E-MOBILITY

Technology Roadmap

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List of Abbreviations

°C	Degree Celsius
A*STAR	Agency for Science, Technology and Research
AC	Alternating Current
AGR	Annual Growth Rate
ARF	Additional Registration Fee
BAU	Business as usual
BCA	Building Construction Authority
BEV	Battery Electric Vehicle
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditures
CEVS	Carbon Emissions-based Vehicle Scheme
CEVS	Carbon Emissions-based Vehicle Scheme
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CREATE	Campus for Research Excellence And Technological Enterprise
DC	Direct Current
EDB	Economic Development Board
EMPSO	Electro-Mobility Singapore Programme Office
ERIAN/ERI@N	Energy Research Institute at NTU
EU	European Union
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCL-ETH	Future Cities Laboratory - Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology)
GPV	Good and Passenger Vehicle
GWh	Gigawatt Hour
HDB	Housing & Development Board
HGV	Heavy Goods Vehicles
HGV	Heavy Goods Vehicles
ICE	Internal Combustion Engine
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transport Systems
km	Kilometers
kt	Kilotons
kW	Kilowatts
kWh	Kilowatt Hour
LGEV	Light Goods Electric Vehicle
LGV	Light Goods Vehicle

LTA	The Land Transport Authority
LTMP	Land Transport Master Plan
MEWR	Ministry of the Environment and Water Resources
MJ	Mega Joule
MND	Ministry of National Development
MRT	Mass Rapid Transit
Mt	Millions of Tons
NCCS	National Climate Change Secretariat
NiMH	Nickel–metal Hydride
NRF	National Research Foundation
NTU	Nanyang Technological University
NUS	National University of Singapore
OEM	Original Equipment Manufacturer
OMV	Open Market Value
OPEX	Operational expenditures
PHEV	Plug-in Hybrid Electric Vehicle
PSPC	Public Sector Panels Of Consultants
PV	Photo Voltaic
R&D	Research & Development
SAE	Society of Automotive Engineers
SMART	Singapore-MIT Alliance for Research Technology
SME	Small and medium-sized enterprises
SMU	Singapore Management University
SUTD	Singapore University of Technology and Design
TCO	Total Costs of Ownership
TUM	Technical University of Munich
TWh	Tera Watt Hour
U.S.	United States
US$	US Dollar
VHGV	Very Heavy Goods Vehicle

1 EXECUTIVE SUMMARY

The National Research Foundation (NRF) and the National Climate Change Secretariat (NCCS), together with the relevant government agencies, are working together with members of the research community and private sector of Singapore to develop a series of technology roadmaps on energy and climate change related technologies.

The Land Transport Authority (LTA), as part of the roadmap development effort is developing a technology roadmap on electromobility until the year 2050. LTA has engaged the Energy Research Institute (ERI@N) of Nanyang Technological University (NTU) for the development of the Electromobility Roadmap to serve as a blueprint to guide the formulation of policies and infrastructure plans that could enable successful electromobility deployment in Singapore.

The roadmap is structured in 5 phases (Figure 1).

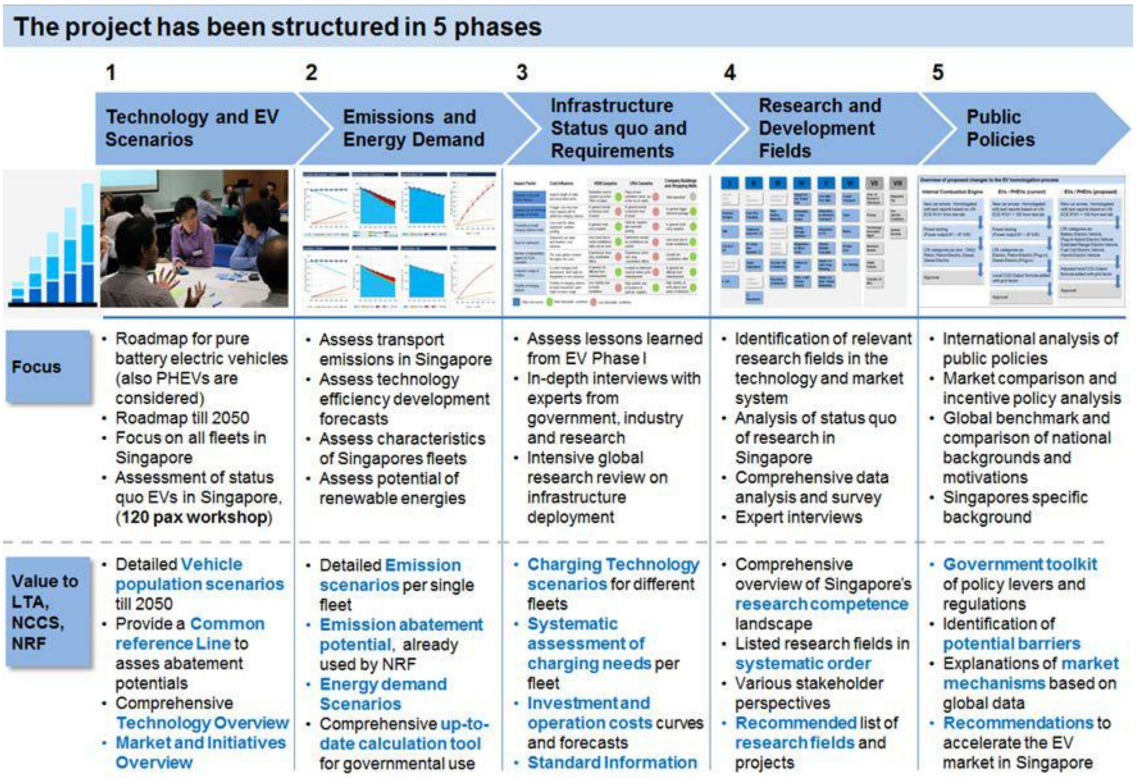


Figure 1: Overview Project Structure
Source: ERI@N

Several scenarios about how the global share of electric drive trains in the overall vehicle population will develop have been published by the International Energy Agency (IEA) and further renowned organisations. Singapore as a City-State, aims to be at the forefront of green technology adoption, and therefore would like to build towards more ambitious targets. The term “electric vehicles” (EVs) in this report refers to pure battery electric vehicles (BEVs) and Plug-in Hybrid EVs (PHEVs). This report analyses the fleet integration of both technologies with a priority set on BEVs. Based on assessments of relevant stakeholders from industry, academia and government the following low, medium and high fleet electrification scenarios for the shares of EVs in Singapore’s fleets in 2050 have been developed.

Key Findings

Fleet Electrification	• Electrification between 134,000 EVs (Low scenario) and 532,000 EVs (High Scenario) in 2050 • **Public Buses** and **Taxis** offer the biggest potential for electrification
Energy Demand	• The High Scenario requires **6.9%** (3.1 TWh) of today's electricity consumption in 2050 (45 TWh) • This equates to **45%** of projected PV electricity generation in 2050 (7 TWh, conservative PV scenario)
Emissions and Abatement	• Replacing a conventional bus in Singapore with a battery electric version could lower emissions up to **56%** per vehicle already today • In the High Scenario, EVs can bring emissions down by **30%** compared to BAU in 2050 (1.4 Megatons) • In the High Scenario, EVs powered purely with solar PV-generated electricity can bring emissions down by **64%** (3 Megatons) compared to BAU in 2050
Competitive Research	• Competitive advantage potential in ► Autonomous urban electric (micro) systems ► Smart connected urban electric transport ► Charging infrastructure solutions ► System integration • Enabled by • Strong research landscape of Singapore • Conducive test-bed Conditions • Continue research in next generation batteries with strong monitoring of outcomes to justify investment and ensure leading edge research
Charging Infrastructure	• Infrastructure to be built by private sector, in case **EV market is accelerated** and **investment framework** provided by politics • Main barriers: policies, regulations and investment uncertainty • **Decision** on and **commitment** to one **standard recommended**

2 Introduction

Singapore's transportation strategy targets to public transport a choice mode, managing road usage and meeting diverse needs. To ensure that roads are smooth-flowing and to limit congestion on the dense urban island, the government has to regulate the amount of vehicles on road through active implementation of several schemes. Dating back to 1960s, where various schemes such as imposing 30% import duty tax on private cars in 1968 and the introduction of a diesel tax in 1970 are classical examples.

To further encourage the development of green transportation, an EV Test Bed was launched in 2011. In the following year, CNG special tax was replaced by a CNG duty of S$ 0.20 for every kilogram of CNG consumed. Road tax for electric, petrol-electric hybrid, CNG and Bi-fuel commercial vehicles was targeted to be 20% lower compared to diesel consuming ICEs.[1] In 2014, the LTA announced plans of a BEV car-sharing trial, which is designed to introduce up to 1,000 BEVs as well as the supporting charging infrastructure to Singapore.

As a result of careful planning and implementation of the above schemes, the government has gradually reduced the annual vehicle growth rate from 3% in 1990 to 1.5% in 2009, 1% in August 2012 and 0.5% since February 2013.[2] In view of the limited scope, to further increase the road network different scenarios for the development of Singapore's overall vehicle population till 2050 are discussed (Figure 2).

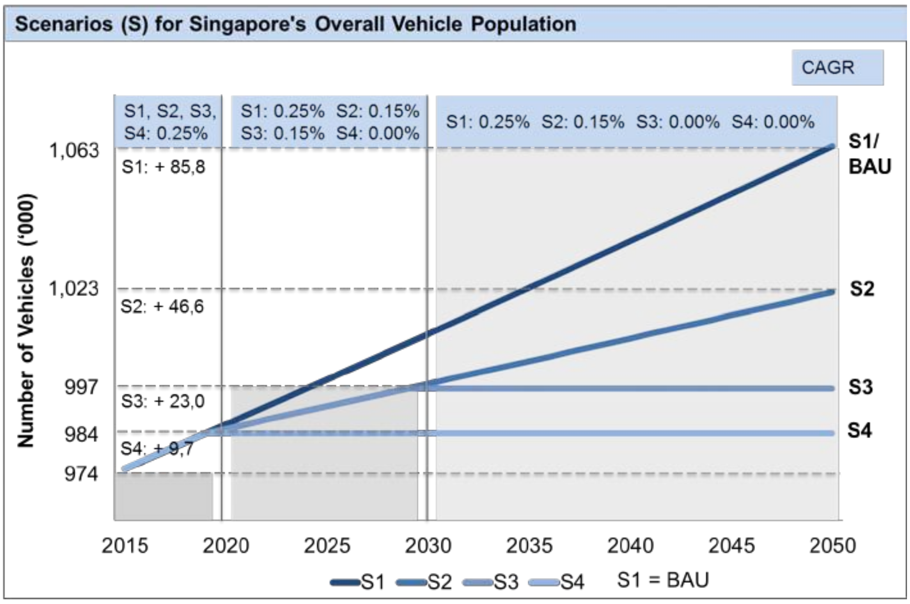


Figure 2: Scenarios for Singapore's Overall Vehicle Population Development
Source: ERI@N

[1] ERIAN Analysis based on NEA Green Vehicle Rebates
[2] ERIAN Analysis based on LTA LTMP 2013

2.1 Vehicular Population and Fleet

The overall vehicle population in Singapore consist of different fleets (Figure 3). Each fleet has its own characteristics in terms of vehicle population, mobility patterns, mileage and impact on the environment. Cars with a fleet size 616,609 make up for 65% of Singapore's overall fleets and therefore produce the highest total amount of CO_2 emissions. In terms of annual CO_2 emissions per vehicle public buses rank highest with around 100kt per vehicle per year. Taxis account for only 3% of the overall vehicle population but clock the highest mileage with around 125,000km per vehicle per year.

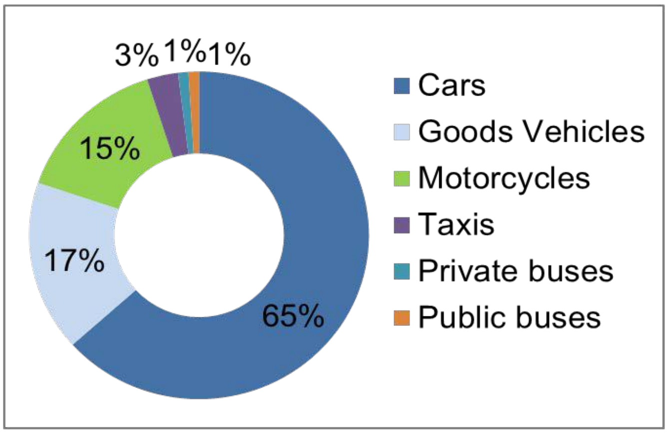


Figure 3 Shares of Fleets in Singapore 2014
Source: ERIAN Analysis based on LTA

Private Vehicles (Cars)

Due to Singapore's transport strategies, which focus on public transport as a choice mode, strict limitation of number of cars allowed on the roads, car ownership and possible carsharing concepts for Singapore have to be considered from different angles. As of Mar 2016, there are two pure electric vehicles and 112 Plug-in Petrol Electric Vehicles registered. A commonly cited reason for the small number of EVs in Singapore is the high cost of the vehicles as well as the unavailability of charging infrastructure. The technical capabilities of EVs should not be seen as a major concern for private EV buyers. Stakeholders express that the driving range is 100km per charge for an EV, which is greater than the driving range of an average Singaporean user, at 55km, and thus this does not pose a big issue. Furthermore, vehicle performance is thought to be decent as well in terms of speed, power and acceleration of currently available EVs. However, there are other requirements that need to be in place to increase the number of privately owned EVs. These include the availability of home charging facilities in housing estates (HDB/ Condominium). Moreover, the HDB and condominium environment should be more EV charging friendly in terms of the ease of getting charging station approvals. A wider range of EV selection models such as electric high-end vehicles for the more affluent (landed property owners) and larger vehicles for people buying family size cars would help EV-uptake as well.

