuperate. Feasibility of meeting such service obligations constitutes a strong barrier in switching. Further, there are several vehicle technologies to choose from, such as pantograph based (for buses), plug-in, battery swap, and so on. Electric buses may use either lithium titanate (LTO) and lithium-ion batteries.

To switch to electric fleets, PTAs need to determine the nature of replacement electric fleets required to maintain or improve existing service levels. Considerations relating to range, capacity, comfort, driver convenience and safety need to be factored in the decision process. Many PTAs have successfully overcome these barriers by using Proof of Concept experiments, pilot projects and phased introduction of electric vehicles, typically timed with re-fleeting. For instance, both Chinese and Indian cities have introduced electric buses in phases, with the first phases limited to a smaller fleet. The experience gained from this was then used to expand to larger fleets. More discussion in this area is described in Chapter 4, Step 7 “Assessing Feasibility of Bus Electric Fleets and Charging Infrastructure”.

Barrier 4: Availability of charging infrastructure

Perhaps the most widely known barrier to EV adoption is charging infrastructure. Studies of China’s experience have shown that “compared to consumer subsidies, investment in charging infrastructure is about four times as cost-effective in promoting EV sales” (Li et al., 2022). Studies for other countries have shown this to be true elsewhere too, but not as much as in China (Li et al., 2017). In other words, it is more cost effective to subsidize charging infrastructure than to subsidize EV purchases.

The type of charging varies by vehicle. While cars and two- and three-wheelers can also be charged at home, fleets typically need heavy-duty captive charging, as seen for buses in Guangzhou, China (*Figure 3*). Electric buses need high voltage electricity, drawn directly from the grid using a separate array of step-down transformers. *Table 1* provides a simple overview of the type of charging for different vehicle types.

Figure 2. Charging infrastructure in Guangzhou City, China

Source: Alamy

Table 1. Type of charging applicable for different types of vehicles

	Home Charging	Public Charging	Captive Charging
Buses	No	No/limited	Yes
Cars / Vans	Slow (on charger supplied with vehicle)	Fast (using faster chargers)	Yes for fleets
Three Wheelers	Regular	Possible with high cost barriers	Yes for fleets
Two wheelers	Regular	Possible with high cost barriers	Yes for fleets

Source: Author

Each type of charging has implications in terms of land and space requirements, urban planning, business models, cost recovery, availability of electricity power, and safety-related regulations (for example, electricity is not allowed to be resold in many jurisdictions). These factors need to be considered while planning for EVs, whether for public or private transport.

Appreciating the barriers to EVs, such as the ones described above, will allow policymakers to target their efforts and help accelerate the take-up of electric mobility.

Step 3: Learn from the EV policies of other countries

The expansion of global EV markets has been actively supported by generous incentives and policies, such as direct purchase incentives, tax credits, indirect mechanisms and special treatments. At the same time, policies to discourage the use of fossil fuel vehicles are also being introduced. Both these factors seem to have contributed to high EV penetration. The total financial incentives are estimated to have been $43 billion from 2013 to 2020 in the top 13 EV markets, and were responsible for inducing around 40 per cent of total EV sales during the period (Foster et al., 2021).

Learning from the EV policies of other countries can inform your policy designs. Examples of key EV policies in selected Asian countries are presented in *Table 2*. It may be pointed out that no country is likely to develop a specific policy for electrification in PT alone, and PT related packages are incorporated in the main EV policy frame. Some general observations are:

Variations in EV penetration across countries are associated with variations in policies and incentives

A World Bank study on EV adaptation in 16 countries (Li et al., 2021) points out that a "*highly uneven EV penetration across countries is partly driven by cross-country variation in incentives and especially in the availability of charging infrastructure*." In Asia, this has been shown in the example of China, particularly in public transport, where national, regional and city policies are leveraged to deliver impactful transformation at the local level. Lately, policies in India such as FAME, or Faster Adoption and Manufacturing of Electric and Hybrid Vehicles, have been instrumental in transforming electric bus landscape in the country. This policy is a prime example of prioritising PT within the overall EV policy landscape. In a nutshell, the penetration of EVs would be weaker in a non-incentivised scenario, particularly for public transport.

Nations seem to have adopted a comprehensive approach for promoting EVs

Since EVs exist as an ecosystem, simultaneous development of each component of the EV ecosystem is required for faster adoption. Policies which strengthen one part of the market will impact other parts; for example, the deployment of electric vehicles needs a well-developed network of charging stations. This, in-turn, escalates the need for a balanced power grid management system. This is reflected in different country experiences. In the case of Singapore, the rate of adoption had been limited, despite fiscal incentives, because it lacked supporting infrastructure. As a result, the government rolled out an initiative in 2020 to promote charging stations across the country. The World Bank study referred to above concluded that "*the variation of EV market shares would be reduced by 69% among the top 13 EV countries if all countries had the same size of charging* *network (at the global average). Whereas the dispersion of EV market share would be only reduced by 17% if all countries had the same level of subsidies for EV purchase*" (Li et al., 2021). For captive systems such as public transport in particular, the supporting infrastructure plays a critical role.

Incentives, both fiscal and non-fiscal, are a major driving force for EV adoption.

Fiscal incentives are a major driving force for EV adoption, with purchase incentive and exemption of taxes and registration charges for EVs being a common strategy in most countries. Manufacturers are also provided incentives to reduce capital outlays. For example, India provides a Production Linked Incentive (PLI) for battery manufacturing. Non-fiscal incentives, such as providing free parking spaces for EVs, access to priority lanes, creating low emission zones, etc., also feature in a lot of policies.

Policies at multiple governance levels enhance the implementation process

Countries such as India, China, and Australia have prepared state and/or city level policies in line with their national policies. Some states have prioritised manufacturing by providing incentives. Cities provide land on lease for charging stations. Some cities in China and India received national and state funding for large purchases of E-bus fleets. Cities took this opportunity by augmenting these incentives with their own resources, which they might not have done without the trigger of the national or state incentive.

Table 3 shows city-level examples for Shenzhen, China; Surat, India; and Seoul, Republic of Korea. *Table 4* provides a snapshot of low carbon transport policies in the five pilot countries under this project, namely Georgia, Lao People's Democratic Republic, Nepal, Republic of Fiji, and Thailand.

Table 2. EV Policies Across Selected Asian Countries

Country	China	India	Malaysia	Republic of Korea	Singapore
Key Targets and Goals	>80% NEVs in new (or replaced) public fleets (e.g., buses, taxis, delivery vehicles) in pilot zones and key air pollution regions by 2025. 100% electrification of the public fleet stock by 2035 (IEA, 2021).	30% share of EVs in passenger LDV sales by 2030 (IEA, 2021).	80% reduction in land transport emissions by 2050. 100% (electrified, CNG, LPG or biofuel vehicle) stock for all private transport by 2030 and 40% in public transport (across all modes) (IEA, 2021).	The 2020 Policy planned to subsidise 99,950 electric vehicles; 65,000 passenger cars, 13,000 freight cars, 650 buses, 21,000 motorcycles, and 300 PHEVs.	By 2030: 1) All new car & taxi registration to be of cleaner-energy models 2) Government to deploy 60,000 EV charging Points By 2040: All vehicles run on cleaner energy. (LKH Electric, 2021)
Electricity Generation by source (Share in % in 2021) (Ember, 2022)	Coal: 62.93% Hydro: 15.32% Wind: 7.73% Nuclear: 4.8% Solar: 3.85% Gas: 3.21% Bioenergy: 2% Other: 0.14%	Coal: 74.17% Hydro: 9.36% Solar: 3.99% Wind: 3.97% Gas: 3.75% Nuclear: 2.56% Bioenergy: 2.07% Other: 0.13%	Coal: 44.39%, Gas: 36.39%, Hydro:16.78%, Bioenergy: 0.94% Solar: 0.86% Other: 0.64%	Coal: 35%, Gas:30%, Nuclear: 26%, Solar: 4.12%, Bioenergy: 1.65%, Other: 1.22% Hydro:1%, Wind: 0.55%,	Coal: 44.39% Gas: 36.39% Hydro: 16.78%, Bioenergy: 0.94%, Solar: 0.86%, Other: 0.64%
Focused Modes	Multiple Vehicle Categories	Public Transport - Buses	Multiple Vehicle Categories	Cars, Buses, 2-wheelers	Public Transport - Buses and Rails, Taxis
Fiscal Incentives	Introduced generous subsidies starting from 2009. Extended beyond the original 2015 expiration date and continuing (in a phased manner in the last few years) (Interesse, 2022).	Subsidies are provided based on battery sizes for 2-wheelers, 3-wheelers, 4-wheelers and trucks; primary focus is on buses (India, 2019).	Direct and indirect tax relief for assembly or manufacture of EVs, component parts, and the development of EV ecosystems such as charging facilities (MIDA, 2021).	The direct subsidies and tax incentives available to BEV buyers add up to a substantial monetary benefit. Subsidies were reduced in a phased manner (Kim & Yang, 2016).	Fiscal incentives like subsidies and tax exemption are supporting adoption of electric cars for private and corporate purposes.

Country	China	India	Malaysia	Republic of Korea	Singapore
Public Transport	Cities like Shenzhen, Tianjin, Zhengzhou have achieved 100% bus fleet electrification (Yiyang & Fremery, 2022).	Demand incentives for buses are provided only for procurement under operational expenditure model (India, 2019).	Malaysia is in the initial phase of procuring electric buses. It is exploring various business models.	From 2021, public bus companies are required to purchase only zero-emission vehicles, starting with replacements.	All of Singapore's 5,800 public buses to run on cleaner energy (electric and hybrid) by 2040.
Charging Infrastructure	1,000 battery swap stations and production of more than 100,000 vehicles capable of battery swapping (IEA, 2021).	To set up 2,877 charging stations in 25 states and 1,576 charging stations across 9 expressways and 16 highways (IEA, 2021).	To set up 9,000 alternating current charging stations and 1,000 direct current charging stations by 2025 (IEA, 2021).	The country will have 500,000 EV charging stations by 2025 (Yonhap, 2020).	Aims to deploy 60,000 EV charging points across Singapore by 2030 (40,000 in public car parks and 20,000 in private premises) (LTA, n.d.).

Source: Collated from various sources, as indicated.

Table 3. City level EV policies in China, India and Republic of Korea

Country	Shenzhen, China	Surat, India	Seoul, Republic of Korea
Target Modes	Buses and Private Cars	2-Wheelers, 3-Wheelers, Cars and Buses	Cars, Buses, 2-Wheelers
Fiscal Incentives	• Regional subsidies, tax incentives provided for BEV passenger car (based on the electric range were provided) and BEV Buses. • Electric taxis were exempted from fuel tax and regional subsidy	• State subsidy on cars and 2W & 3W • Vehicle Tax exemption – 100% on 1st year, and reduced in phased manner. • 100% Rebate in Environment Improvement Charge • Rs.5000 per Pink Auto (3W)	• Subsidies for the purchase of electric and hydrogen vehicles was 94,000 units, an increase of 57% from 60,000 units in 2019. • Reduction in Vehicle Tax is proposed.
Regulatory Strategies	Car number plate lottery (20,000 NEV) scheme introduction. Number plate restrictions for fuel vehicles.	• Free parking for EVs on parking lots operated by the city. • City Municipal Corporation Employee vehicles and garbage collection vehicles to shift to EV in a phased manner.	• Lowering the prices of electric vehicles by 10 million KRW by 2025 by focusing on local manufacturers like Hyundai. • Battery Leasing to cut CAPEX by nearly half.
Public Transport	For NEV Buses, funding covered by Shenzhen City and bus supplier BYD through third party finance.	State level viability gap funding for procurement of E-buses.	From 2021, public bus companies to purchase only ZEVs starting with replacing older fossil fuel vehicles.
Charging Infrastructure	• Optimized charging and operation to have 1:3 ratio (charging station: e-buses). • All e-buses to be charged overnight when electricity prices are low, and recharged at terminals during off-peak travel times.	• Targeting to install 500 Public / Private Charging Stations or points • Municipal Corporation shall provide land on rental basis for first 2 years and revenue sharing basis from 3rd year.	The Government to install 70 units of 350 kW-class ultra-fast chargers that can charge vehicles three times faster than chargers already installed (from next year on PPP basis).