Taxis

Taxis are a major part of Singapore's transport system. As car-ownership has to be limited, Taxis offer a convenient daily door-to-door mobility for Singapore's commuters. Currently 6 taxi companies operate 28,736 taxis on Singapore's streets. While taxis make only 3% of the overall vehicle population fleet, they make with around 125,000km per year the highest annual mileage of all vehicles and account for around 15% of the total distance covered by all vehicles in Singapore. In 2011, about 9 million passenger-km per day were covered by taxis in Singapore which represent about 19% of the total public transport. Furthermore taxi availability standards, introduced in 2013 make sure that taxis drive at least 250km per shift. Since taxis highly complement the strengthening public transport, a population scenario with a slightly positive annual change rate (ACR) was developed which will saturate in 2030 when a limit of road capacity is reached and strong MRT and bus network will cater to the people's a high portion of mobility needs.

Buses

In Singapore, the bus network is an important and integral component of the road transportation system. At present, nearly 18,000 (public and private) buses are in service on Singapore's roads. Though this represents about 2% of the existing motor vehicle population, the average daily distance travelled by buses is about 227km, which is among the second highest daily utilised fleet in operation. It is anticipated that the population of buses would grow to meet the growing mobility demands of the population. Public buses travel an estimated peak of 250km, running about 18 hours each day. There are two travel patterns, namely regular loop services and long distance services. Public buses have a maximum utilisation rate during peak hours. SBS and SMRT stated that its peak hours are similar to the normal bus lane operating hours mandated by the LTA. The challenge in deploying full electric buses lies in the operation range which has to be covered during the day and thus in the battery and charging technology used. The size and number of batteries needed to provide energy to cover the required range of public buses consumes space within the vehicle and such generates a trade-off to the number of passengers which can be seated in the interior.

Urban Freight Transport

Global freight transportation demand is projected to grow to 27.5 billion tons in 2040, requiring ever-greater amounts of energy and seeing more and smaller deliveries through e-commerce. While the number of private vehicles is expected to be reduced in Singapore, freight transport is a main pillar of economic growth. While the government want to boost economic growth, a high quality of life has to be ensured at the same time. Therefore a demand for low-carbon, energy-efficient and route-optimised urban logistics emerges. The market of urban freight transport in Singapore is highly fragmented. A great variety of companies operate with micro-fleets of sometimes a few vehicles only. Little is known about the driving patterns of the different fleets as research on the electrification of freight transport is Asia is just emerging. The delivery business in Singapore, mostly done by fleets LGVs shows the potential for the introduction of BEVs. BEV-suitable mobility patterns of delivery vehicles show reoccurring driving routes on limited, well planned distances.

2.2 Moving Forward

Several strategic plans and roadmaps developed by government agencies touch the topic of future green transportation in Singapore. Three major strategy plans show the future strategic framework in which electromobility in Singapore is or will be integrated: the LTMP by LTA, the Smart Mobility 2030 Strategy by LTA and the Sustainable Singapore Blueprint by MEWR and MND (Figure 4). The LTMP states that Singapore, in its quest for a high quality and sustainable living environment, requires stricter standards on vehicle emissions and promoting greener alternatives to reducing air pollution from vehicles. It further describes the Carbon Emissions-based Vehicle Scheme (CEVS), introduced in 2013 and renewed in 2015, which encourages consumers to buy more fuel-efficient through financial charges and incentives.

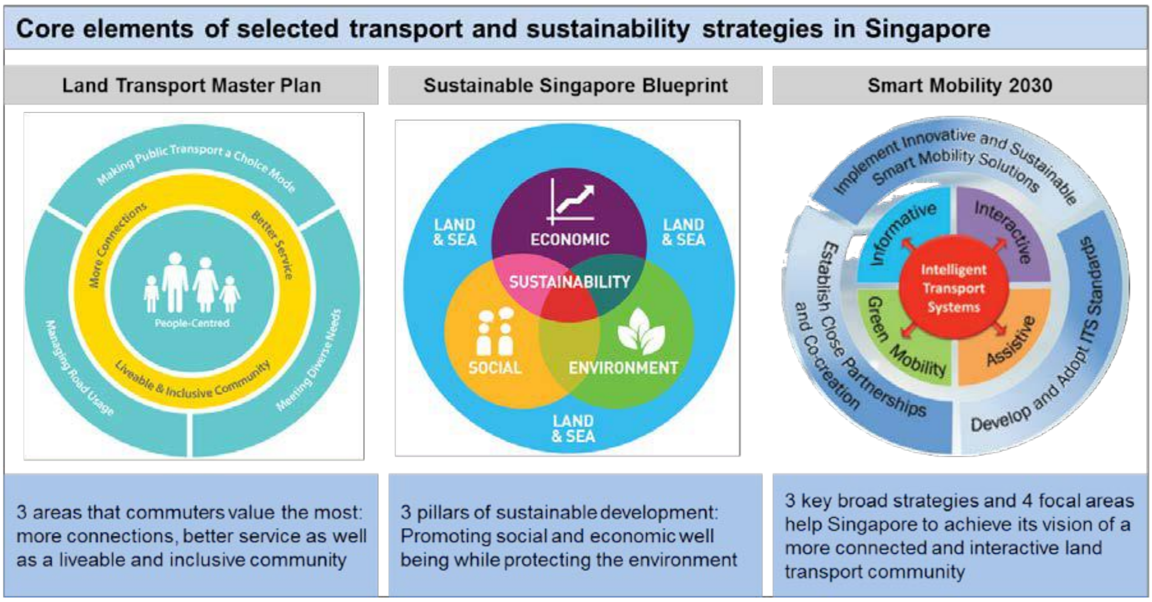


Figure 4 Core Elements of Selected Transport and Sustainability Strategies in Singapore
Source: ERI@N Analysis based on LTA and MEWR

The "Sustainable Blueprint Singapore 2015" understands Greener Modes of Transport as one systemic part to create a more liveable Singapore, promoting social and economic well-being while protecting the environment.[3] EVs are regarded as integral part of greener modes of transport. With the planned EV carsharing trial that could last up to 10 years, announced at the end of 2014, the government aims to gain a deeper understanding of the operating models and support required for EVs to succeed on a larger scale in Singapore.[4] The carsharing scheme will build on the lessons of the earlier test-bed and make EVs more widely available to the public.[5] This trial coordinated by LTA and EDB might be broadened to commercial vehicle fleets in the next steps. The ITS Strategic Plan for Singapore "Smart Mobility 2030" regards "Green Mobility" as a focal area in the nations ITS strategy to achieve a more connected and interactive land transport community. According to the plan, to reduce impact on the environment increased emphasis should be placed on green and sustainable transport systems by integrating EVs.[6] Electromobility bears the potential to seamlessly fit into all three strategy plans, providing essential support for national priorities in security, economy, and environment. When integrated in a systematic and holistic manner, EVs can support the transition towards a benchmarking, smart, sustainable human transport system ensuring a world-class level of quality of life.

[3] Based on Sustainable Singapore Blueprint; MEWR, 2015
[4] Based on plans for electric car-sharing trial for up to 1,000 vehicles; Zengkun, F; The Straits Times; 2014
[5] Based on Sustainable Singapore Blueprint; MEWR, 2015
[6] Smart Mobility 2030 – ITS Strategic Plan for Singapore; Land Transport Authority; 2014

3 Technical Performance and Economics of Current, Emerging and Future Electromobility Technologies

In general, electro-mobility embraces all passenger motor vehicles and commercial vehicles, as well as two-wheelers (scooters and electric bicycles), used on the road, that can cover at least a portion of the route propelled purely by electricity, regardless of whether they get their energy from a battery or from a fuel cell. The Figure 5 gives an overview and examples of alternative drivetrain vehicles that are currently available and vehicles that are expected in the future.

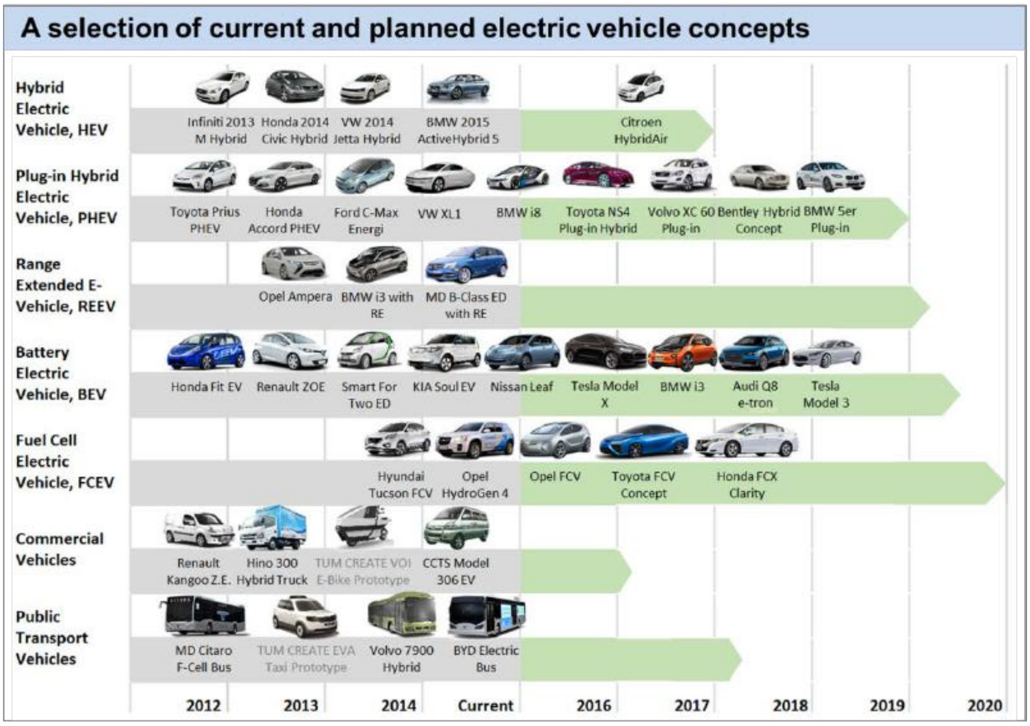


Figure 5 A Selection of Current and Planned Alternative Drivetrain Vehicles

The key factors determining the performance of a BEV are driving range, battery capacity, charging time etc. Table 1 below summarises the performance parameters of popular BEVs currently on-road.

Model name	Driving Range (miles)	Price (US$)	Battery Type	Battery Capacity (kWh)	Charging Time
Mercedes B-Class Electric Drive (Daimler)	124	49,000	Lithium-ion	28	• 230V/13A: 9 - 21h • 400V/16A: 4.4h
Kia Soul EV (Hyun-dai-Kia)	93	33,700	Lithium-ion polymer	27	• 6.6kW: 5h
i3 (BMW)	118	46,700	Lithium-ion	18.8	• 2.4kW/10A: 7h for 80% SOC • 7.4kW/32A: 3h for 80% SOC • 50kW/125A: 0.5h for 80% SOC
Leaf (Nissan)	84	29,010	Lithium-ion	24	• 6.6kW: 5h
Chevrolet Spark EV (GM)	82	25,995	Lithium-ion	18.4	• 120V: 20h • 240V: 7h • SAE Combo DC Fast Charger: • 50 minutes for 0-80% SOC
Fit EV (Honda)	82	36,625	Lithium-ion	20	• 120V: 15h • 240V: 3h
ZOE (Renault)	121	20,482	Lithium-ion	22	• 3kW /16A: 6 to 9h • 22kW /32A: 1h for 80% SOC • 43kW /63A: 0.5h for 80% SOC

Table 1: Key Performance Parameters for Common BEV Models

In Singapore, though vehicle manufacturing is not present, it is a global market for EVs potentially. The government has also taken initiatives for test bedding these technologies and their deployment for the local land transport usage. The vehicle emission factors are significant to compare among the different propulsion concepts.

3.1 Batteries and Cost

One of the major technology challenges for EVs is cost reduction of batteries, which accounts for 25 – 50% of the total EV price[7]. Reduction in the price will make EVs more cost competitive as compared to ICEs. Currently experts estimate that battery prices range between US$ 300 and 600 per kWh.[8] However, there are also aggressive projections for battery costs to go as low as US$ 125 per kWh[9]. Driven by the need to reduce battery cost to increase deployment of EVS, there is worldwide research work focused on doing just that while improving the performances of the batteries. Materials and chemistries of the battery, the way of assembling the cells, required production processes, cost of labour and in the end economies of scale influence the final purchase prices of batteries (Figure 6).

Projections of battery cost vary but there have been observable trends where improvements in performances and reduction in cost has been a gradual process. Since 2008, for example the cost of Tesla's battery packs has been cut approximately in half, while the storage capacity has increased by about 60%. Experts expect that prices of batteries have been at a level of US$ 300 per kWh in 2014 and are on track to reach US$ 230 per kWh in 2018 (Figure 7).