Table 4. Snapshot of low carbon transport policies in pilot countries

Country	Georgia	Lao PDR	Nepal	Republic of Fiji	Thailand
NDC Commitments	Georgia submitted its revised NDC in May 2021 (Georgia, 2021). • Reduce greenhouse gas emissions by 50-57% by 2030 compared to 1990 levels, subject to international support. • Greenhouse gas emissions reduction target to 35% by 2030 compared to 1990 levels.	Lao PDR submitted its revised NDC in May 2021 (UNDP, 2021). • Unconditional emission reduction target of 60% by 2030, relative to the baseline scenario. • Strengthened mitigation measures in the forestry and energy sectors. • The revised NDC references circular economy as a key instrument to pursue a low-carbon development pathway.	• Updated NDC, Long Term Strategy & Net Zero Target submitted • Net Zero by 2045 after achieving low emissions during 2020-30.	Republic of Fiji's emission reduction target focuses on the energy sector, specifically on electricity generation and transmission and demand-side energy efficiency (Fiji, 2019). The 30% target includes: • 20% reduction in GHG emissions by achieving 100% renewable electricity generation in power sector. • Additional 10% reduction in GHG emissions is expected from economy-wide reduction in CO_2 emissions, implicitly from transport, industry and electricity demand sectors.	Thailand submitted its revised NDC in Oct. 2020 (UNDP, n.d.). • Unconditional NDC: Reduce greenhouse gas emissions by at least 20% from business-as-usual (BAU). • Conditional NDC: up to 25% from BAU by 2030.
Electricity Generation by source (share in %)	Hydro:80.49%, Gas:18.8%, Wind: 0.71%, (2021)	Hydro: 56%, Biogas: 22%, Biomass: 11%, Solar: 11% (2013)	Hydro: 100% (2019)	Hydro: 55%, Biomass: 5%, (2013) (Energypedia, 2022a)	Gas: 64.54%, Coal: 20.58%, Hydro: 2.57%, Solar: 2.32%, Wind: 2.28%,

Country	Georgia	Lao PDR	Nepal	Republic of Fiji	Thailand
(Ember, 2022)					Other:0.4% (2021)
ZEV Share, strategies and ZEV in Public Transport	• Current EV Share: 1.21% (2019) • Based on vehicle registration 2021, 6.4% hybrid vehicles and 0.2% electric vehicles were registered in Georgia (Georgia, 2022) • 95% of electric vehicles imported to Georgia are used ones (Georgia, 2022).	Existing ZEV Share: <1% Targets: 1% of the cars sold to be electric by 2025, and 30% by 2030 (Department of Promotion and Energy Saving, 2022).	Existing ZEV Share: <1%	• Launched first-ever environmentally friendly electric vehicle (Electric Car – MG ZS EV) in May 2022 (S. Prasad, 2022). • Planning to pilot Electric Buses with local technical capacity to operate and maintain e-bus transportation (Vula, 2022).	-

Source: Collated from various sources, as indicated

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Step 4: Understand the EV-based public transport ecosystem and stakeholders involved

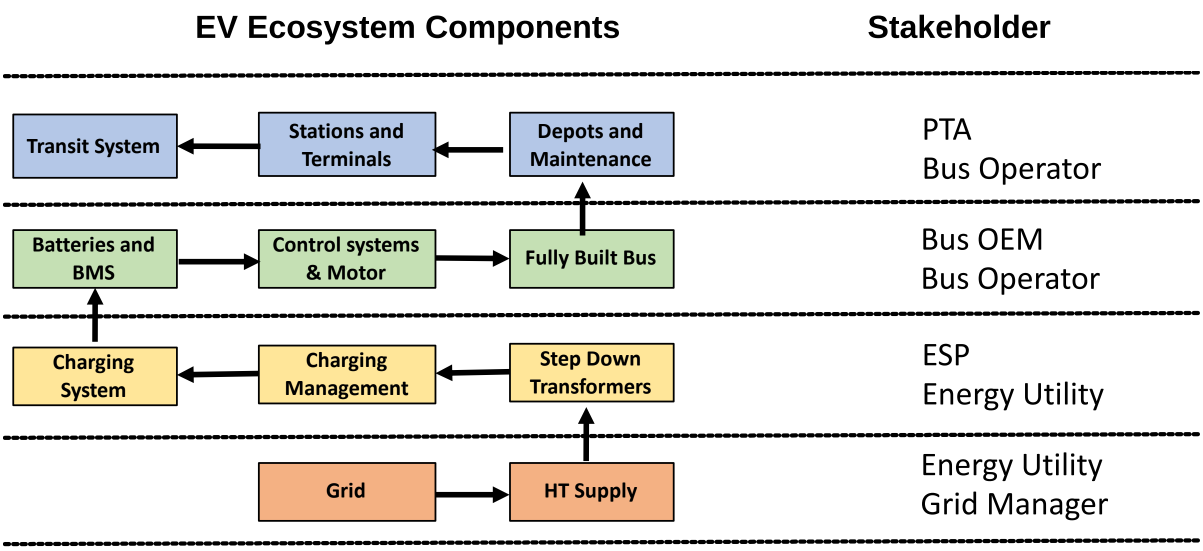
Step 5: Formulate targeted policy framework from a standard policy and stakeholder template

Step 6: Establish national standards for EVs

Step 4: Understand the EV based public transport ecosystem

EVs are a cross-sectoral issue, with their own networked ecosystem. Success of one sub-system influences the success of others. Hence it requires action and collaboration among its many stakeholders. For example, a typical E-bus based Public Transit System would involve an ecosystem related to (i) the main transit ecosystem component, (ii) the electric vehicle component, (iii) the charging system and its power supply and (iv) the grid and bulk power supply systems (*Figure 3*). Each component involves multiple stakeholders, as described in *Table 5*.

Figure 3. An illustration of an EV ecosystem



PTA: Public Transport Agency, OEM: Original Equipment Manufacturer, ESP: Energy Service Provider

Source: Author

Efforts to introduce EVs into a public transport ecosystem, therefore, need to be a well-coordinated effort, led from the top. For instance, in both China and India, the initial efforts were led by the central government with strong policies. These then percolated down to city governments, who led the difficult transition. Specific working groups could be formed to understand each component of the ecosystem and make recommendations to the top executive authority. External subject experts should be made part of such working groups. City governments, public transport authorities, vehicle manufacturers and utility managers should be represented in these groups. *Table 5* shows the list of key stakeholders, their roles, and their possible contributions, though the situation may vary from country to country.

Table 5. Key stakeholders and their possible roles in the EV ecosystem

Stakeholder	Possible Role
Central Governments	• Emissions regulations for vehicles • Policy formation • Funding for EVs in public transport • Import taxes • Electricity price and taxes • Establish technical standards for vehicle and charging • Empower research and academic institutions • Model documents and training frameworks • Promote EV manufacturing • National targets, commitments and phasing • Scrappage and battery recycling regulations • Zero Emission Vehicle (ZEV) mandates for manufacturers
Local/ Regional/ City Governments	• Vehicle registration charges and toll exemptions for EVs • Determine preferential parking and parking charges • Stipulate low emission zones, accessible for only zero emission or low emission fuel vehicles • Mandate conversions or replacement of fleets • Promote skill development and training through local institutions and agencies • Permit approvals for charging stations • Land availability for electric bus depots and top up points • Procure fleet for government offices • Amend building codes and regulations to facilitate charging infrastructure
Public Transport Agencies	• Fleet addition and replacement plans and procurements • Manage e-bus and public EV fleets • Create of charging and top-up facilities • Business model and operator contracts • Take opportunity to reform public transport
Vehicle Manufacturers / Suppliers	• Design and supplying EVs suitable for public transport • Follow national technical standards and safety norms • Provide training for operation and maintenance • Technology innovation and cost leadership
Fleet Operators/ Aggregators	• Support transition by adopting EVs • Develop skills for EV operation and maintenance • Leverage new technology to develop new business models

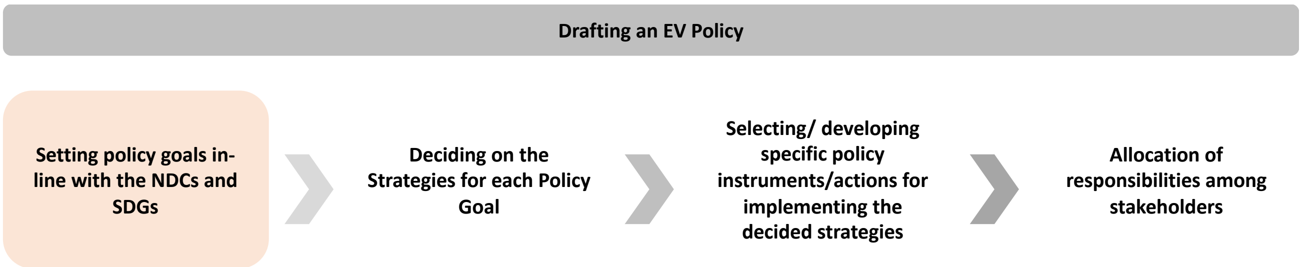
	• Follow and contribute to safety related protocols and practices
Energy Service Providers	• Provide energy and charging services to assume battery and charging related risks and responsibilities • New business models • Develop methods to monitor and optimize batteries and vehicles • Charge solutions for home, office and public charging
Utility and Grid Managers	• Make available adequate quantity and quality of power supply at required locations for charging • Grid load management • Innovative solutions to support home-based charging

Step 5: Formulate targeted policy framework from a standard policy and stakeholder template

Formulating a national EV Policy needs to start with a country-level assessment on broad goals, in line with the Nationally Determined Contributions (NDCs)[1] and Sustainable Development Goals (SDGs). These policy goals can be derived from the barriers which each country is facing in transitioning from Internal Combustion Engine (ICE) vehicles to Electric Vehicles.

Once this is set, the next step is to divide these policy goals into strategies. To implement these strategies, policymakers must select or develop specific policy instruments or actions. The entire process may involve multiple stakeholders, making it a complex process. Therefore, responsibilities need to be appropriately allocated among stakeholders, based on the strategies and policy instruments or actions developed. *Figure 4* shows the flow of steps which need to be taken in drafting an EV Policy.

Figure 4. Sequence of steps for formulating an EV policy



Source: Author

A more comprehensive sketch of the process is shown in *Figure 5*. Countries can select the parameters suitable for them, modify them if necessary, and develop new parameters based on their contextual needs.

A suggested standard policy framework template outline is placed as Appendix 1. This can be modified to the local country context if required.

[1] As part of the Paris Agreement, NDCs are the policies and targets for countries to reduce national emissions and adapt to climate change.

Figure 5. Policy goals, strategies, and policy instruments for EV adoption in public transport

Long Term Policy Targets on EV

Policy Goal	Strategies	Instruments for implementing the strategy	Stakeholder wise role							
			Govt	Transport Agency	Vehicle OEM	Fleet Operators	Finance Provider	ITS Provider	Energy Provider	Power Utility
Improve EV Cost Competitiveness and Supply	Provide direct financial incentives	• Purchase subsidies for E Buses, E taxies and E- IPT • Vehicle Tax, toll, parking rebates • No/limited Import Tariffs for EV imports	P	S	S	L	S	L	L	S
	Non - Financial Incentives for EVs	• ZE mandates • Low emission zones in cities • Exemption from time of day restriction • Encourage in country manufacturing	P	S	P	S	L	L	L	L
	Disincentivize ICE Vehicle purchase and operation	• Tighter emission norms • Stringent Scrappage Policy • Higher taxes for diesel vehicles	P	L	P	S	L	L	L	L
	Battery recycling and reuse	• Encouraging Energy Services • Battery banks for used batteries • Scientific disposal policies	P	S	P	P	S	S	P	P
Accelerate EV Adoption in Fleets and Public Transport	Accelerate Public Transport Fleet Transition	• Direct support to meet transition costs such as land for depots and charging etc. • Strengthen access to finance • Improved Business Models	P	P	P	P	P	S	P	P
	Accelerate EV Adoption in IPT	• Improved access to credit • Encourage aggregators • Strategic charging infra	P	S	P	P	P	S	P	P
	Commercial and Corporate Fleet Transition	• Reduced tax burden on commercial EV. • Supporting policies for ridesharing	P	S	S	P	P	S	P	P
	Govt Fleet Transition	• Transition of Govt Fleet • All additions / replacements by EVs	P	L	S	L	L	S	P	S
Develop EV Standards and Charging Infrastructure	Technical standards and enabling regulations	• Vehicle Tech, Design and Safety Standards for Vehicles, motors, Battery, Chargers and Charging infra • Safety Audits and SOPs • Battery disposal protocols	P	S	P	P	S	P	P	S
	Business Models	• Optimized charging / Smart Payments • Charging companies to make money	S	P	P	P	P	L	P	L
	Home and Workplace infra	• Facilitating Building Regulations • Improved access to power with infra	P	L	S	L	L	P	P	S
Awareness and Capacity	Creating awareness and capacity on EVs	• Public Awareness on EV Benefits • Capacity building of stakeholders • EV technician training programs	P	P	P	P	L	L	L	L

P: Primary, S: Secondary, L: Limited

Source: Collated from study of EV Policies across countries from various sources

Step 6: Establish national standards for EVs

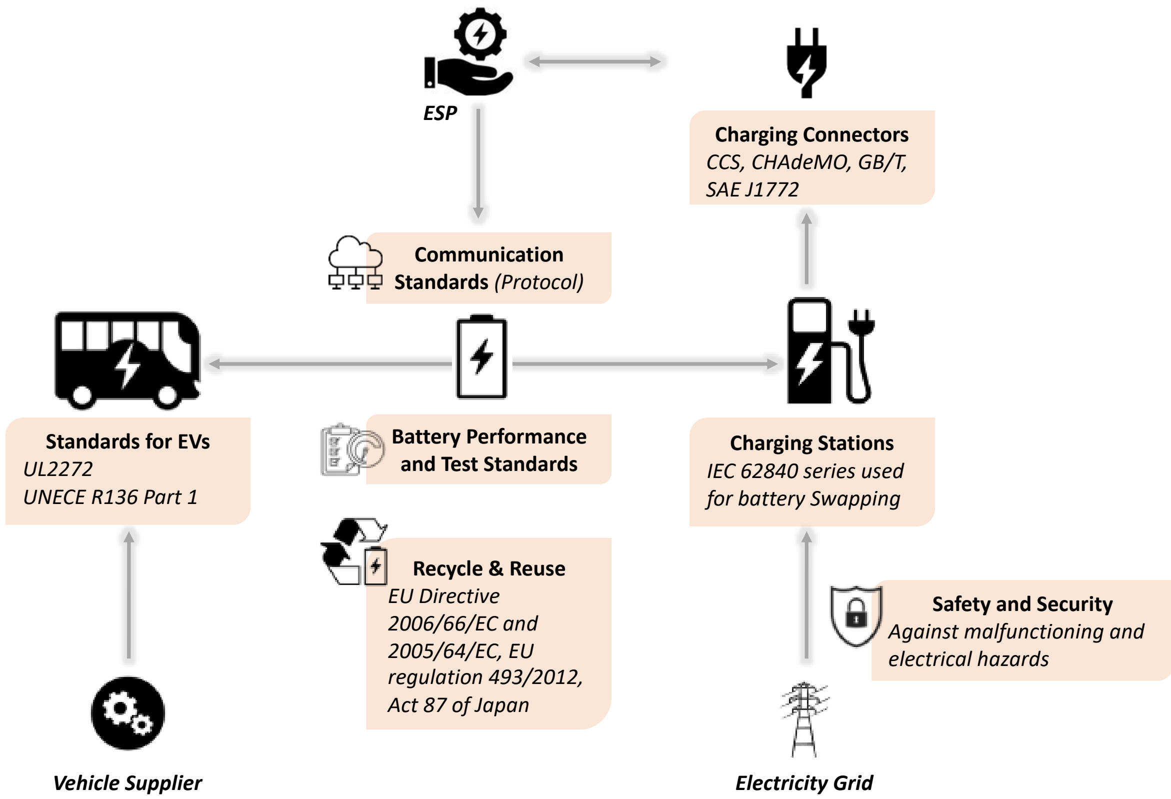
As the EV ecosystem emerges in any country, it becomes imperative to ensure the reliability, safety, acceptability and consumer confidence in EV products and services. Regulations, Codes and Standards (RCS) contribute to this requirement. They represent specifications and testing procedures that ensure consistency of performance. They align market expectations and also help in commercializing new technologies. Standards directly contribute to economies of scale by simplifying product development and speeding up production. Finally, standards help in ensuring interoperability of common charging infrastructure leading to cost reduction. It is therefore critical for any country to notify RCS for the EV ecosystem. This section provides guidance on how to prepare to create, modify or improve their own RCS for EVs.

Standards are guided by regional contexts and defined by national Standard Development Organizations (SDOs). In broader terms, RCS may be technical (define specific material, processes and product components) and performance-based (establish measurable performance criteria). RCS may require certification of components and systems.

Types of Standards

Since EVs are still evolving, there is no single common global set of EV RCS presently. China, Japan, Europe and U.S.A. have established their own standards. Global efforts in formulating RCS are spearheaded by the International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO) and the United Nations Economic Commission for Europe (UNECE). It would be useful for SDOs in each country to draw guidance from RCS formulated by these international institutions. An overview of global standard setting efforts is given in *Figure 6* and *Table 7*.

Figure 6. Global standards in Electric Vehicles



ESP: Energy Service Provider, CCS: Combined Charging System, CHAdeMO: Charge de Move

Source: Author

Table 6. Global standards for Regulations, Codes and Standards

No.	RCS Types	Areas covered
1	Safety and Security	Protection against malfunctioning batteries and electrical hazards as well as functional safety of vehicles and charging stations.
2	Charging Stations	Include standards for conductive, inductive and swap charging. Conductive standards specify required material and functionalities for on/off board chargers, including voltage, current, port for AC and/or DC power. Inductive standards deal with wireless systems (general, communication and magnetic power transfer) and pantograph-based charging for e-buses and e-trucks. The standard IEC 62840 series (IEC TS 62840-1 and IEC 62840-2) elaborate battery swapping process and safety requirements.
3	Charging Connectors/Plugs	While there is no consensus on a universal plug technology, there is a critical mass for Combined Charging System (CCS), CHArge de MOve (CHAdeMO), GB/T (China) and the SAE J1772 (IEC 62196 Type 1), also known as a J plug. They define a common conductive charging system architecture including functional and dimensional requirements for vehicle inlet and mating connector. The acceptance of these standards in different regions is shown below:

<table>
<tr><td></td><td></td><td><table><tr><th>Power Type</th><th>EU Zone</th><th>North America</th><th>Japan</th><th>China</th></tr><tr><td>DC</td><td>CCS2</td><td>CCS1</td><td>CHAdeMO</td><td>GB/T</td></tr><tr><td>AC</td><td>Type 2</td><td>J1772 (Ty 1)</td><td>J1772 (Type 1)</td><td>GB/T</td></tr></table></td></tr>
<tr><td>4</td><td>Communication Standards between EVs and Charging System</td><td>Digital communication between electric vehicles and charging station for charging/discharging of vehicles is enabled by communication standards. They are key enablers of the “plug & charge” capability of EVs.</td></tr>
<tr><td>5</td><td>EV Performance and Test Standards</td><td>They mainly relate to battery performance, durability, range, energy efficiency and battery recycling.</td></tr>
<tr><td>6</td><td>Recycling and Reuse (post-mobility)</td><td>The EU Directive 2006/66/EC provides for maximum permissible residual quantities of hazardous elements in batteries, as well as recycling, collection and disposal procedures. EC Regulation 493/2012 specifies the required methodology for achieving recycling efficiency. Further, Act 87 of Japan specifies battery recycling requirements. EU Directive 2005/64/EC provides a general framework for the reusability of vehicle components, systems and separate technical units. Battery re-use refers to alternate uses for batteries after their useful life in vehicles, for which there are currently no standards.</td></tr>
<tr><td>7</td><td>Specific Standards for Electric Bike/ Motorcycle</td><td>Some countries have adopted specific standards for two wheelers. For instance, Singapore has adopted UL2272 for Electric Bike/Bicycle with speed less than 25 km/h. The UNECE R136 Part 1 deals with Electric Motorcycle and Moped (L category-2W and light weight 4W).</td></tr>
</table>

The Regulations, Codes and Standards Development Process

SDOs of respective countries are generally entrusted with development of automotive standards for EVs, just as they are for conventional vehicles. The process involves formation of Technical Committees and Sub-Committees with the SDOs acting as nodal agencies. The Committees draw representation from the government, industry, academia and consumer organisations and hold wide ranging consultations with all stakeholders. The Committees interact with international organisations like IEC and ISO to discuss global standards and assess their compatibility with their country’s existing regulatory standards and safety tolerances. They also customise standards, depending on the stage of development of the industry in the country and the requirement for innovation and growth.

Enforcing Standards

Standards can be either mandatory or recommendatory. Mandatory standards are governed by regulators who authorise agencies to design tests to verify conformity. Recommended standards are voluntary compliances and may be developed by individual members of the industry or by associations, to propagate practices that help grow the sector as a whole.

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Step 7: Assess feasibility of e-bus fleets and charging infrastructure

Step 8: Procurement, financing and business models for EVs in public transport

Step 9: Carry out pilot projects in stages, according to promotion objectives, technical development status and operational models

Step 7: Assess feasibility of e-bus fleets and charging infrastructure

This step includes understanding the operational requirements and existing service levels of the public transport system, and selecting the right technology for battery charging and e-buses. Conceptually this is brought out in *Figure 10*, found at the end of this chapter. Systemically, it would involve the following steps:

Assessment of Service Levels

The principal concern of a PTA during any transition process is to protect its existing service levels, since these are strongly linked to passenger expectations. To begin with, existing service levels must be articulated at three levels:

- Level 1: Existing coverage of the PT system, headways maintained, and seat capacity deployed per route at different times;
- Level 2: Stop or station access, physical and fare integration with other modes;
- Level 3: Comfort and safety levels offered.