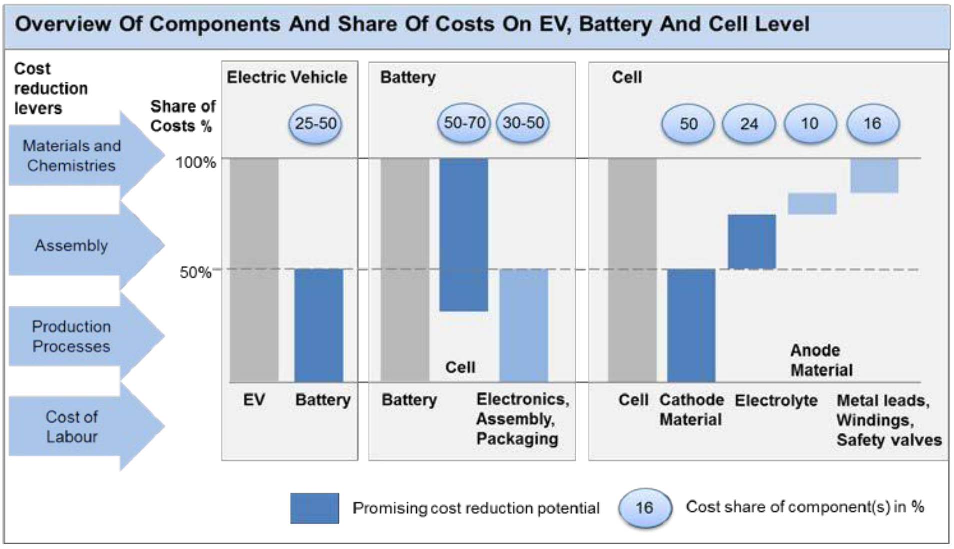


Figure 6 Simplified Overview of Share of Costs on EV, Battery and Cell level
Source: ERI@N Analysis based on MIT Entrepreneurship Review

[7] ERIAN Analysis based on MIT Entrepreneurship Review; 2011
[8] Based on Electric Vehicles in EU by McKinsey, 2014; Rapidly falling costs of battery packs for electric vehicles - Nykvist, 2015
[9] Based on U.S. Department of Energy

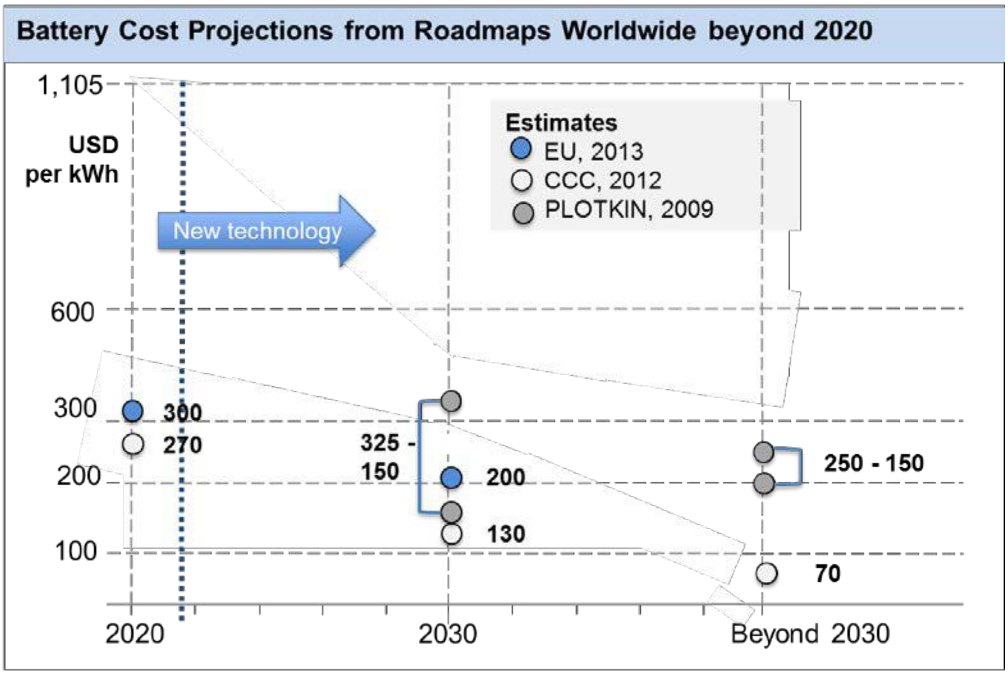


Figure 7: Battery Cost Projections from Roadmaps Worldwide beyond 2020[10]

Today lithium-ion batteries are the most common accumulators to be used in buyable EVs because they are relatively light and compact, have good charging characteristics and a high energy density. The main component of a lithium-ion battery is the cell, which makes up 50% to 70% of the battery costs. The remaining 30% to 50% of the costs comes from electronics, assembly and packaging. On cell level again the cathode material and the electrolyte constitute the biggest share of costs. [11] The cost of the lithium-ion batteries for EV can decrease by close to US$ 300 per kWh in 2020, without unrealistic assumptions on the technical progress and manufacturing technology. Further cost reduction on the contrary requires the development of more innovative technologies, not available today.

Apart from lithium-ion, nickel-metal hydride (NiMH) batteries are also commonly used for EV propulsion. At present, the automotive industry mostly implements NiMH batteries for high performance applications. But as lithium-ion batteries have energy density level higher than NiMH, they are widely recognised as being the battery technology with the best long-term prospects thanks to its low weight and long durability. By cost, effectively lead-acid and molten salt battery stand-out as being much lower in comparison to others, but due to physical limitations in size and weight, they are not considered for electromobility. Table 2 is a comparison of various battery types that are in use for EV applications and clearly shows that lithium-ion performance characteristics are more suitable for EVs.

[10]ERI@N based on E-mobility Roadmap for the EU battery industry 2013; Cost and performance of EV batteries Final report for the Committee on Climate Change, CCC ; 2012 and Multi-Path Transportation Futures Study:
Vehicle Characterisation and Scenario Analyses, 2009
[11]ERIAN Analysis based on MIT Entrepreneurship Review; 2011

Battery types	Cycle Durability	Life (years)	Self-discharge (%/month)	Cost (USD per kWh)	Energy Density (Wh/kg)
Lead-acid	500-800	5-8	3-4	125-200	30-40
Nickel-metal hydride	500-1000	n.a.	30	~360	30-80
Nickel-cadmium	1500	n.a.	20	400-800	40-60
Lithium-ion	400-1200	2-6	8	200-360	80-200
Lithium iron phosphate	8000	>10	n.a.	200-330	80-120
Vanadium redox	14000	10 (stationary)	20	n.a.	25-35
Molten salt	3000	<= 20	n.a.	220	70-290

Table 2: Common Battery Types and Specifications

Singapore a small market for the battery manufacturers, there are no significant battery manufacturing/ mass production activities in Singapore. But the local research institutions are significantly focusing on energy storage material research, which is discussed in further chapters. For BEV/PHEV deployment, the cost and performance of the energy storage system is greatly affected by the ambient temperature of the region Figure 8 shows the advantage of Singapore conditions for good battery performance and lifetime. The lower temperatures for battery also requires an external heating unit to warm up the battery for normal working and in humid, high temperature conditions special cooling mechanisms are to deployed to maintain the battery performance. This significantly affects the vehicle overall performance.

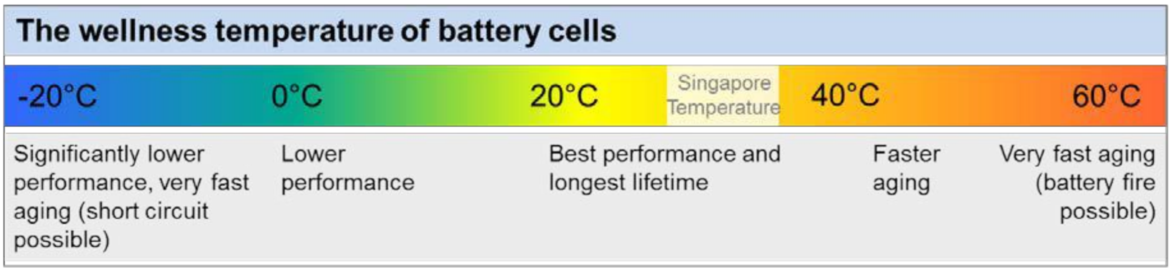


Figure 8: Wellness Temperature Range for Battery Cells

3.2 Charging Infrastructure

While the refueling process of conventional combustion engine vehicles is fast and convenient today, charging of an EV remains more onerous, in locating a charging station and the duration of charging required. Unlike conventional fuels which requires minutes to refuel, batteries require relatively long charging times based on existing battery technology (current fast-charging of battery to 80% requires 20-30 minutes depending on the battery size, and slow-charging usually takes 4-7 hours).Hence, one of key challenges to higher take-ups of EVs is linked to the deployment of charging infrastructure.

3.2.1. Electric Vehicle Supply Equipment (EVSE)

EVSE is the terminology used for the off-board device that connects vehicle to the Grid. EVSE consists of the collective of cords, connector and attachment plugs, to all other fittings, devices, power outlets or apparatus that are installed specifically for the purpose of delivering energy to an EV (see Figure 9).

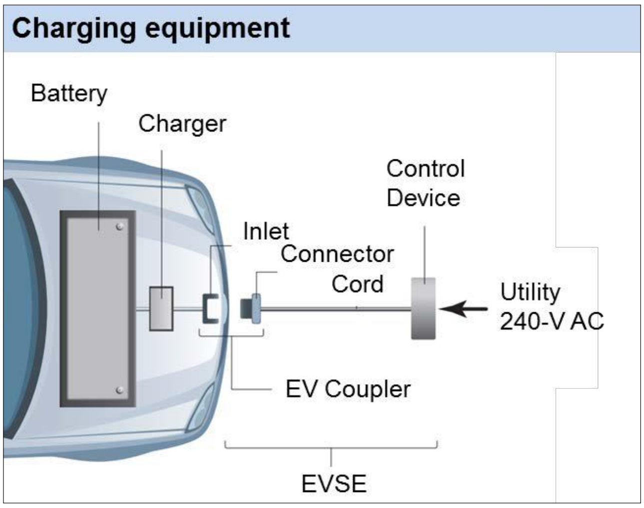


Figure 9: Charging Schematic Diagram

Source: ERIAN Analysis based on U.S. Department of Energy

EVSE products vary in the types of features they offer and the corresponding price, for example, the City of Houston in the U.S. reported installation costs of US$ 860 to US$ 7,400 per EVSE unit - Factors affecting the cost (and installation time) include the number of circuits and EVSE units installed, indoor versus outdoor installation, required electrical upgrades, required ventilation, and the use of DC fast-charging EVSE[12].

12 ERIAN Analysis based on U.S. Department of Energy

3.2.2 Types of EV Charging

There are different technologies to charge / transfer electrical energy to on-board energy storage systems (batteries or super capacitors) such as through wired/plug-in charging, battery swapping, flash charging and wireless/induction charging (Figure 10).

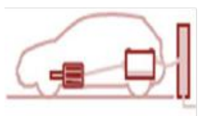
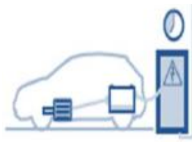
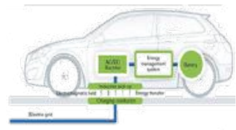
Charging concept	Plug-in slow charging	Plug-in fast charging	Inductive charging	Battery swapping
				
Description	Charge with cable while parked	Charged with cable while parked	Charged wirelessly	Drained batteries are replaced with freshly charged ones at swapping stations
Advantages	Low power Cheap Long charging time	High power Charging times in 10 – 30min Extends driving range	High convenience	Takes 5 minutes Unlimited driving range
Challenges	Takes 3 to 12 hours Limited driving range	High power Expensive	Expensive Low efficiency	Requires extra batteries Cost intensive system
Efficiency	96%	94%	91%	Depend on internal changing method use
Deploy-ment area	Personal in-house overnight charging	Public (car park near express way, office building ....)	Short, rapid charge area (ex: shopping mall)	Highway road, serving far travel-ling vehicles

Figure 10: Overview of Charging Concepts and Features

Wired/plug-in charging: This is the most conventional and common form of charging for EVs today whereby an EVSE is used to connect the battery and charger within the vehicle with the electrical grid. The interface between the EVSE and the premise's wiring may be through a plug and receptacle interface or hard wired into the electrical unit.
EVSE are classified based on different power levels (U.S. Terminology - Level 1, 2, 3/DC fast charging, EU terminology – Mode 1,2,3,4) based on the power ratings, i.e. voltage & current values at which the batteries are charged and summarised in the Figure 10. The amount of electric power that an EVSE can deliver to a battery is measured in kilowatts (kW).

Battery swapping: In 'conventional' EVs, the battery is charged inside the vehicle as needed, using direct or alternating current. However, battery swapping replaces the on-board depleted batteries with charged ones. This is currently the fastest full battery charging method, between two to five minutes only.

Flash charging: New charging technology that allows a vehicle to be partially charged in a shorter time (in few seconds) through conductive charging methodology. This requires an ultra-high power source, such as super capacitor based energy storages at the charging points.

Inductive charging: Inductive charging is a method of recharging the battery without physically connecting to a charging station. An electromagnetic force induces to transfer electrical power from a transmitter to a receiver without the use of cables or connections. For recharging the battery, a transmitter could be built under a road surface. Current systems have efficiencies around 90%. The elimination of cable and plug makes this technology much more consumer friendly and may help to lower the cost of maintenance by avoiding the careless handling of plug-in wires by multiple people.