This information should be collated, along with other data about the number of routes, peak/off-peak ridership per route, seasonality in ridership, type and size of buses deployed, revenues and cost per passenger km, service and parking depots and so on. This is useful for planning the vehicle type and technology selection. For instance, if smaller e-buses are chosen to replace larger existing buses, it would be necessary to narrow the headways in order to maintain the same seat capacity, resulting in the need to procure a larger number of smaller electric buses. Further, if existing services provide fare collection through advanced ITS, the new e-buses must be ordered with the same ITS equipment on board.

Another big concern is range. Most urban PT buses transit around 200 – 250 km per day on average. A PTA purchasing electric buses for the first time usually expects replacement e-buses to be able to travel the same distance without refuelling. However, at the current level of technology, most NMC or LFP battery buses would need to top up at least once during the day to run this distance. Thus, existing service levels would greatly influence (i) the number, size, technology and design of the e-buses to be purchased; (ii) operations planning; and (iii) charging infrastructure requirements.

The selection of technology for e-buses is usually based on the evaluation of options among bus design elements, battery types, and charging types. Each of these are discussed below.

Technology Selection – Bus Design Elements

Bus design elements include technical specifications relating to energy efficiency, acceleration and speed, design of bus aggregates, size, type and number of seating, EV drivetrain, layout and dimensions, access and doors, suspension, braking, safety features, material specifications, automation, ITS and fare collection equipment. Clarity of the functional and operational requirements emerging from the service levels is needed to write appropriate specifications. The specifications should be technology agnostic as far as possible, and prescribe only the performance outcome parameters. The detailed design choices are best left to the manufacturer. The nature of tests to be conducted and type of agencies whose tests results are acceptable must also be prescribed. For instance, in India, only three agencies are authorized for vehicle type testing. The purchaser must demand certifications that the bus meets the national or international standards of performance.

Technology Selection – Batteries and Charging Type

A second important technology choice is around the type of batteries and charging type. Larger numbers of batteries add to the vehicle range, but also consume more space and charging time. Around 30-40 per cent of an e-bus cost is accounted for by the batteries. There are principally three battery types (NMC, LFP and LTO) for e-buses, each with its own merits and demerits. NMC and LFP are more commonly used, but LTO batteries are fast catching up. The range, bus availability and cost are highly related to the type and size of batteries. As a rule of thumb, the longer the range required, the higher the battery capacity, price and weight of the bus. There is a trade-off between the battery size (range) on the one hand, and the cost and carrying capacity on the other hand. *Table 7* presents some of the trade-offs.

Table 7. Trade-offs between range, weight, seating capacity and charging speed

	Typical for LFP/NMC bus	Impacted by	Offset by
Range	• 1.2 kWh/km for 12 m bus (35-27 seats + 15 standing) • 1 kWh/km for 10 m bus (30-35 seat+10 standing)	Higher the bus size, larger the batteries in kWh terms	Higher weight and volume compromising seating capacity
Charging	150-220 kW chargers. In some cases, 300 kW also used.	Higher capacity chargers offer faster rate taking lower charging time.	Higher cost and faster battery degradation on fast charging regimes

Source: Author

Owing to these trade-offs, the decision on battery size and charging type becomes complex. Such decisions can be made through an iterative process by first freezing a few parameters like range and simulating the others. This creates options in terms of battery type and size, charging speeds necessary, and so on. Typically, once the charging speeds and matching charging equipment is identified, the choice of battery is best left to the manufacturer. If plug-in is chosen, the type required would be NMC/LFP. If pantograph is chosen, it can be any of the three types, but LTO is usually more effective. Appendix 1 makes a comparison about these battery types. Appendix 2 provides a comparison between charging types.

Step 8: Procurement, financing and business models for EVs in public transport

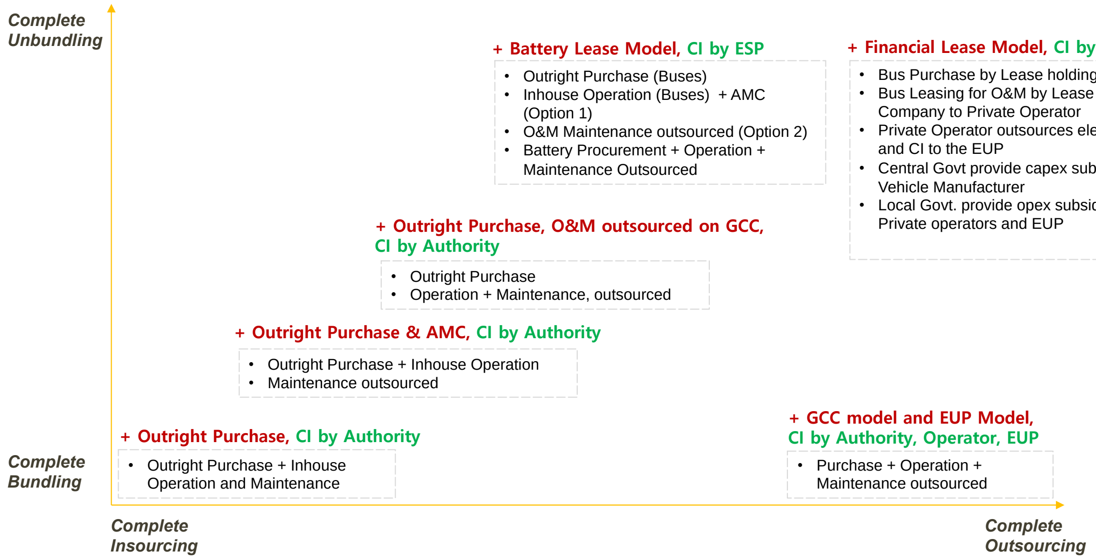
An e-bus system consists of buses, the battery driven propulsion system and the charging infrastructure. E-bus operations require the support of a wide range of stakeholders. It requires sufficient funding resources and innovative business models that contractually bind stakeholders into providing the necessary support, as well as allocates risks to parties. In particular, the special risks associated with an e-bus system calls for judicious examination of all available funding tools. This section discusses possible takeaways from international experiences in funding e-bus systems.

Electric buses have special characteristics which distinguish them from conventional buses. E-buses have an inverted cost structure, in that they have higher capital costs but lower operating costs, which tends to be the opposite of fossil-fuel based buses. Their fuel price sensitivity is also lower compared to conventional buses.

However, higher technical capabilities are required for maintenance, while there is a greater need for driver trainings and safety precautions. Additionally, the deployment of e-buses is restricted by the range and availability of charging points. Therefore, there are several important challenges, including funding, bus performance, maintenance, safety and disposal. All of these represent risks that need to be addressed through suitable business and funding models.

Given the above, several business models have emerged. These are placed in a conceptual matrix in *Figure 7*. It can be seen that the business models differ in terms of how bundled they are (same service provider for several activities) or how outsourced they are (how much the PTA chooses to outsource). It starts with the conventional model where buses are purchased outright and are operated and maintained by an in-house staff of supervisors, technicians, drivers, and managers. The other extreme is the Financial Lease Model, where the bus is leased from a financial lessor, and the battery is leased from an energy service provider. All activities, such as bus operations and maintenance (O&M), battery management, charging and disposal, are outsourced.

Figure 7. Types of business models for electric buses in public transport



CI = Charging Infrastructure, EUP: Energy Utility Provider, AMC: Annual Maintenance Contract, O&M: Operation and Maintenance, Govt: Government

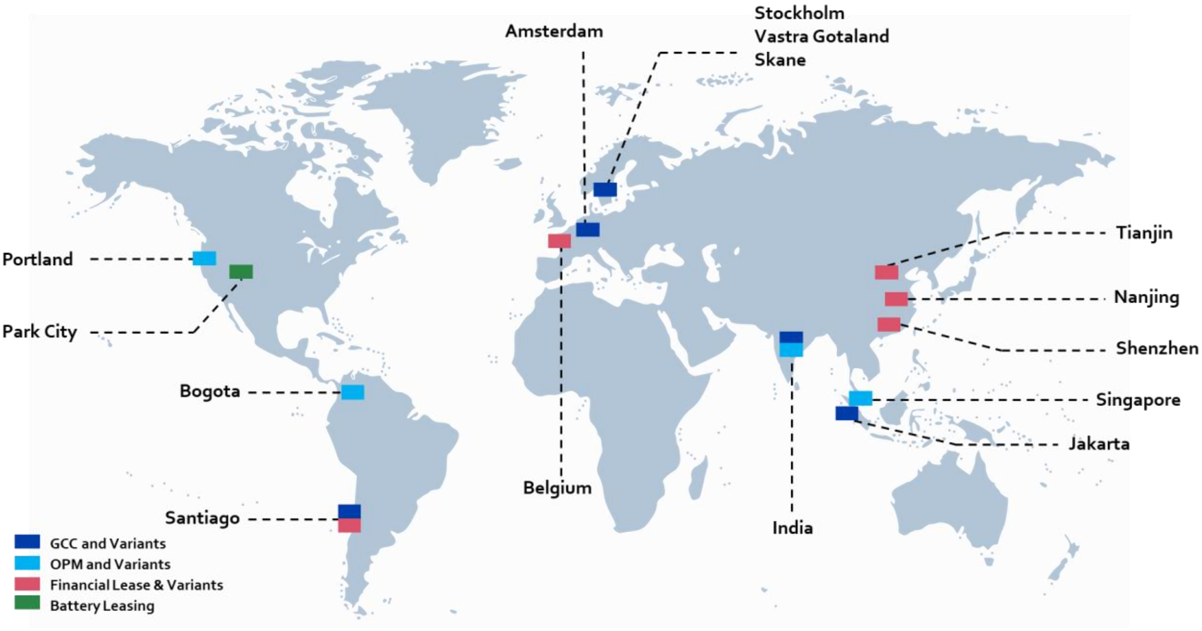
Source: Author

Globally, e-bus procurement approaches have been a mixed basket of insourcing and outsourcing. Within Asia, both government and industry at Shenzhen, China, contributed to the development of the Financial Lease Model, which is a complete unbundling and outsourcing of services. Meanwhile, authorities in Singapore and Jakarta, Indonesia, deployed e-buses on a Gross Cost Contract (GCC) basis. The Jakarta PTA procured the buses and outsourced the O&M to the private operator. In India, the procurement of e-buses gained momentum with the FAME India schemes, launched by the Government of India. Phase 1 of the FAME scheme was announced in 2015, in which cities like Kolkata, Lucknow, Guwahati and Jammu procured buses on an outright purchase basis, while Mumbai, Ahmedabad and Jaipur selected the GCC model. Indore was the only city to select the Net Cost Contract (NCC). Interestingly, the bus manufacturer participated in the supply, operation and maintenance of the buses. The NCC model for e-buses has some risks related to the performance of buses, batteries and chargers, in addition to revenue and funding risks, so it has not been adopted widely. Learning from the experience, the Government of India has made GCC mandatory for e-buses under Phase 2 of the FAME India Scheme, 2019.

In Europe, the Netherlands opted for GCC, while Sweden deployed e-buses in Stockholm, Västra Götaland and Skåne County on GCC with variations. London worked out a complete unbundled model, which is a hybrid of the Battery Lease Model and Financial Lease Model. Under this model, buses are financed by the PTA and procured, operated and maintained by the Operator, while batteries and charging services are provided separately by other private entities. However, Belgium opted for conventional outright purchase.

Further, in South America, the PTA in Bogota purchased e-buses and outsourced on a GCC basis, while the O&M of depot and charging infrastructure is outsourced to an ESP. Chile explored GCC and Financial Lease Model, mainly to mitigate the performance risks. North American cities such as Park City and Portland have Battery Lease Models and Outright Purchase with ESP. *Figure 8* shows the different types of business models worldwide.