3.2.3. Installation of Charging Stations and Cost

Figure 11 illustrates the variety of factors which influence the costs associated with the installation of charging stations in Singapore. The varying site conditions result in broad price spans, when it comes to installation costs (Figure 12)

Selected impact factors on installation costs for charging infrastructure at parking sites

Impact Factor	Cost Influence	HDB Carparks		URA Carparks		Company Buildings and Shopping Malls	
■ Distance to the next Power Source	Impacts length of cable and associated works	Substation next to carpark (up to few 100m of cable)	More favourable	Distance to next substation varies (up to few km of cable)	Less favourable	Site dependent	
■ General size of electrical package of building	A bigger size may have more capacity left for additional charging stations	In general provide a minimum level of power	Less favourable	In general provide a minimum level of power	Less favourable	In general bigger electrical package	More favourable
Possibility to install charging stations inside	Less need for safety equipment, weather-proofing	In general multi-story carparks	More favourable	Open-air carparks and road-side parking	Less favourable	In general multi-story carparks	More favourable
Need for earthworks	Earthworks are labor and therefore cost-intensive	Less need due to inside installations, walls can be used	More favourable	Earthworks needed as installations are outside	Less favourable	Less need due to inside installations	More favourable
Number of stakeholders (agencies) to be consulted	The more parties involved the higher the costs	Experiences show long coordination efforts	Less favourable	Experiences show very long coordination efforts	Less favourable	Usually low coordination effort	More favourable
Long-term usage of location	In a fast changing built environment land might be designated to new purposes	In general not affected from redevelopment	More favourable	Located on state land could be taken up for redevelopment	Less favourable	In general not affected from redevelopment	More favourable
Visibility of charging stations	Visibility of charging stations at highly frequented spots might increase usage	Low visibility due to inside installation	Less favourable	High visibility due to locations of open-air carparks	More favourable	High visibility at work places and points of attraction	More favourable

■ Main cost source · More favourable conditions · Less favourable conditions

Figure 11 Selected Factors that Influence the Costs Charging Station Installations[13]

13 ERIAN analysis based on interviews with electromobility stakeholders in Singapore

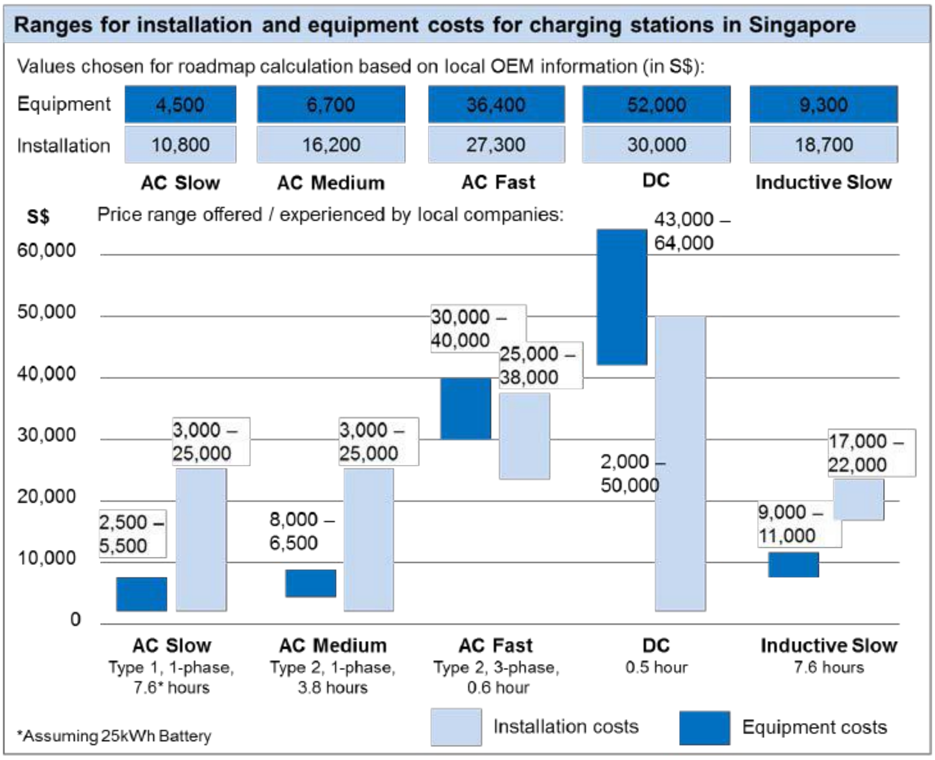


Figure 12 Ranges for Installation and Equipment Costs for Charging Stations in Singapore

3.3 EV Charging Standards

To enable EV drivers to roam between networks and ultimately between countries, standardisation of charging system is necessary. It helps to address the type of physical infrastructure - plugs, sockets, connectors etc. and the communication protocols for grid connectivity, billing, and payment.

The global charging standards are developed by International Electrotechnical Commission (IEC), Society of Automotive Engineers (SAE), Institute of Electrical and Electronics Engineers (IEEE), International Organisation for Standardisation (ISO) and GuoBiao (GB). In addition, CHAdeMO is a DC quick charging standard which was developed in Japan. Figure 13 below shows the most important standards on conductive and inductive charging.

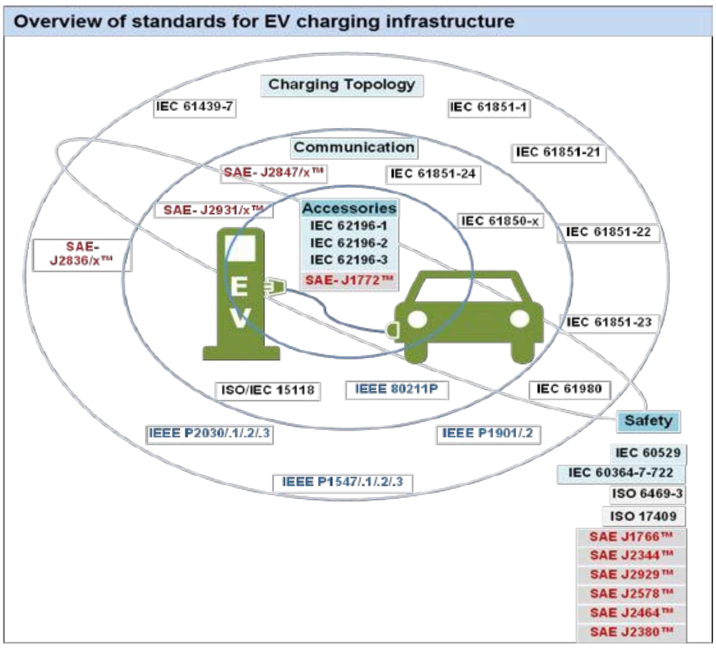


Figure 13 Overview of EV Infrastructure Charging Standards
Source: ERI@N based on SAE

IEC 61851-1 provides the general requirement for EV conductive charging system; Figure 14 shows the various modes of charger classification based on IEC 61851-1. This standard describes different charging modes as a basis for the regulations in the subsequent standards.

IEC EV charging modes based on IEC 61851-1				
Mode	**Supply**	**Duration**	**Charger configuration**	**Example charger**
Mode 1	AC	Slow(~4.5 hours at 3.7kW)	Standard household-type connector	1- phase plug
Mode 2	AC	Slow (~2.2 hours at 7.4kW)	Standard household-type socket-outlet with an in-cable protection device	1 or 3-phase
Mode 3	AC	Slow/Fast (~1.1 hours at 14.5kW)	Specific EV socket-outlet and plug with control and protection function permanently installed	SAE J1772, IEC 62196
Mode 4	DC	Fast (~ 20 min at 50kW)	Fast external charger	CHAdeMO

Figure 14 Comparison of Various Modes of EV Charger Operation
Source: ERI@N based on E.ON Energy Research Center Series, 2010

Apart from the standards specified, there are standards for safety and interoperability of the charging interfaces. The description global charger connecters and the standards are presented in the following section. On broad scale the chargers are categorised based on the current used namely, alternating current (AC) and direct current (DC) chargers. Figure 15 shows the common charging standards for AC and DC chargers available across the world.

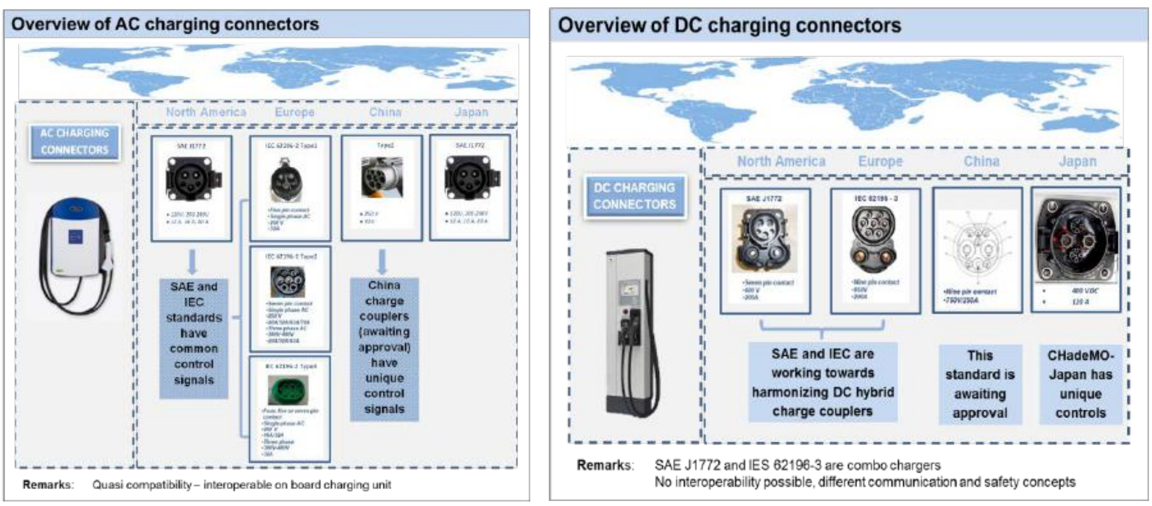


Figure 15 Overview of EV AC (Left) and DC (Right) Charging Connectors[14]

There are various configurations of the multi-standard systems[15]. The more common one incorporates two DC charging standards in one charger, e.g. CHAdeMO plus CCS or other combinations. Some chargers may also incorporate both AC and DC charging in a single charger. Type 1 from Japan is only designed for single-phase operation offers limited options for three-phase grids. Type 2 copes with all relevant performance classes around the world: from single-phase AC in the private home to high-performance three phase connections with 63A. Type 2 is also the basis for the Combined Charging System for DC charging[16].

14 ERI@N based on U.S. Department of Energy; Frost & Sullivan Analysis and TUV SUD
15 Based on Technical Guidelines on Charging Facilities for Electric Vehicles, Electrical and Mechanical Service Department, The Government of the Hong Kong special administrative division
16 www.mennekes.de

3.4 Grid and Energy Supply

The emergence of electromobility is an important development for the power sector. While the adoption of EVs can provide new opportunities – such as creating additional electricity sales for utilities and a demand for charging infrastructure and related services – the charging of EVs at a large scale can also create challenges for local distribution grids and their operators, if not properly managed. While the energy demand of EVs in general can be served by the energy grid, local concentrations of EV demand can lead to bottlenecks.

Based on research done by TUM-Create for electric vehicle load on Singapore power grid, there were approximately 600,000 cars on Singapore's roads in the year 2012. If all these cars were electric cars, this would have a notable impact on the power system. Assuming that every private car drives 52km per day on average, the overall mileage is about 11.4 billion km per year. Further assuming an energy consumption of 200Wh/km (including air conditioning), this sums up to approximately 2,500GWh per year (including transmission losses) which is about 5.2% of Singapore's electricity generation of 2012. The shift in the power demand due to the above scenario is shown in Figure 16.

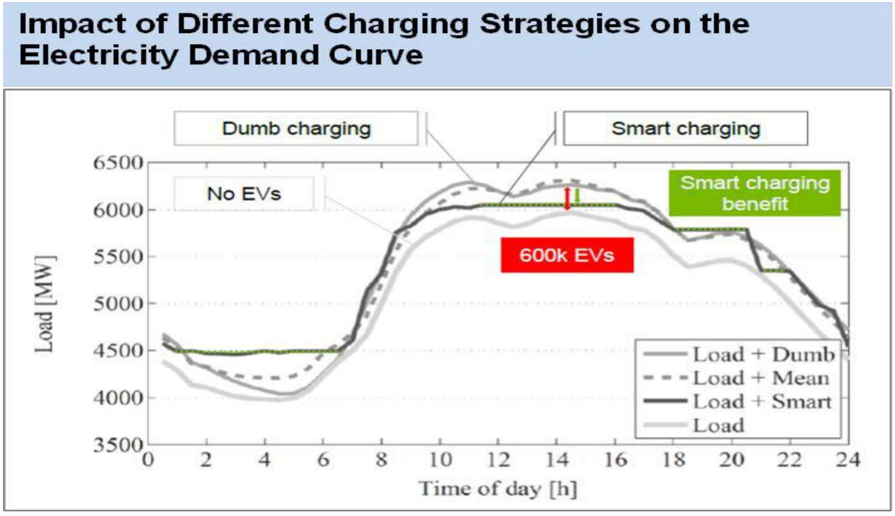


Figure 16 Impacts of Different Charging Strategies on the Electricity Demand Curve

Source: TUM Create

In addition to demand fluctuations, issues regarding load from EVs on the grid will also need to be addressed. Charging stations allowing quick recharging and charging stations for several cars have high connected loads. Grid planning of distributed generation networks needs to consider simultaneity of load profiles in order to assess the worst-case situation regarding total grid load.

The strategy to cope with the new load profiles shaped by EVs is to determine the total maximum load level for lines where EV charging stations are connected to, understand the level of simultaneity for the loading processes, setting limitations for the maximum allowable load conditions and develop local power management, balancing total and individual loading level, number of cars, state estimation of grid, (perhaps) consideration of economic aspects.

To increase the overall benefits of EVs, the energy used to power the vehicles should be a clean as possible, ensuring the maximum possible integration of renewable energies. In future EV (batteries) could serve as buffer storage, storing generated energy exceeding demand and feeding it back to the grid (Vehicle-to-Grid) when needed. This generates new business opportunities and may serve as important component towards a clean energy system in Singapore. In parallel (I) locally concentrated charging of EVs (II) the integration of renewable energies to the grid and (III) the bidirectional Grid-to-Vehicle Vehicle-to Grid charging pose challenges to the grid and create a new need for intelligent load, charging and fleet management systems.

3.5 Consumer Behaviour

This chapter analyses the consumer expectations from EVs as it is important to understand for large scale EV adoption. Several global surveys were conducted to find consumer expectations in terms of range, reliability, etc.[17]. They had the first-hand experience on EVs in local conditions.

Research indicates that there are multiple segments in the EV consumer market, with consensus on the fact that there is a continuum of sorts, with enthusiastic early adopters, followed by groups who are willing to try EVs after overcoming some initial scepticism, and finally the traditional ICE faithful, who are reluctant to switch from ICE vehicles to EVs.

The below insights are from the survey conducted by McKinsey in Shanghai. They identified 6 consumer segments and analysed their general and EV-specific attitudes & concerns.