Figure 8. Business models for e-buses in public transport used in different parts of the world



GCC: Gross Cost Contract, OPM: Outright Purchase Model

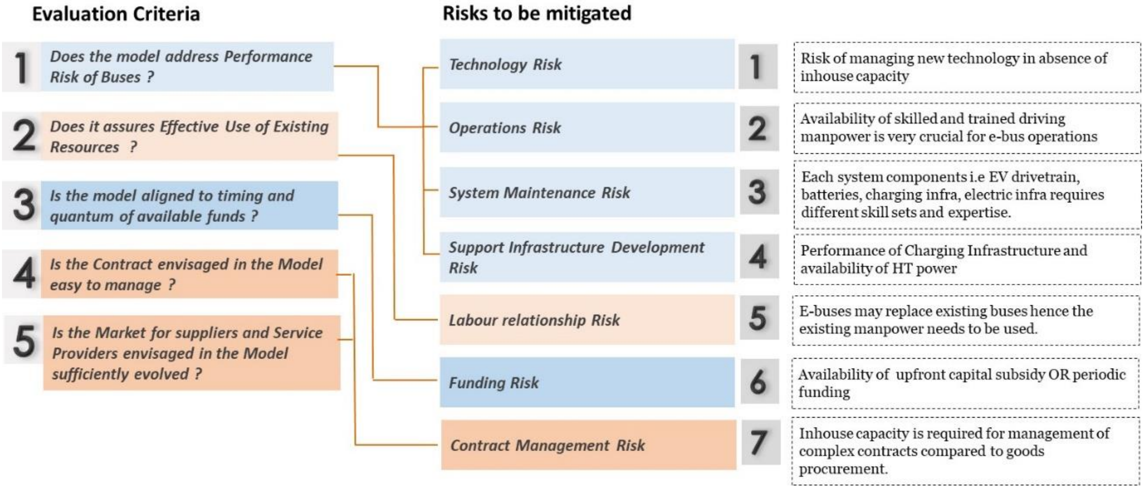
Source: Author

So how does a PTA decide what which is the most suitable model? This is best done by listing and evaluating the criteria which matter the most to the PTA, and evaluating each risk in the context of this criteria. *Figure 9* provides a conceptual model for this process.

To understand this further, let us take a hypothetical example of a particular PTA.

The "ABC" PTA operates a conventional gasoline fleet. It directly employs a large number of drivers and some maintenance staff. Its total revenue from fares and other sources is less than what it needs to operate and maintain the service. It meets the capital shortfall (for purchasing rolling stock / upgrading infrastructure, etc.) through one-time grants from the Government every few years and meets its operating shortfall from a committed monthly cashflow from the government, which pays it through the vehicle tax. It has no experience of operating electric buses.

Figure 9. Criteria for evaluation of alternative business models for e-buses in public transport



Source: Author

In the above case, all five evaluation criteria mentioned in Figure 9 are relevant and must be examined. For instance,

- The business model must ensure that vehicle performance is not a challenge, since the "ABC" PTA has little in-house expertise to fall back on, for example if there is poor warranty support from the e-bus manufacturer (must mitigate Risks 1-4).
- Its existing manpower resources are most likely unionised and would oppose any outsourcing attempts. Thus, these existing resources must be used. Further, the model selected should match its funding pattern (Risk 5).
- The funding requirement of the business model must match the present funding pattern of the "ABC" PTA (Risk 6).
- Since it has been managing an in-sourced model so far, it has relatively less experience in managing out-sourced contracts, and hence it should choose a contract which is easy to manage (Risk 7).

Looking to vehicle performance risk, an outright purchase with in-sourced operation and maintenance, similar to conventional buses, can be ruled out immediately. The GCC variants are also ruled out as they will employ outsourced labour, leaving existing resources unused. Both the Battery and Financial Lease Models are too complex for the first-time as they are not easy to manage. This leaves Outright Purchase using government grants, coupled with an Annual Maintenance Contract with the manufacturer supplier paid through periodic tax revenue, as the most suitable option for the "ABC" PTA. In this way, every PTA should evaluate different business models against each risk, and select the model which mitigates all of the listed risks.

Box 1: Battery Lease Agreement between Proterra and Park City Council, Utah, U.S.A.

In 2016, Park City Transit entered into a Battery Lease Agreement with Proterra, a private firm, for six e-buses. Under the Agreement, Park City Transit would own the electric buses, charging infrastructure and depot, while Proterra would own and service the batteries of the buses. The key terms of the lease between Proterra and Park City Transit are given below:

1. ***Bus purchase and spare parts***: Park City Transit would purchase the bus at a cost of $614,679 from Proterra (including bus, configuration cost and spare part costs during life of the bus).

2. ***Overhead charging station and depot charger***: Park City Transit would pay $349,000 for each of two overhead charging stations and $40,000 for a depot charger.

3. ***Lease term***: 12 years.

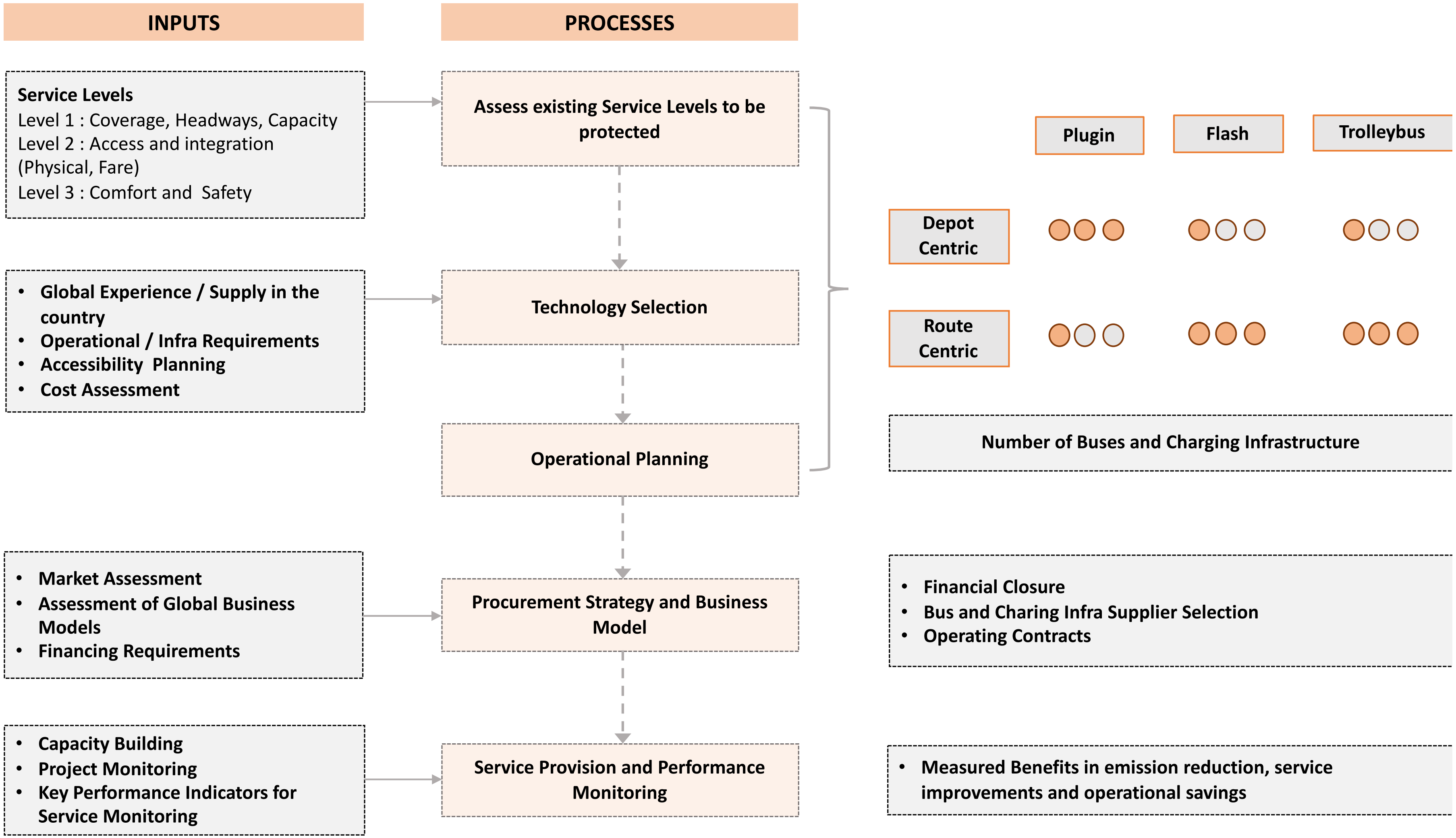
4. ***Lease fees***: $40,708/bus/year, including battery renewal/replacement.

5. ***Battery performance guarantee***: Proterra is responsible for battery performance (including maintenance). It is allowed to replace or service its batteries at any point. It guarantees that its batteries will operate at above 70% of their original capacities.

6. ***Battery charging service conditions***: batteries must be maintained between 20% and 90% state of charge at all times, barring a few exceptions.

7. ***Incentive for additional miles run***: additional service fees of $0.50/exceeded mile to be given as incentive to Proterra, if miles exceed 90,260 miles in any given year.

Figure 10. **Process for E Bus Adoption in PT**



Source: Author

Step 9: Carry out pilot projects in stages, according to promotion objectives, technical development status and operation models

Taking into account the country's energy structure, vehicle technology development status, climate, and environmental conditions, a pilot or demonstration project to test the selected e-bus system can be carried out in three phases (*Figure 11*).

Phase I: Pilot Project Implementation

- *Development of rules:* According to the policies and standards selected, technology assessment, and the business and operational model chosen, the rules for the promotion of electric public transport can be refined and the key tasks for pilot projects proposed.

- *Strengthen the organization:* In accordance with the promotion objectives, government authorities and stakeholders, establish clear division of labour and collaborative efforts to promote the pilot project implementation.

- *Selecting typical examples:* Each pilot country may select the most representative 1~3 pilot projects as demonstration projects, and conduct the tracking and evaluation throughout the demonstration project. The selection of pilot projects needs to be combined with regional development, considering the scale of the pilot, including the type and number of pilot services, appropriate operating routes, setting of charging points, and charging methods.

- *Strengthen scientific research:* To address any problems in the pilot project, research and development may be needed to provide technical support.