Early adopters (30% of all consumers)

1. Trendy greens (15%) – Willing to pay premium and sacrifice performance for green. Like EV designs & lower running costs, willing to pay for a home charger.
2. Running cost sensitive (15%) – Willing to pay upfront premium for lower running costs / TCO. Less concerned about safety and reliability.

Shape-able groups (33% of all consumers)

3. Bargain hunters (16%) – Care about both upfront and running costs and shop to find lowest price. Like low EV running costs but concerned about upfront cost and reliability.
4. Performance seekers (17%) – Like new technology and like to show off. Convenience seekers. Not very price-sensitive. Attracted by EV technology, concerned about range / charging / performance.

Late adopters (37% of all consumers)

5. Trend followers (22%) – Try new products after majority. Prefer popular models and have clear brand preference. Concerns about new technology. Concerned about EV choices, price and reliability.
6. ICE traditional (15%) – Highly reluctant to change behaviour for new products. Not green conscious. Have strong concerns about EVs and reject EVs on all attributes.

If Singapore targets large scale implementation they might aim at pushing EV adaptation beyond the early adopters to guarantee a mass deployment of the technology. On the other hand convincing late adopters to switch earlier in the product life-cycle of EVs might be over proportionally expensive or even impossible. This leaves a focus on the shape-able group. In this group reliability and availability of charging infrastructure become critical. It is for the purpose of winning those groups over and making them adopt EVs that Singapore adopts a balanced mix of policies and regulations to grow EV purchases and to develop groundwork for private investors to deploy charging infrastructure.

Figure 17 shows a comparison of characteristics of different drivetrains from consumer perspective in Singapore based on Singapore based stakeholder insides and meta-study analyses summarised by ERI@N. It's a first assessment and only shows general tendencies, helpful for further investigation.

17 Electric Vehicles in Megacities – Shanghai Charges Up; McKinsey; 2010; Report by The Boston Consulting Group; 2009 and 2010

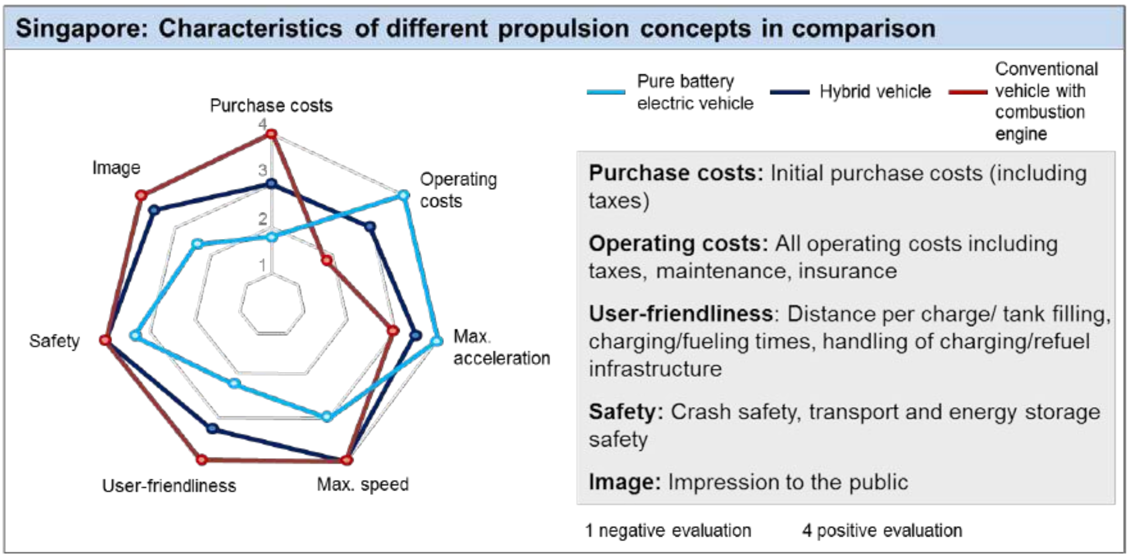


Figure 17 Singapore: Characteristics of Different Propulsion Concepts in Comparison
Source: ERI@N Analysis

A strong benchmark is done by consumers on vehicle characteristics as purchasing a car is highly expensive. EVs still have the image of being unsafe, with limited range and high user inconvenient because of the required charging process. As little visible demonstration projects exist, almost no experience about EV driving characteristics can be obtained (fast acceleration, high speed, noiseless, smooth). Furthermore high concerns in sufficient range and available charging infrastructure exist. Demonstration projects could help to make electromobility explore-able for Singaporeans. While operating costs are much lower for EVs due to less need for maintenance and repair compared to ICE, the high purchase price for EVs is still a main barrier for potential EV buyers.

4 Scenarios for Singapore

4.1 Overview

In order to assess the feasibility of EV penetration into the Singapore vehicular fleet, scenario analysis were conducted from now to 2050 to determine the:

- Number of EVs (BEVs and PHEVs) in each fleet of Singapore's transport system
- Energy demand required by the calculated number of EVs
- CO_2 emissions produced by the different fleets and abatement potential
- Number and kind of charging stations required by each fleet
- Costs for the required charging infrastructure

4.2 Methodologies Used

This section provides an overview of the methodologies and assumptions used for the scenario analysis.

4.2.1 Number of EVs (BEVs and PHEVs) in each fleet of Singapore's transport system

A low, medium and high electrification target was set for 2050 for the various fleet types for both BEVs and PHEVs. The BAU scenario assumes that Singapore's vehicle population develops according to scenario 3 as a pure ICE-based fleet with no integration of electric drive trains at all. In a linear development, based on the year 2013, the electric share of the respective fleet grows until it reaches its target in 2050 (Table 3).

Targets **Share of BEVs in Singapore's fleets in % in 2050**	**Low**	**Medium**	**High**	**BAU**
Private Vehicles	10%	30%	50%	0%
Taxis	20%	40%	60%	0%
Public Buses	20%	60%	100%	0%
Private Buses	10%	30%	50%	0%
Freight Vehicles[1]	10%	30%	50%	0%
Motorcycles and Scooters	30%	50%	70%	0%
BEV Carsharing	100%	100%	100%	0%

Table 3 :Targets: Share of BEVs in Singapore's fleets in % in 2050

In the target setting process BEVs had priority. As current market development suggests a share of PHEVs in Singapore's future vehicle population, sub-targets for PHEVs were developed as listed in Table 4.

Targets Share of PHEVs in Singapore's fleets in % in 2050	Low	Medium	High	BAU
Private Vehicles	5%	10%	15%	0%
Taxis	5%	15%	25%	0%
Public Buses	5%	10%	0%	0%
Private Buses	5%	10%	15%	0%
Freight Vehicles[2]	0%	5%	10%	0%
Motorcycles and Scooters	0%	0%	0%	0%
BEV Carsharing	0%	0%	0%	0%

Table 4 Targets: Share of PHEVs in Singapore's fleets in % in 2050

4.2.2 Energy demand required by the calculated number of EVs

The annual energy demand of each fleet is calculated based on the efficiency of the different drive trains in the fleet as well as the annual vehicle mileage (AVM) (Figure 18).

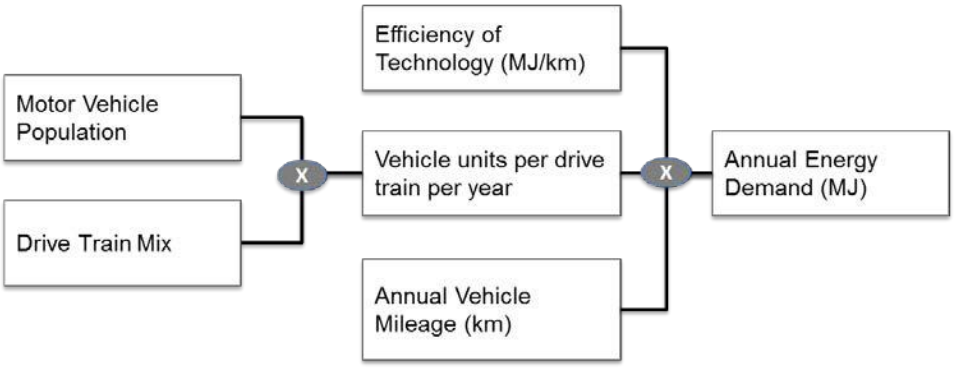


Figure 18 Method to Calculate the Annual Energy Demand of a Fleet
Source: ERI@N

Figure 19 illustrates the annual vehicle mileage (AVM) assumed. However, AVM is sensitive to new technologies and influences such as innovative city planning and change in human travelling behavior are just examples of relevant impact fields. The AVM is assumed to remain unchanged till 2050 and is based on 2013 data (Figure 19). Further research beyond this roadmap is recommended. The AVM of carsharing vehicles is calculated based on the experience from existing carsharing schemes.[18]

Annual Vehicle Mileage (km)	2013
Private Vehicles	17,800
Taxis	124,895
Public Buses	82,780
Private Buses	51,800
GVPs, LGVs	30,000
HGVs, VHGVs	38,100
Motorcycles and Scooters	12,900
BEV Carsharing (1 trip=10km, 8 trips per day, 365 days per year)	29,220

Figure 19 Annual Vehicle Mileages of Fleets

[18] Based on report from Taipei Times; 2015

4.2.3 CO_2 emissions produced by the different fleets and abatement potential

The CO_2 emissions of each fleet result from a fleet's annual energy demand and the emission factor of the energy or fuel type used (Figure 20).

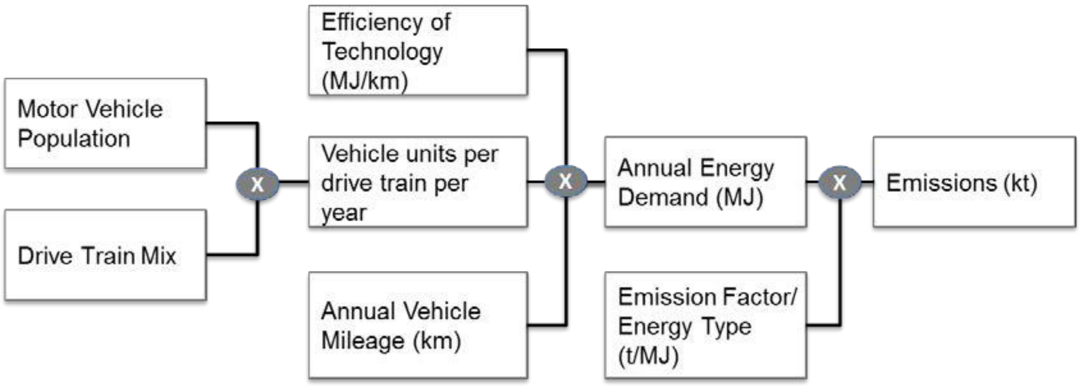


Figure 20 Method to calculate the annual CO2 emissions of a fleet

Table 5 lists the emission factors assumed for the roadmap calculations.

	Emission Factor (gCO_2/MJ)	
Fuel	**Tank-to Wheel**	**Well-to-Tank**
Diesel	73.326[3]	15.5 (international figure)[4]
Petrol	68.607[5]	18.5 (international figure)
Electric	0	137.4[6]

Table 5 Emission Factors for Different Fuels

The abatement potentials of each fleet result from subtracting the emissions produced in the respective electrification scenario from the emissions produced in the corresponding BAU scenario.

4.2.4 Number and kind of charging stations required by each fleet

The amount of charging stations required for every fleet is calculated from the energy required per fleet, the mix of charging technologies used by a fleet, the power capacity of the respective charging technologies and the degree to which a charging station might be used per day (Figure 21).

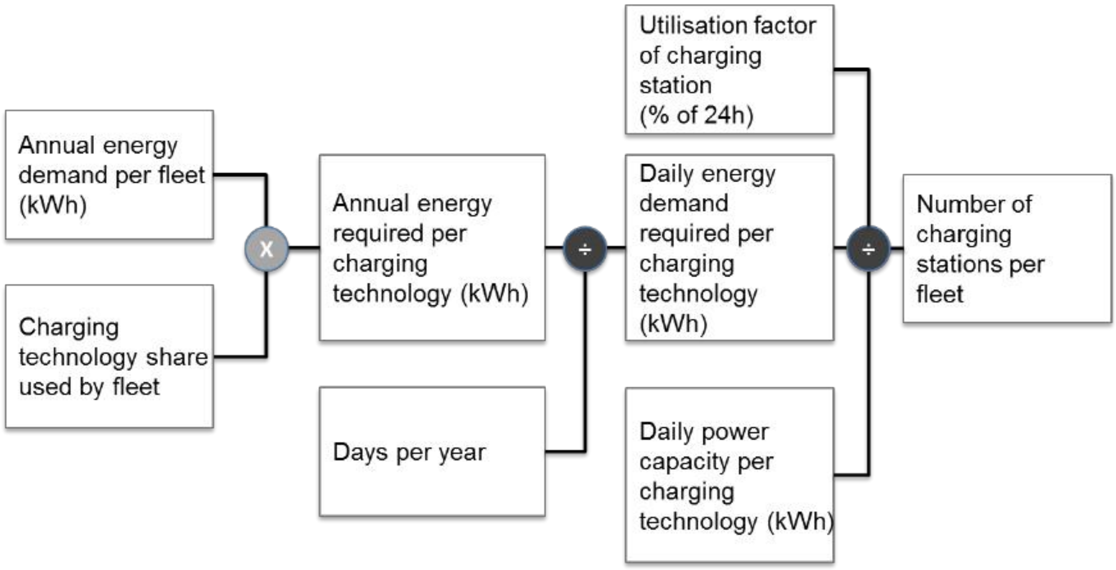


Figure 21 Method to Calculate the Annual Number of Charging Stations Required per Fleet
Source: ERI@N

Charging technologies considered in the roadmap calculations comprise conductive and inductive solutions which are currently common on the market (conductive solutions) and might become market ready in future (inductive solutions). Table 6 lists the charging technologies and respective characteristics used in the roadmap calculations. As at the time of writing no charging standard has been set in Singapore and EV models come globally with varying charging options, both AC types 1 and 2 are considered. Efficiency rates are based on OEM information.