Phase II: Summary and improvement

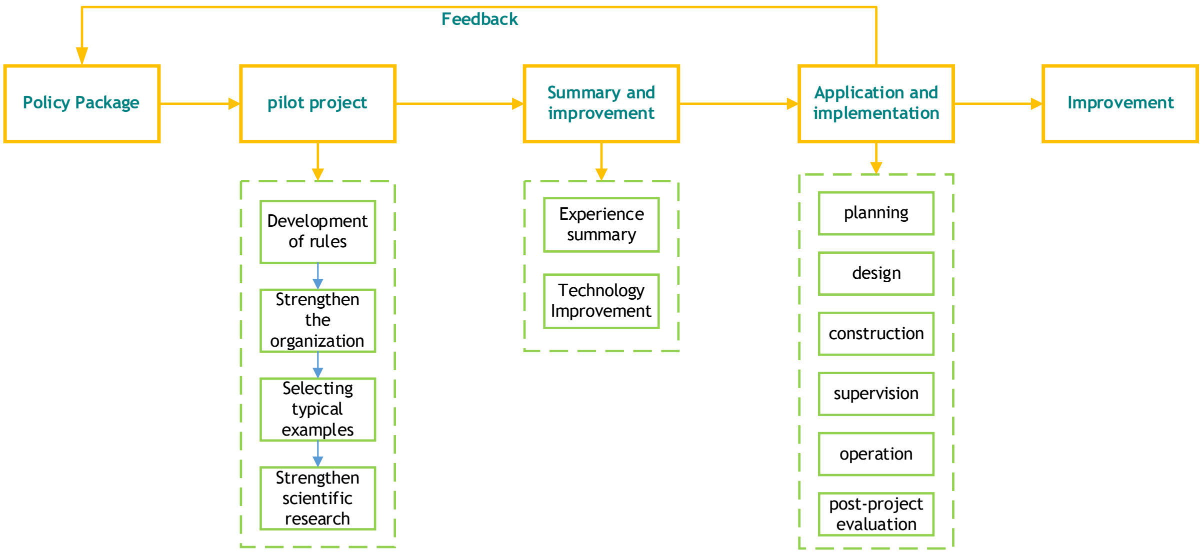
- *Experience summary:* Summarize and analyse the implemented demonstration projects. Government authorities and stakeholders should hold observation meetings, seminars, and exchange of experience at all stages of the pilot project.

- *Technology improvement:* To overcome any technical difficulties in the promotion, continue to carry out technical research and development in conjunction with the pilot, and apply technological innovation to solve problems.

Phase III: Application and implementation

Taking into account the status and process in developing the pilot projects, summarize the experience of the whole process, such as planning, design, construction, supervision, operation, and post-project evaluation, and improve policies and standards to move towards a scaling up exercise.

Figure 11. Pilot projects



5 Managing the Transition

Step 10: Workforce skill development

Step 11: Prepare for and manage end-of-life issues of EVs, battery re-use, and disposal

Step 10: Workforce skill development

To successfully transition towards electric mobility in PT, the transition should be managed in a sustainable manner. Skills and knowledge are required to manage this transition across the EV value chain. The incorporation of EVs into PT, therefore, requires the existing system to be significantly modified in several areas, and completely overhauled in others. For instance, many PTAs have well-equipped diesel vehicle maintenance workshops, with operatives skilled, for example, in diesel engines. These technicians have a close understanding of the local context in which the vehicle operates. Similarly, drivers of conventional buses have an unmatched understanding of local driving conditions, and it would be a waste of their knowledge to bring in new drivers. It is therefore very important to re-skill the existing workers and drivers.

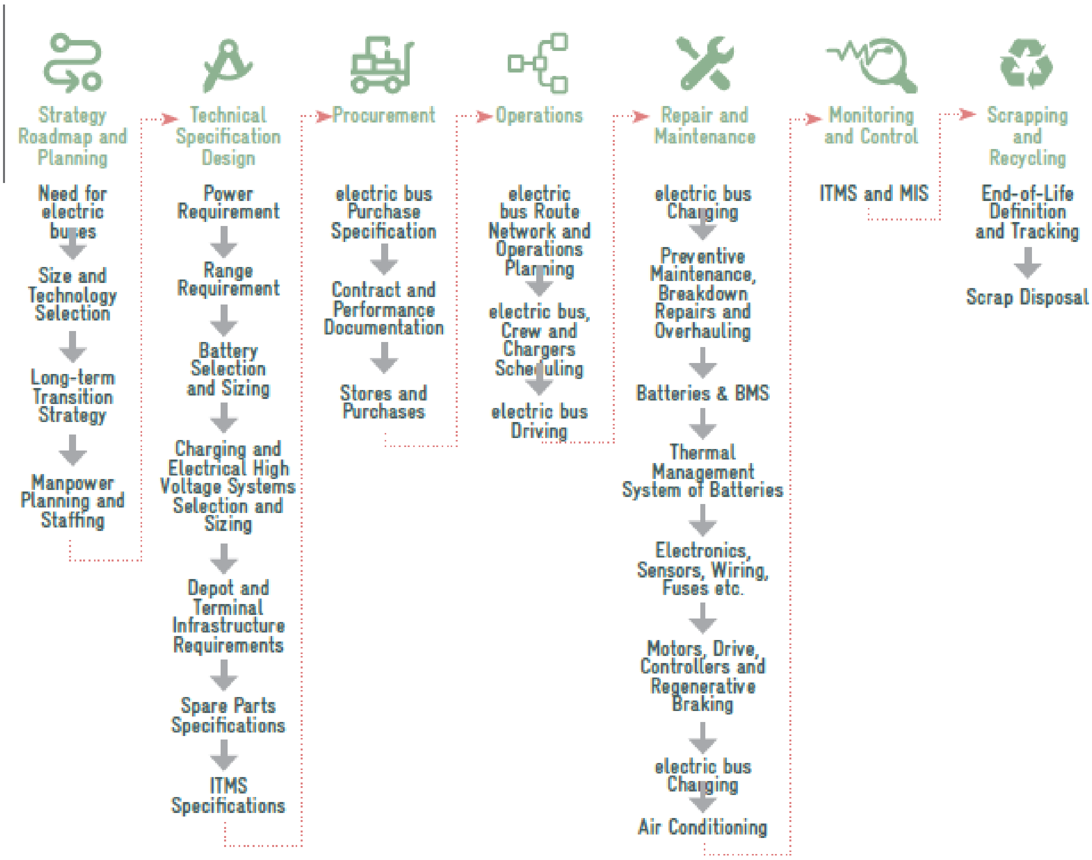
Finally, PTA managers have a good grasp of passenger demand patterns, and are well versed with the socio-economic contexts in which the service operates. However, they need to be trained to plan and manage e-mobility related transitions.

Therefore, retraining would be required in PT across the board in all functional areas. The following lists the key areas for training and re-skilling:

- Strategy Roadmap and Planning function
- Technical Specification and Design function
- Procurement and Business Model function
- Operations function
- Repair and Maintenance function
- Monitoring and Control function
- Scrapping and Recycling function

Figure 12 sets out additional details of these sections. It can be seen that knowledge gaps could arise at the planning stage itself, for example, in determining the right size of the battery for the e-bus to be purchased. Therefore, training must begin with the Strategic Planning function. The Technical Specification Design is also critical. It is possible that countries may not have finalised EV Standards discussed in Step 6 above (Establish National Standards for EVs). In that case, training must be organised to learn about international standards.

Figure 12. Key training and reskilling areas



Source: "Training Needs Assessment for Electric Buses in India", GIZ (2021).

Each PTA can identify the training needs for various levels, i.e., senior, middle and lower, based on the above functions, and arrange for such training to be imparted in stages. For the training, a partnership with an international organisation which can provide or advise on such resources could be valuable. Modules could be assigned and different experts could be invited for training in each area. For some aspects, training could be arranged in partnership with vehicle manufacturers and suppliers. For technical standards, international training is strongly recommended to provide an understanding of global standards.

Training should not be restricted to the public sector alone, but should also include as many stakeholders as possible, depending on the context.

Step 11: Prepare for and manage end-of-life issues of EVs and battery disposal

The final step is to prepare for the eventual end-of-life issues for EVs and batteries. Unmanaged disposal, especially of batteries, could negate the environmental benefits envisaged through the transition. Principally, policies must address the following areas:

- Warranty and end-of-Life management
- Vehicle and lithium-ion batteries scrapping and recycling processes.

Most EVs are sold with some warrantees on batteries. However, manufacturers and OEMs typically tend to be sparing in their commitments. There are several ways to address this: (i) set regulations that bind OEMs to commit to re-possess batteries and critical parts at the end of their life, possibly with replacements sold only to those providing used batteries; (ii) set policy regulations for the scientific disposal, reuse, or recycling; and (iii) create policy support for setting up recycling and reuse banks and markets.

End-of-life EV batteries are still considered useful for non-dynamic uses such as storage, and so at least initially, such use could be incentivised. On their part, PTAs could insist on supporting warranty contract clauses while purchasing EVs.

6 CONCLUSIONS

As electric vehicles rush to substitute fossil fuel vehicles, public transport vehicles should not be left behind but should be prioritised for electrification. This Guidebook attempts to explain the why, what and how of this process, and to provide a step-by-step sequence for pursuing an accelerated adoption.

Experiences of Asian countries that have gone through the EV transition cycle in their public transport fleets, either fully or partially, provide us with valuable lessons. It is evident that successful transitions are driven by well-designed policy stimulus. Countries such as China and India, particularly the former, were able to transform their massive public transport fleets in relatively short times, sometimes within a decade, through phased policy measures that focused on easing transition barriers. Some of the key barriers addressed are around higher costs, availability, and supply of EVs, feasibility of operations to maintain and improve service levels, and creation of infrastructure to meet charging needs. In fact, an interesting lesson that emerged is that the availability of charging infrastructure tends to influence broad EV adoption even more than direct incentives.

Another important observation is that supporting policies need to exist not only at the national level but also at the sub-national and city levels. This is because the EVs cannot be adopted in isolation, particularly for public transport fleets. Many stakeholders need to synergise, including municipal authorities, vehicle and equipment manufacturers, service providers, existing transport agency staff, environment agencies, utility managers and fleet operators and aggregators. Only through a concerted action wherein each stakeholder is incentivised, can accelerated adoption in public transport become a reality. This will require design and implementation of policy instruments for each stakeholder. For instance, retraining of public transport fleet personnel becomes important to assuage their concerns around multi-generational change in technology. New financial instruments that explore the potential for green funding need to be created. Battery disposal and reuse schemes need to be devised well in advance of battery maturity.

Two further areas for attention stand out for high prioritisation. The first is development of national Regulations, Codes and Standards for EV manufacturing, performance and safety. While these are more relevant for countries that manufacture EVs, even countries that import vehicles have local needs and concerns. Hence each needs to devise locally relevant standards to ensure safety, ecosystem-development-at-scale, and performance. In particular the development of charging plugs and points, availability of parts in markets, and re-use of batteries are relevant to all countries. Overall, RCS can become the technological frame around which innovation, financing and business models could emerge.

The second important area is development of business models for vehicle operations, maintenance and charging. Not until the operators and service providers are sufficiently confident of the business potential will they enter markets to provide vehicles, equipment and services. This will require careful analysis and apportionment of risks bound by contracts which are easy to manage. This Guidebook describes several types of models and the criteria by which agencies can select the right models.

In many Asian countries, buses are not the primary, or even secondary, mode of public transport. Para transit, such as tuk-tuks in Thailand and jeepneys in the Philippines, carry a significant share of total trips. Finding an appropriate business model becomes even more relevant in such contexts.

While much has been said in this Guidebook about the opportunity to electrify public transport, electrifying is not enough. Public transport is losing market share to private vehicles in many countries. Much more needs to be done to augment public transport ridership, such as improving access to bus and metro stations, integrating different modes, automatic ticketing and intelligent information, prioritising buses in dedicated lanes, and so on. Electrification therefore must be seen as an impetus for building climate resilient, safe, and healthy societies.