Charging Technology	Power Levels (kW)	Efficiency (%)	Power capacity per day (kWh)	Time for one charge[7] (hours)	Lifetime (years)
AC Slow, Type 1, Single Phase	3.3	95	75.2	7.6	5
AC Medium, Type 2, Single Phase	6.6	90	142.6	3.8	5
AC Fast, Type 2, 3-Phase	44.0	90	950.4	0.6	5
DC Fast Charging	50.0	90	1,080.0	0.5	5
Inductive Charging, slow	3.3	87	68.9	7.6	5
Inductive Charging, fast	50.0	85	1,020.0	0.5	5

Table 6 Charging technologies and characteristics considered in the roadmap

Private vehicles will mostly charge at home or at work and thus have a greater share of AC slow charging. DC charging will be used at popular points like shopping malls, eateries or super markets. Taxis will have a high share of DC charging during their shifts while using AC charging back in the HDBs. Current solutions for electric buses show options for either AC fast or DC charging. As the business for private buses remains to the private sector, different charging solutions will emerge over time. The use case for LGVs assumes AC slow charging in the depot after completing an EV-optimised delivery tour. Based on experiences form existing models, Carsharing BEVs will most likely charge at AC slow charging stations with a small share in DC charging. Inductive charging becomes market feasible at a later stage and is assumed to be first introduced in the private vehicle segment.

Increasing use rates of charging stations result in higher financial viability of stations on the one side (industry perspective) and reduce the need for (space occupying) infrastructure and investment on the other side (city perspective). Furthermore technology development is expected to lead to optimised assignment of cars to stations which increases the utilisation of stations.

Costs for the required charging infrastructure

Cost calculations comprise capital investment costs and operational costs (Figure 22). Capital investment costs include the costs for the charging station plus costs for optional network features (e.g. communication with other charging stations / systems, backend system, etc.) as well as the costs for the installation of a charging station. Operational costs include maintenance and repair costs over the lifetime of a charging station.

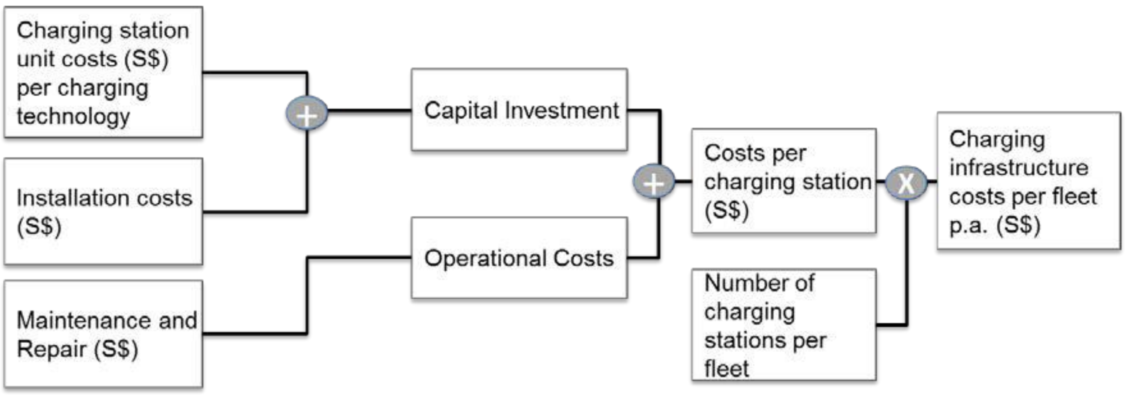


Figure 22 Method to Calculate the Annual Costs of Charging Infrastructure

The roadmap calculations use average prices for networked charging station solutions, provided by local charging infrastructure providers (Table 7). Costs are expected to fall dramatically with achieved economies of scale due to globally rising demand for charging infrastructure (-5% in the calculation tool). Especially costs for AC Fast and DC charging stations are expected to fall radically.[19] For example current available DC options in Singapore come with a price tag of S$ 52,000, while companies publish already near-term target prices of US$ 6,500 (~S$ 9,000). Installation costs vary heavily from site to site in Singapore as well as in other cities. The main cost driver here is the distance to the power source. Installation costs are expected to decrease as future charging sites will be built with appropriate electrical infrastructure required to install charging stations.

[19] Based on BMW and Bosch Press Release on DC fast charge; 2015

Charging Technology	Equipment Costs (EC) 2015 (S$)	Annual Change Rate EC	Install. Costs (IC) 2015 (S$)	Annual Change Rate IC	Operational Costs (OC) 2015 (S$)	Annual Change Rate OC
AC Slow	4,500	-5.0%	10,815	-3.0%	534	0.1%
AC Medium	6,750		16,223		561	
AC Fast	36,455	manually	27,350		617	
DC	52,000		30,000		614	
Inductive Slow	9,347	-5.0%	18,694		534	
Inductive Fast	18,694		37,388		534	

Table 7 Equipment, Installation, Operational Costs of Charging Technologies in 2015 and Annual Change Ranges

Table 8 shows the costs for single stations per charging technology over time.

	2015			2020			2030			2050		
Charging Technology Costs (S$)	EC	IC	OC	EC	IC	OC	EC	IC	OC	EC	IC	OC
AC Slow	4,500	10,815	534	3,482	9,287	537	2,085	6,849	542	747	3,724	553
AC Medium	6,750	16,223	561	5,223	13,931	564	3,127	10,273	569	1,121	5,586	581
AC Fast	36,455	27,350	617	24,027	23,486	620	4,000	17,319	626	2,000	9,418	639
DC	52,000	30,000	614	25,000	25,762	617	4,000	18,998	624	2,000	10,331	636
Inductive Slow	9,347	18,694	534	7,233	16,053	537	4,330	11,838	542	1,552	6,438	553
Inductive Fast	18,694	37,388	534	14,465	32,107	537	8,661	23,676	542	3,105	12,875	553

Table 8 Cost for Single Stations per Charging Technology over Time
Source: ERI@N

5 Model Findings: Energy, Emissions and Costs

5.1 Cumulated Results

The tables below show the cumulated results from the roadmap calculations. The detailed results for the different fleets are described in the following chapters. Table 9 shows the overall vehicle population development till 2050.

Population (units)		2015	2020	2030	2050
Scenario 3	979,354	983,567	989,094	992,440	

Table 9 Singapore's Overall Vehicle Population Development
Source: ERI@N

In case no EVs are integrated in the above vehicle population (BAU Scenario), overall emissions are produced as in Table 10.

	2015	2020	2030	2050
Emissions BAU (kt)	6,150	6,020	5,632	4,659

Table 10 Emissions of BAU Scenario of Singapore's Overall Vehicle Population
Source: ERI@N

Table 11 shows the developed low, medium and high electrification scenarios.

Electrification	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs (#)	80	19,166	47,405	75,643	57,270	142,449	227,628	134,012	333,133	532,255
BEVs (%)	0%	2%	5%	8%	6%	14%	23%	14%	34%	54%
PHEVs (#)	100	9,729	15,923	22,005	17,685	36,403	54,756	33,469	77,256	120,174
PHEVs (%)	0	1	2	2	2	4	6	3	8	12

Table 11 Scenarios for the Electrification Singapore's Overall Vehicle Population
Source: ERI@N

Table 12 shows the emissions produced in the different electrification scenarios and the abatement potentials, based on the current energy mix in Singapore.

Emissions (kt)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs	0	58	155	252	160	432	705	308	832	1,356
PHEVs	0	26	59	85	57	147	219	98	272	410
ICEs	6,150	5,882	5,647	5,423	5,265	4,604	3,975	3,962	2,687	1,474
Sum	**6,150**	**5966**	**5861**	**5761**	**5482**	**5184**	**4899**	**4368**	**3791**	**3240**
Emission abatement compared to BAU scenario:										
Abatement (kt)	0	54	159	259	150	448	733	291	868	1,419
Abatement (%)	0	1	3	4	3	8	13	6	19	30

Table 12 Emissions and Abatement of Singapore's Overall Vehicle Population
Source: ERI@N

Table 13 shows the energy demand required by the different electrification scenarios.

Energy Demand (GWh)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs	0	117	313	510	323	874	1,425	622	1,682	2,741
PHEVs	0	19	51	76	52	142	212	99	272	406
Sum	**0**	**136**	**364**	**586**	**375**	**1,016**	**1,637**	**721**	**1,954**	**3,147**

Table 13 Scenarios for the Energy Demand of Singapore's Overall EV Population
Source: ERI@N

Table 14 shows the potential annual electricity generation from PV in Singapore. It is assumed that 50% of this generation could be used for EVs.

PV electricity generation (GWh)	2015	2020	2030	2050
Total	-	800	4,000	7,000
For EVs	-	400	2,000	3,500

Table 14 PV Potential Annual Electricity Generation from PV
Source: ERI@N

Table 15 shows the emissions and abatement potential generated if above calculated solar power is available for charging EVs.

Emissions with PV integration (kt)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
SUM	**6,150**	**5,900**	**5,681**	**5,563**	**5,296**	**4,681**	**4,090**	**4,011**	**2,825**	**1,684**
Abatement (kt)	0	120	339	457	336	951	1,542	648	1,834	2,975
Abatement (%)	0	2	6	8	6	17	27	14	39	64

Table 15 Emissions and Abatement with PV Integration
Source: ERI@N

Table 16 shows the cumulated number of charging points, required to deliver the necessary energy demand of all fleets.

Charging Points (units)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
AC Slow	- -	7,348	19,122	30,898	11,767	30,774	49,784	10,973	28,587	46,199
AC Medium	-	869	2,545	4,222	2,015	5,809	9,604	2,453	7,078	11,703
AC Fast	- -	232	699	1,163	335	1,005	1,675	298	896	1,492
DC	- -	180	440	700	286	681	1,076	344	815	1,285
Inductive Slow	- -	-	-	-	832	2,497	4,162	3,422	9,445	15,467
Inductive Fast	- -	-	-	-	-	-	-	85	255	426
Sum	- -	**8,629**	**22,806**	**36,983**	**15,235**	**40,766**	**66,301**	**17,575**	**47,076**	**76,572**

Table 16 Charging Infrastructure for Singapore's Overall EV Population
Source: ERI@N

Table 17 shows the cumulated annual investment costs (equipment + installation) for charging infrastructure.

CAPEX (million S$)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
AC Slow	- -	93.8	244.2	394.5	105.7	274.9	444.7	49.1	127.8	206.6
AC Medium	-	16.6	48.7	80.9	27.0	77.8	128.7	16.5	47.5	78.5
AC Fast	- -	11.0	33.2	55.3	7.7	23.0	38.4	3.4	10.2	17.0
DC	- -	9.1	22.3	35.5	6.6	15.7	24.7	4.2	10.0	15.9
Inductive	- -	-	-	-	13.5	40.4	67.3	28.7	79.5	130.4
Sum	- -	**130.5**	**348.4**	**566.2**	**160.5**	**431.8**	**703.8**	**101.9**	**275**	**448.4**

Table 17 Cumulated CAPEX of the Required Charging Infrastructure for All Fleets
Source: ERI@N

Table 18 shows the cumulated annual operational costs (maintenance and repair) for charging infrastructure.

OPEX (million S$)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
AC Slow	- -	3.9	10.3	16.6	6.4	16.7	27.0	6.1	15.8	25.6
AC Medium	-	0.5	1.4	2.4	1.1	3.3	5.5	1.4	4.1	6.8
AC Fast	- -	0.1	0.4	0.7	0.2	0.6	1.0	0.2	0.6	1.0
DC	- -	0.1	0.3	0.4	0.2	0.4	0.7	0.2	0.5	0.8
Inductive	- -	-	-	-	0.5	1.4	2.3	1.9	5.4	8.8
Sum	**- -**	**4.6**	**12.4**	**20.1**	**8.4**	**22.4**	**36.5**	**9.8**	**26.4**	**43.0**

Table 18 Cumulated CAPEX of the Required Charging Infrastructure for All Fleets
Source: ERI@N

Table 19 shows the cumulated CAPEX and OPEX costs for all fleets.

Charging Infra. Costs (million S$)	2015		2020			2030			2050		
			Low	Med	High	Low	Med	High	Low	Med	High
Sum CAPEX	-	-	130.5	348.4	566.2	160.5	431.8	703.8	101.9	275	448.4
Sum OPEX	-	-	4.6	12.4	20.1	8.4	22.4	36.5	9.8	26.4	43.0
Sum	-	-	**135.1**	**360.8**	**586.3**	**168.9**	**454.2**	**740.3**	**111.7**	**301.4**	**491.4**

Table 19 Cumulated CAPEX and OPEX
Source: ERI@N

5.2 Private Vehicles

With a share of 65% of Singapore's vehicle population in 2015, private vehicles account for the biggest fleet in Singapore. Based on the population growth assumptions mentioned in Table 20 and Table 21 the overall private vehicle population develops as in Table 20. Table 21 shows the emissions produced in case no electric drivetrains are introduced to the fleet. The relatively high increase of emission reductions till 2050 in the BAU scenario results from the assumption of constant technology improvement of ICE vehicles (1% per year). However it can be expected that a constant improvement till 2050 won't become reality as the possibilities for ICE optimization will be exhausted at a certain point in future. It is recommended to adjust the assumptions for technology improvements beyond this report as soon as data is available.

	2015	2020	2030	2050
Population (units)	624,936	623,997	622,441	619,956

Table 20 Singapore's Private Vehicle Population Development
Source: ERI@N

	2015	2020	2030	2050
Emissions BAU (kt)	2,012	1,910	1,723	1,404

Table 21 Emissions of BAU Development of Private Vehicles
Source: ERI@N

Electrification targets for BEVs and PHEVs in 2050 result in the electrification scenarios in Table 22. Because of the private vehicle fleet size, the calculated numbers of EVs are quite significant. With Singapore's energy mix, 2014 emission reductions of up to 25% can be achieved in 2050 (Table 23).

Electrification	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs (#)	80	8,914	26,743	44,571	26,676	80,028	133,380	61,996	185,987	309,978
BEVs (%)	0	1	4	7	4	13	21	10	30	50
PHEVs (#)	100	8,783	13,240	17,697	16,215	29,553	42,891	30,998	61,996	92,993
PHEVs (%)	0%	1	2	3	3	5	7	5	10	15

Table 22 Scenarios for the Electrification of Private Vehicles
Source: ERI@N

Emissions (kt)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs	-	15	46	77	42	125	208	79	238	396
PHEVs	-	14	24	34	30	57	84	51	103	154
ICEs	2,012	1,867	1,798	1,730	1,615	1,429	1,243	1,202	849	495
Sum	**2,012**	**1,897**	**1,869**	**1,841**	**1,686**	**1,610**	**1,535**	**1,333**	**1,189**	**1,046**
Emission abatement compared to BAU scenario:										
Abatement (kt)	0	13	41	69	37	113	188	71	215	358
Abatement (%)	0	1	2	4	2	7	11	5	15	25

Table 23 Emissions and Abatement of Private Vehicles
Source: ERI@N

Table 24 shows the resulting annual energy demand in GWh. While the annual energy demand of max. 949 GWh in the high scenario might be unobjectionable to Singapore's power generation level; bottlenecks might appear on distribution grid level, mostly at HDB, condo and company carparks. Private vehicles will mostly charge at home or at work and thus have a greater share of AC charging. DC charging will be used at popular points like shopping malls, eateries or super markets. It is expected that in the private vehicle segment, the willingness to pay for additional charging comfort (no cable) will be higher than in business-driven fleets. Inductive charging will gradually cannibalise its conductive counterparts.

Energy Demand (GWh)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs	0	31	93	156	84	253	421	160	481	801
PHEVs	0	10	19.00	29	26	52	78	49	99	148
Sum	**0**	**41**	**112**	**185**	**110**	**305**	**499**	**209**	**580**	**949**

Table 24 Scenarios for the Energy Demand of Cars
Source: ERI@N

It remains to be seen which stakeholder will pay for the costs of charging stations. In the private vehicle market charging infrastructure will play a business enabling role for e.g. mobility providers. Investments from private actors can stimulate the market and reduce the costs of installing charging stations. In the case of private vehicles, as a first step, the trialling of electrified fleets such as car-sharing can help to create a market. Such a fleet'-test bed could also help to further understand broad EV integration and enable a daily-life experience of EVs by citizens. Following chapters focuses on how policies can encourage and support the growth of the EV market and to attract investment in charging infrastructure.

5.3 Taxis

Singapore's taxi fleet accounts for 3% of the overall vehicle population, but has with around 125,000km, the highest annual mileage per vehicle. Based on the population growth assumptions mentioned in Table 25 and Table 26, the overall taxi population develops as in Table 25. Table 26 shows the emissions produced in the case where no electric drivetrains are introduced to the fleet.

	2015	2020	2030	2050
Population (units)	28,336	29,168	30,022	30,023

Table 25 Singapore's Taxi Population Development
Source: ERI@N

	2015	2020	2030	2050
Emissions BAU (kt)	575	564	527	434

Table 26 Emissions of BAU Development of Taxis
Source: ERI@N

The electrification targets for BEVs and PHEVs in 2050 result in the electrification scenarios below (Table 27). With Singapore's energy mix 2014, emission reductions of up to 27% can be achieved in 2050 (Table 28).

Electrification	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs (#)	-	833	1,667	2,500	2,573	5,147	7,720	6,005	12,009	18,014
BEVs (%)	-	3	6	9	9	17	26	20	40	60
PHEVs (#)	-	806	1,223	1,640	1,053	2,340	3,627	1,501	4,503	7,506
PHEVs (%)	-	3	4	6	4	8	12	5	15	25

Table 27 Scenarios for the Electrification of Taxis
Source: ERI@N

Emissions (kt)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs	-	10	20	30	28	56	85	54	108	162
PHEVs	-	7	14	20	12	30	48	17	52	87
ICEs	575	543	517	492	475	404	333	340	204	68
Sum	**575**	**560**	**551**	**542**	**515**	**490**	**466**	**411**	**364**	**317**
Emission abatement compared to BAU scenario:										
Abatement (kt)	-	4	13	22	12	37	61	23	70	117
Abatement (%)	-	1	2	4	2	7	12	5	16	27

Table 28 Emissions and Abatement of Taxis
Source: ERI@N

Table 29 shows the resulting annual energy demand in GWh. While the annual energy demand of max. 411 GWh in the high scenario might be unobjectionable to Singapore's power generation level; bottlenecks might appear on distribution grid level.

Taxis operate in 12 hour shifts and are often double shifted resulting in a 24 hour operation. As taxi companies charge daily taxi rental fees, taxis are often used in a 24/7 hours operation. In combination with the high annual mileage, taxi operations require a higher share of quick charging infrastructure. Inductive charging is introduced at a later stage when it becomes economically feasible.

Energy Demand (GWh)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs	-	20	41	61	57	114	171	109	218	327
PHEVs	-	3	9	16	9	26	44	17	50	84
Sum	-	**23**	**50**	**77**	**66**	**140**	**215**	**126**	**268**	**411**

Table 29 Scenarios for the Energy Demand of Taxis
Source: ERI@N

It remains to be seen which stakeholder will pay for the costs of charging stations. Electric taxi projects around the world are mostly based on subsidised charging infrastructure or similar incentives from the government. As privately owned taxi companies have to economise and therefore require positive business cases, appropriate incentive frameworks have to be created. At the same time new mobility providers like Uber or GrabTaxi enter the market. Viable business models will lead to the integration of electromobility in the portfolio of taxi start-ups. The following chapter focuses on how policies can encourage and support these actors to further attract charging infrastructure investment.

5.4 Buses

In Singapore, the bus network is an important component of the road transportation system. At present, around 18,000 (public and private) buses are in service on Singapore's roads. This represents about 2% of the existing motor vehicle population. The bus fleet is the second highest daily utilised fleet in operation. Based on the population growth assumptions mentioned in Table 30 and Table 31 the overall public and private bus populations develop as in Table 30. Table 30 shows the emissions produced in case no electric drivetrains are introduced to the fleets.

Population (units)	2015	2020	2030	2050
Public Buses	4,924	5,260	5,656	5,804
Private Buses	13,113	13,311	13,512	13,512

Table 30 Singapore's Bus Population Development
Source: ERI@N

Emissions BAU (kt)	2015	2020	2030	2050
Public Buses	491	499	485	408
Private Buses	819	791	726	594

Table 31 Emissions of BAU Development of Public and Private Bus Fleets
Source: ERI@N

As buses in Singapore currently produce the highest amount of CO_2 emissions per vehicle and therefore show the highest emission reduction potential, the high scenario for public bus electrification lies at 100%. The electrification rate for private buses lies significantly lower as these fleets are operated by a variety of private companies which will only switch to electric drive trains when they become economically feasible. Table 32 and Table 33 show the numbers and shares of EVs and PHEVs in the public and private bus fleets till 2050.

Electrification Public Buses	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs (#)	-	150	451	751	485	1,454	2,424	1,161	3,483	5,804
BEVs (%)	-	3%	9%	14%	9%	26%	43%	20%	60%	100%
PHEVs (#)	-	39	76	-	122	243	-	290	580	-
PHEVs (%)	-	1	1	-	2	4	-	5	10	-

Table 32 Scenarios for the Electrification of Public Buses
Source: ERI@N

Electrification Private Buses	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs (#)	-	190	570	951	579	1,737	2,895	1,351	4,054	6,756
BEVs (%)	-	1	4	7	4	13	21	10	30	50
PHEVs (#)	-	97	192	287	291	580	870	676	1,351	2,027
PHEVs (%)	-	1	1	2	2	4	6	5	10	15

Table 33 Scenarios for the Electrification of Private Buses
Source: ERI@N

With Singapore's energy mix 2014, emission reductions of up to 56% (public buses) and 34% (private buses) can be achieved in 2050 (Table 34 and Table 35). The relatively high mileage travelled generates a great leverage to reduce pollution, especially at bus stops where pedestrians are usually closest to the vehicle's emissions.

Emissions (kt) Public Buses	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
EVs	-	6	19	31	18	55	91	36	107	178
PHEVs	-	2	4	-	6	12	-	12	24	-
ICEs	491	482	449	428	434	340	277	306	122	0
Sum	**491**	**490**	**472**	**459**	**458**	**407**	**368**	**354**	**253**	**178**
Emission abatement compared to BAU scenario:										
Abatement (kt)	-	9	27	40	27	78	117	54	155	230
Abatement (%)	-	2	5	8	6	16	24	13	38	56

Table 34 Emissions and Abatement of Public Buses
Source: ERI@N

Emissions (kt) Private Buses	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
EVs	-	5	15	25	14	41	68	26	78	130
PHEVs	-	3	7	10	9	18	27	17	35	52
ICEs	819	774	746	717	680	602	524	506	357	208
Sum	**819**	**782**	**767**	**752**	**702**	**661**	**619**	**549**	**470**	**390**
Emission abatement compared to BAU scenario:										
Abatement (kt)	-	9	24	39	24	65	107	45	124	204
Abatement (%)	-	1	3	5	3	9	15	8	21	34

Table 35 Emissions and Abatement of Private Buses
Source: ERI@N

Public buses travel an estimated peak of 250km, running about 18 hours each day. Table 36 and Table 37 show the resulting annual energy demands in GWh. While the annual energy demand of max. 360 GWH (390 GWh private buses) in the high scenarios might be unobjectionable to Singapore's power generation level; bottlenecks might appear on distribution grid level.

Energy D. Public Buses (GWh)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
EVs	-	13	38	63	37	110	184	72	216	360
PHEVs	-	2	5	-	7	13	-	13	26	-
Sum	-	**15**	**43**	**63**	**44**	**123**	**184**	**85**	**242**	**360**

Table 36 Scenarios for the Energy Demand of Public Buses
Source: ERI@N

Energy D. Private Buses (GWh)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
EVs	-	10	30	50	27	82	137	52	157	262
PHEVs	-	4	7	11	10	20	30	19	38	57
Sum	-	**14**	**37**	**61**	**37**	**102**	**167**	**71**	**195**	**319**

Table 37 Scenarios for the Energy Demand of Private Buses
Source: ERI@N

Current electric bus concepts differ between opportunity charging for buses and overnight charging buses. Electric buses, using opportunity charging, do quick charging along the route. These solutions work on fixed routes, with repeated travel schemes, using predictable duty cycles. Overnight buses have more flexibility in their routes, but have to return to the charging stations to recharge their batteries. As technology and market pathways are still open at the time of writing, the roadmap calculations assume a mix of both. A broader variety of charging solutions is selected for privately run buses, as business models for different charging solutions will emerge over time. Beyond this report a detailed look into how e-bus trials, charging infrastructure quantities, technologies and business models, commercialisation and market development for e-buses in Singapore should look like is recommended.

A constant monitoring and adjustment of the EV and infrastructure development is recommended to avoid “rebuilding” of charging stations which are no longer required due to efficiency increase of technologies. Inductive charging is introduced at a later stage when it becomes economically feasible.

Despite low operational costs, investment costs for fully electric buses are still far higher than for the conventional equivalents. Furthermore a lack of information about cost structures and services, including maintenance, insurance, and second-use of batteries leads, exists. However the high emission abatement potential and the significant role of buses in the public transport system make them a priority fleet for electrification.

5.5 Urban Freight Transport

While the number of private vehicles is expected to be reduced in Singapore, the share of freight transport is expected to grow. Therefore a demand for low-carbon, energy-efficient and route-optimised urban logistics emerges. Singapore's freight fleets consist of GPVs, LGVs, HGVs and VHGVs. This chapter focuses on LGVs as the fleet with the highest potential to be electrified in near to medium term.[20]. The overall LGV population develops as in Table 38 while Table 39 shows the emissions produced in case no electric drivetrains are introduced to the fleet.

	2015	2020	2030	2050
Population (units)	108,980	109,745	110,679	111,348

Table 38 Singapore's LGV Population Development
Source: ERI@N

	2015	2020	2030	2050
Emissions BAU (kt)	834	791	707	559

Table 39 Emissions of BAU Development of LGVs
Source: ERI@N

The electrification targets for BEVs and PHEVs in 2050 result in the electrification scenarios below (Table 40). With Singapore's energy mix, 2014 emission reductions of up to 25% can be achieved in 2050 (Table 41)

Electrification Public Buses	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs (#)	-	1,568	4,703	7,839	4,743	14,230	23,717	11,135	33,404	55,674
BEVs (%)	-	1	4	7	4	13	21	10	30	50
PHEVs (#)	-	-	787	1,571	-	2,374	4,745	-	5,569	11,137
PHEVs (%)	-	-	1	1	-	2	4	-	5	10

Table 40 Scenarios for the Electrification of LGVs
Source: ERI@N

Emissions (kt)	2015	2020			2030			2050		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs	-	6	19	32	17	52	86	32	95	158
PHEVs	-	-	4	8	-	11	23	-	21	42
ICEs	834	780	751	722	676	600	523	502	361	220
Sum	**834**	**786**	**774**	**763**	**694**	**663**	**632**	**534**	**477**	**420**
Emission abatement compared to BAU scenario:										
Abatement (kt)	-	5	17	28	13	44	75	25	82	139
Abatement (%)	-	1	2	4	2	6	11	4	15	25

Table 41 Emissions and Abatement of LGVs
Source: ERI@N

[20] The delivery business in Singapore, mostly done by fleets Light Goods Vehicles shows the highest potential for the introduction of BEVs. Mobility patterns of delivery vehicles show reoccurring driving routes on limited, well planned distances. The high utilisation on defined routes has positive impact one the TCO of BEVs.