Appendix 1: National electric vehicle policy framework outline

1. Introduction:

    a. Objectives of the policy framework.
    b. Time frame for policy
    c. Global context in view of increasing transport sector emissions, climate change mitigation needs and net zero commitments

2. Building the Local Country Context: (Note the following briefly):

    a. Energy and Climate Change Mitigation:
        i. Existing energy sources of the country, contribution of non-conventional energy, energy security
        ii. Emission status, concerns, role of transport emissions
        iii. Key plans and polices to combat emissions including commitment to NDCs and Paris Agreement
        iv. Existing policies and plans to accelerate EV adoption such as climate strategy and national energy policies, policies linking sustainable energy to EV charging (special tariff, discounted wheeling and so on), tax incentives, city level plans.

    b. Transport Sector
        i. Vehicle Population and transport sector emissions
        ii. Key modes of transport for residents / modal share in key urban centres, travel behaviour
        iii. Public Transport: Modes (buses, bus types, taxies, others), mode share, ridership, plans and policies
        iv. Number of PT vehicles over the years, type, who owns, who operates, where maintained, depot locations, no. of schedules, ridership over the years, structure and financing of public transport agencies, extend of losses if any, average fares per passenger.
        v. Re-fleeting time and plans
        vi. Gender and inclusiveness in public transport systems.
        vii. Adoption of low emission vehicles, in particular, use of sustainable/renewable fuels (electric vehicles/hybrid or bio fuels) to decarbonize transport (share of renewable energy use by public transport)

3. Data Collection, Analysis and Use of Output for policy development: (Examples of such data analysis given below:)

    a. Electricity supply – availability, grid capacity for transmission and distribution
    b. EV Charging Station space, business model

c. Vehicle Cost, manufacturing and supply chain, maintenance, and service support
d. Standards for EVs in the country
e. Institutional capacity in Transportation that can drive EV adoption
f. Operator market and potential for their organisation
g. Business models in vogue and stakeholders involved (Do existing operators make money? Do they have control on fares and schedules or is that policy driven? If the introduction of EVs in PT is too expensive, how do we overcome this through policy support? Can there be any changes in contractual structures/business models to ensure financial sustainability of operators if they transition to EVs?)

4. Policy, institutional or financing gap analysis
5. The case for Electric Vehicles (Why EVs): Based on above context development and analysis, this section could establish a clear case for EV adoption in the country and in particular accelerated introduction of EVs in PT as an early gain strategy. Reasons could include energy security, emission reduction, operating cost reduction, modernisation, fuel diversification, balance of payments etc.
6. Scope for EV (What EVs) : (Type of Vehicles viz Buses, Vans, Taxies, two wheelers, where and when and how much share)
7. Policy Strategies and Instruments: (How EVs): (refer Figure 5 for specific examples)
8. Useful references on institutions and resources
9. Annexes: Useful data and material such as transport plans, photographs of urban transport systems etc.

APPENDIX 2: EVALUATION OF BATTERY TECHNOLOGIES

Lithium Iron Phosphate (LFP), Nickel Manganese Cobalt (NMC) and Lithium Titanate Oxide (LTO) are the three primary battery technologies used in e-buses. These lithium-based batteries are used in hybrid and full EVs due to their high energy density, fast recharge capability and high discharge power. Other technologies such as sodium based, air aluminium and lithium grapheme are still evolving and are not commercially viable at present.

Lithium-ion Phosphate Battery (LFP)

LFP batteries are the most commonly used batteries globally, mostly due to their cost, availability and large-scale commercial production. These batteries are mainly manufactured by two Chinese manufacturers CATL and BYD, which are supported in scale by the large number of buses manufactured in China. LFP batteries are relatively cost-effective, but come with the trade-off of extra weight. Storing a larger number of batteries to cover a full day's distance compromises passenger carrying capacities, as it uses up the vehicle axle and GVW limits, consuming more energy to carry the extra mass all day. Operations which use LFP batteries typically operate on either a midday opportunity charge or reduced mileage to serve their requirements.

Nickel Manganese Cobalt Battery (NMC)

NMC batteries offers advantages over LFP batteries in terms of higher energy density, and hence more energy capacity can be stored in the same volume. This frees up space for increased passenger capacity and offers a longer range at the same volume of battery. The main manufacturers of this battery are Korean LG and Samsung, and German Siemens. They are used by Mercedes, MAN and Solaris in Europe. In addition, NMC batteries are capable of a faster rate of charge compared to LFP, up to 300 kW.

On the other hand, NMC requires cobalt, whose availability is constrained. This makes it somewhat costly. Tesla, which was using NMC, is said to be moving to LFP for some models due to this factor. It also has a potentially smaller life, but this is yet to be proved empirically as the newer NMC battery vehicles have yet to reach the end of their life cycles.

Both LFP and NMC have the disadvantage of heating up due to fast charging, and the potential electrical short circuit between cells can cause safety issues.

Lithium Titanium Oxide Battery (LTO)

LTO batteries are superior to LFP and NMC batteries in terms of accepting fast charge (up to 1000 kW), with a safer rise in temperature (<10 Deg. Cel) and a longer life (4 to 5 times of NMC and LFP). The manufacturers are Microvast and Toshiba. LTO buses have been running successfully in Chongqing, China, for the last ten years without replacement, on a fast charge regime. In London, some buses were retrofitted with LTO batteries in 2014 and have been running successfully since then.

LTO batteries, however, have a much lower energy density and are also more expensive. To mitigate this, LTO is typically operated on flash charge operations only. It reduces the battery capacity required to a third compared to an LFP, and also reduces comparative weight and cost. Thus, LTO offers the advantages of having a much lower charge time, extending the range if flash charging is available enroute or at suitable locations.

Table 8 provides a comparative picture of the three battery technologies.

Table 8. Comparison of three battery technologies

Type	Lithium Iron Phosphate (LFP)	Nickel Manganese Cobalt (NMC)	Lithium Titanate Oxide (LTO)
Weight	Around 5 kg per kWh	Ard 8 kg per kWh	Ard 14 kg per kWh
Volume	3 litres per kWh	1.75 litres per kWh	4.5 litres per kWh
Packed Price	$152 per kWh (2022)	$175 per kWh (2022)	$800- $1000 per kWh
Max. charge	150 kW	300 kW	800 kW
Lifecycle	5000+ cycles	4000+ cycles	20,000+ cycles
Life	7-8 years	5-6 years	12-14 years
Pros	Thermal stability Scale and superior storage Lower cost due to scale	Higher energy density Better performance	Wider SOC range High power input / output Low fire risk
Cons	Overheating under fast charge; cells expand and create dendrites Needs safe manufacturing process	Potential fire risk from cell cathodes (would need mitigation) Shorter life	Lower energy density Higher purchase cost, but mitigated by lower capacities carried on-board

**This considers the price of a battery pack to be installed in a vehicle, not just the individual cells. ** Based on laboratory test cycles of 0-100%.*

In conclusion, the most suitable battery type must be chosen based on precisely worked out operational requirements. If the operation is simple and not arduous, then LFP is most cost-effective. If weight and space is a concern, an NMC solution could be suitable. However, for a heavy-duty bus operation with frequent charging and high mileage, a capacity optimised LTO solution may be most appropriate.

Appendix 3: Evaluation Of Charging Technologies

The key options for charging technologies are plug-in, pantograph, inductive and battery swap. Catenary (used in trolley buses) or super-capacitors are not considered, as trolly buses have too many infrastructure implications when starting from a zero-baseline, while super-capacitors may be too expensive and are still evolving.

<u>Plug-in</u>

Plug-in is the simplest and lowest cost solution, particularly for countries just introducing an electric fleet. Usually, each bus can be charged using charge power ranging from 120-250 kW rating, as per current technology. It requires high voltage power generally available from high tension lines after being stepped down. However, plug-in requires a longer charging time of up to several hours per vehicle, thus reducing vehicle availability for operations. Usually, the non-feasibility of charging at many locations requires the vehicle to return to base for top-ups during midday breaks, affecting the operational availability and flexibility. Some operators may purchase additional buses to compensate for buses waiting to charge. If large numbers of vehicles need to be charged simultaneously (usually during the night), then there are significant load implications for the grid.

Plug-in also requires special safety considerations. While plug-in functionality is well understood, it should only be handled by trained operators. If there are numerous vehicles being plugged in at a single location, then there has to be a good management system to prevent trailing cables, correctly park vehicles, and ensure that vehicles are unplugged before they are moved.

Figure 13. Plug-in charging in Ahmedabad, India

Source: Ahmedabad Janmarg Ltd.

Flash Charging

Flash charging involves contact with an overhead or underground high-power charging point. It is newer technology compared to plug-in and is fast gaining ground, with deployments in Europe (Geneva) and soon in France. Suppliers include ABB (TOSA System) and Hitachi (Grid-eMotion Flash). Flash charging through strategically placed pantographs at terminals, depots or even stops, allows for charging in minutes without resorting to heavy space-consuming energy storage or frequently having to take the bus out of service for a full recharge. Thus, it addresses the range limitation of buses, makes buses lighter and more energy efficient, and increases bus availability for operations. Charging time is reduced to the time when the bus needs to stop anyway, thus avoiding compromise in schedules.

Usually, flash charging is done through an overhead pantograph, but it can also be done through an inductive mounted below the road surface. Though attractive from the view of decluttering the streets, inductive could be more expensive and cumbersome (need to dig trenches). It also adds to vehicle weight and cost due to the need to fit receiver coils under the bus floor (approximately 400Kg). Also, the charging efficiency is only 70 per cent, versus nearly 90 per cent for stationary applications like the pantograph. The extra cost of the civil works and hardware therefore eliminates the attractiveness of this option in most circumstances.

Figure 14. Inductive charging in Washington

Source: The Driver

The other alternative is to use overhead pantographs. These are lamppost like structures mounted at the roadside, which use a 'down' pantograph mechanism (the moving part is on the fixed infrastructure) to connect with two metal bars mounted to the bus roof. A common charging technology called OppCharge, developed by ACEA, enables vehicle interoperability between different OEMs. It offers a high degree of flexibility and can be mounted at the bus terminal, allowing a 10-minute charge whilst passengers alight and board and the driver takes a comfort break. It usually requires around three recharges of around 10 minutes each for a 200-250 km daily running distance, which can easily be absorbed by most systems.

Figure 15. ABB's first pantograph charging in Sweden

Source: Volvo Buses Global

Pantographs are also safer due to limited field strength. The system is automated via Wi-Fi communication from the bus and only requires the driver to park in the right place. This is normally achieved by placement of small road humps for the driver to park between.

The big disadvantage of flash charging is the higher cost. It is also a newer and evolving technology which has yet to reap the advantages of scale and empirical experience. Each pantograph can cost many times more than an ordinary plug-in charger. However, this is compensated by the fact that you need fewer pantographs and have a large reduction in energy costs. Further, the battery technology in flash charging should be able to accommodate the fast charge rate.

Battery Swap

Battery swaps for four wheelers and above is difficult due to the battery weight and safety risks arising from possible sparking due to loose connectors. However, battery swapping has been tried in Ahmedabad, India. The advantage is that the vehicle is bought without batteries and the battery power is effectively leased from the supplier of the battery swap infrastructure. As the batteries are not owned by the operator, this removes all risks associated with battery life and maintenance. As the battery packs are too heavy for manual lifting, an automated robotic system is used for removing and replacing batteries in the vehicle.

Figure 16. Battery swapping in Ahmedabad, India

Source: Ahmedabad Janmarg Ltd.

The disadvantages of this system are that the battery capacities are still quite small (around 50 kWh per battery) and thus require frequent replacement, typically at the end of each route, potentially up to 10-12 times per day. Automatic swapping stations also consume space for swapping and charging units (equal almost to a container) and need space for circulation. Swapping also does not permit interoperability of batteries between different manufacturers.

As with the pantograph charging, this system does not require any driver intervention. However, due to safety risks, time lost in travelling to the swapping station, and the lack of interoperability of batteries, this application could turn out to be costlier, as additional fleet may be required to compensate for the swapping time. This technology is best suited to smaller vehicles, like two- and three-wheelers, where batteries can be handled manually. Batteries also might degrade faster due to higher cycles. Whilst the battery-less vehicle cost will be lower, the potential costs for the battery replacements, extra buses, and safety precautions may exceed this. *Table 9* provides a comparative picture of the three charging technologies.

Table 9. Comparison of three charging technologies

Type	**Plug-In**	**Flash charging**	
		Pantograph	**Inductive**
Charging Power	Up to 300 kW (dual), 75-150 kW (single)	350-800kW	300-500kW
Costs	X per unit	10X- 12X per unit	20-25X per unit
Standards	IEC CCS2	OppCharge	N/A
Annual energy costs	4X	X	NA
Advantages	Lower unit cost Simpler	Fast charging Shared infrastructure Automated Minimises weight	Fast charging Shared infrastructure Automated Aesthetic
Disadvantages	Trailing cables with potential for human error Increased grid power supply needed for multiple vehicles Increased vehicle weight and smaller passenger capacity	Medium cost but can be amortised across fleet	Additional vehicle weight for receiver coils Higher infra installation cost

Since operating energy costs are much lower, the higher capital costs involved could be paid back within around 5 years for the first purchases and a shorter period when more vehicles share the existing infrastructure.

Appendix 4: Country Data Sheets

Country	**Georgia**
Population	3.708 million (World Bank, 2022)
Per Capita GDP	$5,042.38 (World Bank, 2022)
Electricity Generation by source (Share in %)	Hydro:80.49%, Gas:18.8%, Wind: 0.71%, (2021) (Ember, 2022)
Energy Imports	Georgia depends on imports for all its natural gas (2.69 bcm in 2019) and most of its oil products (1.35 Mt in 2019) (IEA, 2013).
Vehicles manufacturers	None
Emissions Status	• Transport to total GHG emissions: 2.89 Million tons (Mt) of 8.61 Mt of CO_2e (2016) (34%) (Worldometer, n.d.) • According to the State Audit Office 2018 report, transport was responsible for 84% of CO_2 and 80% of NO_2 emissions in 2016.
NDC Commitments	Georgia submitted its revised NDC in May 2021 (Georgia, 2021). • Georgia took on a conditional commitment to reduce greenhouse gas emissions by 50-57% by 2030 compared to 1990 levels, subject to international support. • Increased unconditional GHG emission reduction target to 35% by 2030 compared to 1990 levels (approximately 16% per capita reduction). • The NDC includes measures to reduce losses and damages caused by extreme weather events.
ZEV Share, Strategies and Targets	• Current EV Share: 1.21% (2019) • Based on vehicle registration 2021, 6.4% hybrid vehicles and 0.2% electric vehicles were registered in Georgia (Georgia, 2022). • 95% of electric vehicles imported to Georgia are used ones (Georgia, 2022).
ZEV Policies	Policy preparation is in progress and the proposed provisions and incentives (ESCAP Workshop 15/03/2022).
Charging Infrastructure	• 8 charging stations in Tbilisi for charging private cars – a mix of fast and normal charging stations (Chargemap, n.d.). • Charging electric cars was free of cost in the year 2016 – 2017 (Charge, 2016)
ZEV in PT	None
Key Policy Documents	• Georgia's National Electric Vehicle Infrastructure (NEVI) Planning, 2022 • Green City Action Plan and Sustainable Mobility Action Plan by Tbilisi and Batumi City Halls, 2017 • National Integrated Energy and Climate Plan (NECP) 2021-2030 • Climate Strategy Action Plan (CSAP)

Country	**Nepal**
Population	29.67 million (2021) (World Bank, 2022a)
Per Capita GDP	$1,222.9 (2021) (World Bank, 2022b)
Electricity Generation by source (Share in %)	Hydro: 100% (2019) (Ember, 2022)
Electricity Imports	• 16.7% of the energy was being imported in 2014 (knoema, n.d.). • In 2022, Nepal imported 367 MW electricity from India to meet its domestic needs (Nepal, 2022).
Vehicles manufacturers	None
Emissions Status	• Transport to total GHG emissions: 5 Mt of 48 Mt CO_2e (2019) (10%) • Total emissions increasing by 2.5 times over 1990 levels while transport emissions went up 14 times. • Ranked 89 of 197 countries in CO_2 emissions
NDC Commitments	Nepal submitted its second NDC in December 2020. Some of the goals are (Climate Action Tracker, 2021): • By 2030, ensure 15% of the total energy demand is supplied from clean energy sources. • By 2030, increase sales of e-vehicles to cover 90% of all private passenger vehicle sales, including two-wheelers, and 60% of all four-wheeler public passenger vehicle sales. • By 2030, develop 200 km of the electric rail network to support public commuting and mass transportation of goods.
ZEV Share, Strategies and Targets	• Current EV Share: <1%
ZEV Policies	Policy preparation is in progress with proposed provisions and incentives (ESCAP Workshop 18/05/2022).
Charging Infrastructure	• The Nepal Electricity Authority says it is constructing 50 charging stations for electric vehicles across the country within one year (These, 2021) • At present, there are multiple EV public fast charging stations (List, 2022).
ZEV in Public Transport	• First pilot project (3 buses) was tested in Kathmandu in early 2022, and 37 buses will be procured by the end of 2022. • Nepal imported nearly 2,000 electric vehicles in the last fiscal year, with 800 being imported through Rasuwa border in 2022 from China. • Nepal's plan is to electrify 25% of private cars and 20% of buses by 2025 (Nepal's journey, 2022).
Key Policy Documents	• Environment Friendly Vehicles and Transport Policy, 2014 • Budget Speech of fiscal year 2022/23 (reduction of import taxes for EVs)

Country	Thailand
Population	69.95 million (World Bank, 2022a)
Per Capita GDP	$5,085.97 (World Bank, 2022b)
Electricity Generation by source (Share in %)	Gas: 64.54%, Coal: 20.58%, Hydro: 2.57%, Solar: 2.32%, Wind: 2.28%, Other: 0.4% (2021) (Ember, 2022)
Energy Imports	In 2020, Thailand's energy imports accounted for 12 per cent of the country's total imports. This was a slight decrease from the previous year, which accounted for 14 per cent of the import value (Manakitsomboon, 2021).
Vehicles manufacturers	Largest automotive industry in South-East Asia.
Emissions Status	• CO_2 emissions: 275.06 Mt of CO_2 (2019). From 2018 to 2019, there has been a slight reduction in emissions (Climate Scorecard, 2021) • 24.7% of the CO_2 emissions are from transport sector (2014)
NDC Commitments	Thailand submitted its revised NDC in Oct 2020 (UNDP, n.d.) • Unconditional NDC: Reduce greenhouse gas emissions by at least 20% from business-as-usual (BAU). • Conditional NDC: up to 25% from BAU by 2030
ZEV Share, Strategies and Targets	• ZEVs registered: About 240,000 vehicles (as on Dec 2021) • Vision: Thailand will become the global production and supplier hub for electric vehicles and automotive parts • Goal: Thailand towards 100% Zero Emission Vehicle (ZEV) sales by 2035 • Promotes EV by reducing import tariff on EV cars ranging from 0 to 40% depending on the engine size, until 2023
ZEV Policies	• CO_2 emission-based vehicle excise tax structure • Development of Standards and Regulations for 2W & 3W • Targeting to become global production and supplier hub for EV automotive parts • Purchase subsidies and special tariffs for EV charging
Charging Infrastructure	• DC fast charging is being used for the e-buses which are plying on road at present. • Battery swapping stations are set up and is being used for e-motorbike rental service (Winnonie) (Laoonual, 2022)
ZEV in Public Transport	At present, 27 e-buses are plying roads in Bangkok Metropolitan Area and the target is to procure 500 e-buses and replace 3000 old buses with EV (Laoonual, 2022)
Key Policy Documents	• Regulatory Framework and Investment Privilege Package in the Thai EV Sector Available to the Business and Investment Opportunities in European Automobile Companies (2021)

Country	Lao PDR
Population	7.38 million (2021) (World Bank, 2022a)
Per Capita GDP	$ 2,551.32 (2021) (World Bank, 2022b)
Electricity Generation by source (Share in %)	Hydro: 56%, Biogas: 22%, Biomass: 11%, Solar: 11% (2013) (Energypedia, 2022b)
Energy Imports	Exports electricity given its abundance of renewable energy sources.
Vehicles manufacturers	None
NDC Commitments	Lao PDR submitted its revised NDC in May 2021 (UNDP, 2021). • Unconditional emission reduction target of 60% by 2030, relative to the baseline scenario. • Strengthened mitigation measures in the forestry and energy sectors. • The revised NDC references circular economy as a key instrument to pursue a low-carbon development pathway.
ZEV Share, Strategies and Targets	• Existing ZEV Share: <1% • Targets: 1% of the cars sold to be electric by 2025, and 30% by 2030 (Department of Promotion and Energy Saving, 2022).
ZEV Policies	Powers given to Ministry of Energy and Minerals for policy formation relating to EVs. Promotion of EV manufacturing. Exemption from import tax on equipment and charging station system. Standards being developed.
Charging Infrastructure	• Pilot EV Charger Project was initiated in Vientiane Capital. According to the proposed policy, Loa PDR to develop 100 charging stations throughout the country by 2030.
ZEV in Public Transport	None as yet.
Key Policy Documents	• National Green Growth Strategy • National Energy Efficiency and Conservation Policy Towards 2030 • 9th Five-Year National Socio-Economic Development Plan • Lao PDR Energy Outlook 2020

Country	Republic of Fiji
Population	0.902 million (World Bank, 2022a)
Per Capita GDP	$ 5,085.97 (World Bank, 2022b)
Electricity Generation by source (Share in %)	Hydro: 55%, Biomass: 5% (2013) (Energypedia, 2022a)
Energy Imports	• Republic of Fiji depends heavily on imported fossil fuels. • In 2016 Fuel imports accounted for 16% of Republic of Fiji's total national import bill (US$ 346 million). • Most of this fuel, mainly gasoline, oil and aviation turbine fuel, is consumed by the transport sector.
Vehicles manufacturers	None
Emissions Status	• In 2021, total CO_2 emissions for Republic of Fiji was 1.7 Mt of CO_2 (knoema, 2021). • Road transport in Republic of Fiji is completely dependent on petroleum fuels (R. D. Prasad & Raturi, 2018).
NDC Commitments	Republic of Fiji's emission reduction target focuses on the energy sector, specifically on electricity generation and transmission and demand-side energy efficiency (Fiji, 2019). The 30% target includes: • 20% reduction in GHG emissions by achieving 100% renewable electricity generation in power sector. • Additional 10% reduction in GHG emissions is expected from economy wide reduction CO_2 emissions, implicitly from transport, industry and electricity demand sectors.
ZEV Share, Strategies and Targets	• Launched first-ever environmentally friendly electric vehicle (Electric Car – MG ZS EV) in May 2022 (S. Prasad, 2022). • Preparing to pilot e-buses (Vula, 2022)
Charging Infrastructure	The government is partnering with private entities to set up charging stations for electric cars and buses.
ZEV in Public Transport	Planning to pilot electric buses with local technical capacity to operate and maintain e-bus transportation (Vula, 2022).
ZEV Policy	• 30% emission reduction by 2030 • Net zero by 2050
Key Policy Documents	• Fiji Climate Change ACT, 2021 • Fiji NDC Implementation Road Map 2017-2030 • Fiji Low Emissions Development Strategy 2018-2050 • Transport Decarbonisation Implementation Strategy (planned)

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