Table 42 shows the resulting annual energy demand in GWh. While the annual energy demand of max. 358 GWh in the high scenario might be unobjectionable to Singapore's power generation level; bottlenecks might appear on distribution grid level.

The market of urban freight transport in Singapore is highly fragmented. A great variety of companies operate with micro-fleets of only a few vehicles in some cases. Little is known about the driving patterns of the different fleets as research on the electrification of freight transport in Asia is just emerging. Inductive charging is introduced at a later stage when it becomes economically feasible.

Energy Demand (GWh)	**2015**	**2020**			**2030**			**2050**		
		Low	Med	High	Low	Med	High	Low	Med	High
BEVs	-	13	39	65	35	104	174	64	192	320
PHEVs	-	-	4	8	-	10	21	-	19	38
Sum	-	**13**	**43**	**73**	**35**	**114**	**195**	**64**	**211**	**358**

Table 42 Scenarios for the Energy Demand of LGVs
Source: ERI@N

A constant monitoring and adjustment of the EV and infrastructure development is recommended to avoid "rebuilding" of charging stations which are no longer required due to efficiency increase of technologies.

The highly fragmented freight transport market in Singapore makes it difficult to realise economies of scale when investing in BEVs. As there are currently no environmentally motivated regulations to influence the fleet operator's choice of vehicle, vehicle purchases purely follow cost decisions. Especially in commercial fleets, operating performance and costs are crucial to the business. Costly charging infrastructure or not fully utilised BEVs will not allow for an economically feasible integration of BEVs into the fleet. An BEV optimised route planning, allowing EVs to operate steadily under manageable distances during the day and charging at the depot overnight, might help to fully exploit the low operational costs. The freight sector, especially, requires further intensive analysis, requiring the collection of data in a test-bed before a broad integration of BEVs can be realised. Following chapters best describes this relevant research field in more details.

6 Research and Development Fields

R&D is important to Singapore's well-being and future sustainability. It creates value and enables Singapore to exploit new industries and new economic opportunities. R&D fuels innovation and sharpens Singapore's competitive advantage. Singapore has thus been investing heavily in R&D for more than 20 years and the steadily increasing national research budget acknowledges the importance of science, technology and research for the growth and development of Singapore (Figure 23).

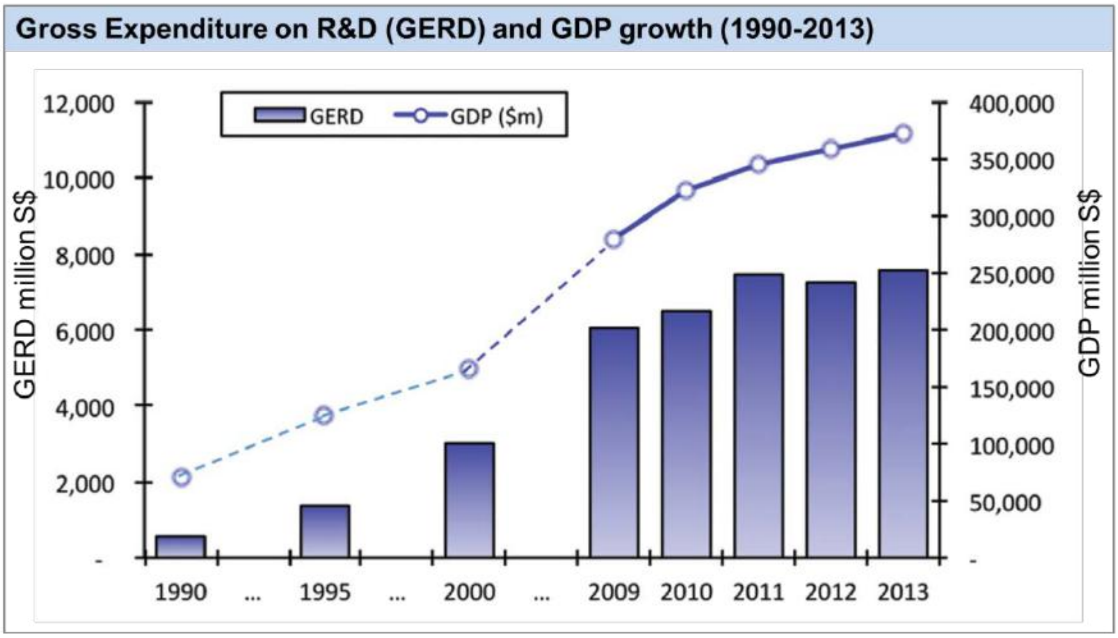


Figure 23 Gross Expenditure on R&D and GDP Growth (1990-2013)
Source: ASTAR

Singapore's research ecosystem has evolved over the last years and has become significantly larger. The nation's universities have strengthened in capabilities and research. Furthermore research shall help to improve the competitiveness of local industries by e.g. support technology uptake by SME's and start-ups.

Against this background research on electromobility in Singapore has to be in alignment with the national research strategy on Singapore's way to a knowledge-intensive, innovation-driven economy. Derived from the research-strategic national interests, research on electromobility should fulfil the following purposes:

- Raise the quality of life in Singapore by enabling a smart, sustainable and human transport
- Provide essential support for national priorities in security, economy, and environment
- Consider interfaces between technologies, provide a holistic approach and ensure system integration
- Enable futureproof solutions for urban systems
- Inform policy and investment decisions with high-quality, credible, and objective analysis
- Provide Singapore with competitive advantages and knowledge, which can be exported to other nations around the world

Process of Research Field Identification

Research priorities should be aligned with Singapore's comparative advantages. One task of this document is to provide Singapore's government with a list of relevant electromobility research fields. This list shall give guidance for future R&D budget planning to strategically deepen and build up knowhow and competitive advantages. Figure 24 shows the process which was undertaken by ERI@N to identify these relevant research fields.

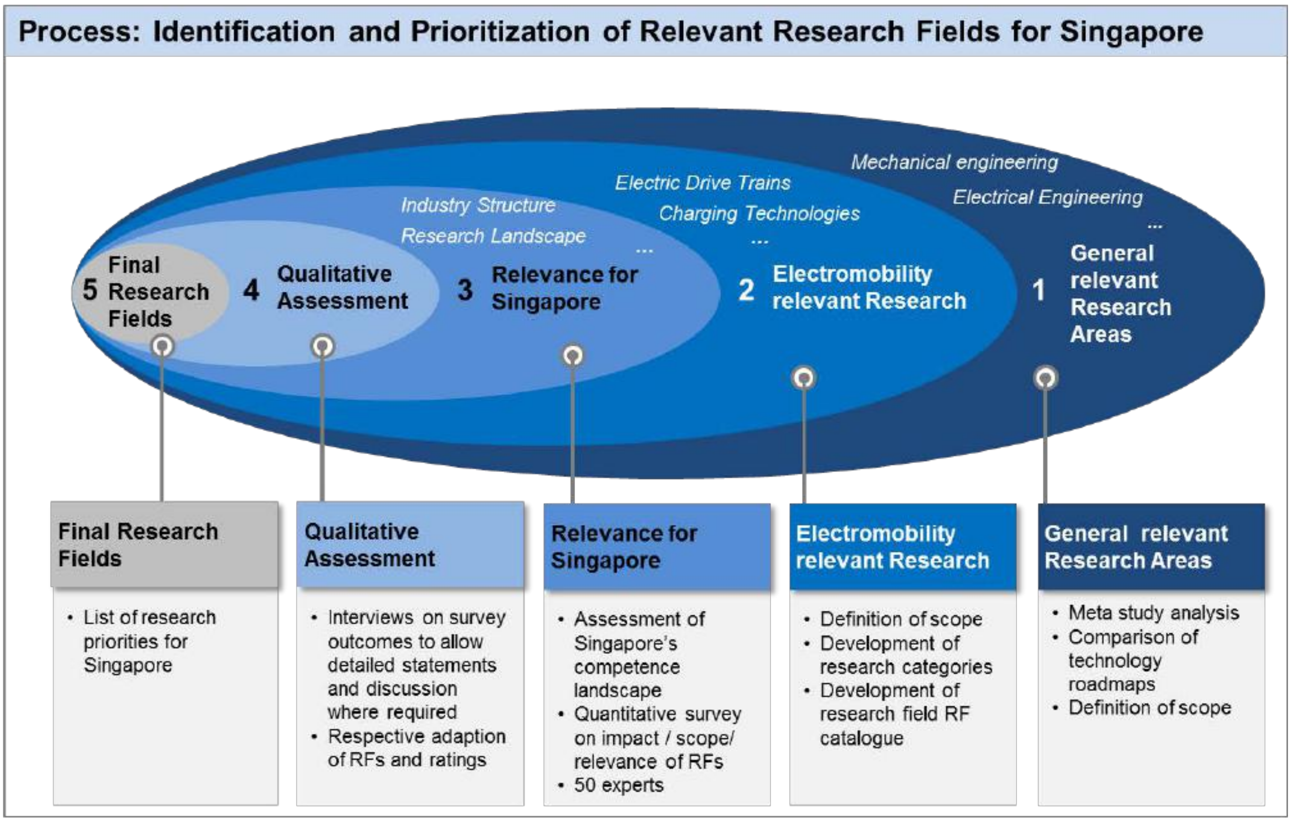
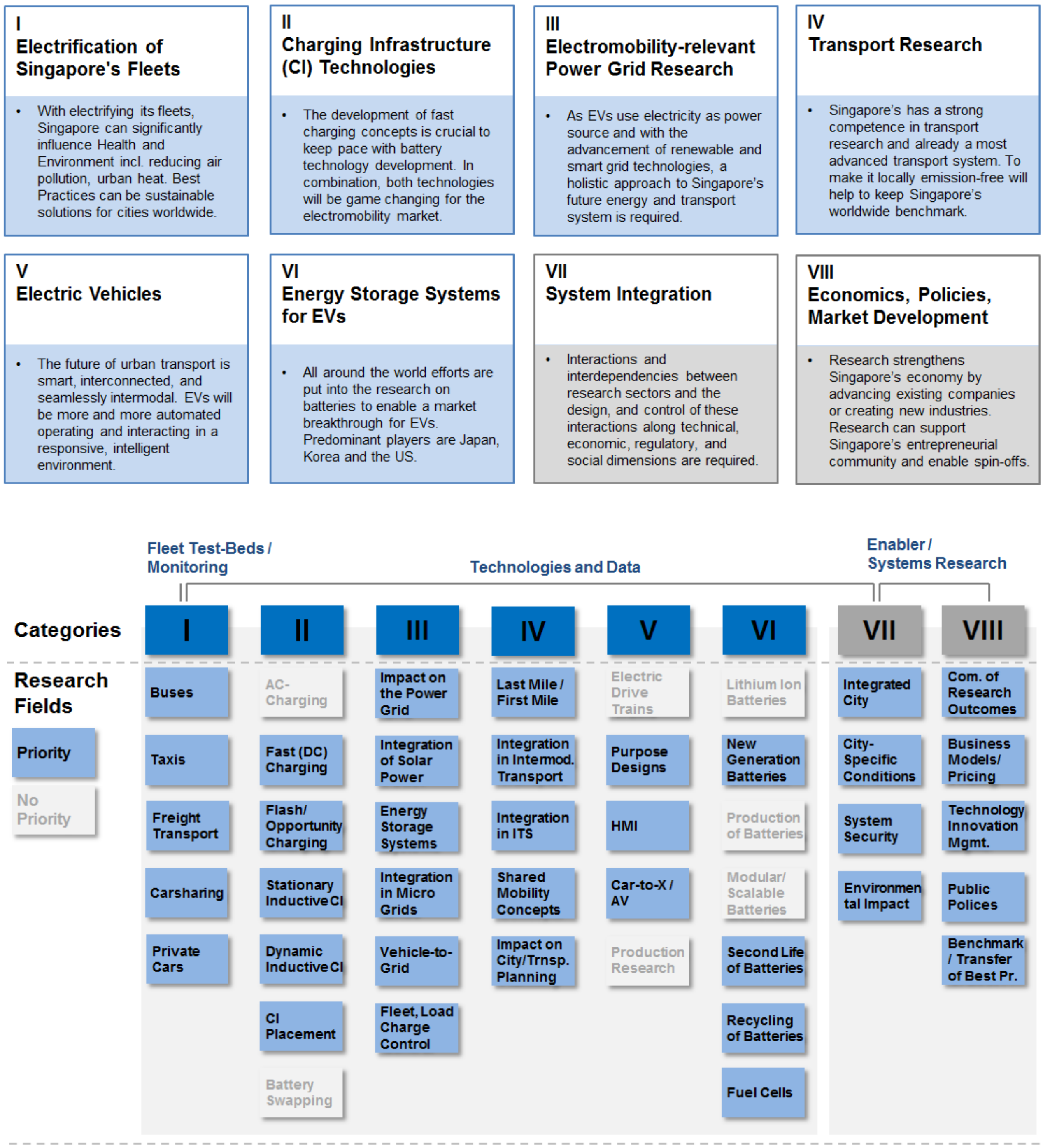


Figure 24 Process: Identification and Prioritisation of Relevant Research Fields for Singapore
Source: ERI@N

Research Fields of High Significance

Figure 25 shows the research categories and the research fields developed in step 2. The boxes show all research fields which were identified as relevant electromobility research fields. The research fields displayed in blue are research fields that majority of the respondents find significant.



I. Electrification of Singapore's Fleets
II. Charging Infrastructure (CI) Technologies
III. Electromobility-relevant Power Grid Research
IV. Transport Research
V. Electric Vehicles
VI. Energy Storage Systems for EVs
VII. System Integration
VIII. Economics, Policies, Market Development

Figure 25 Overview of Research Categories and Research Fields
Source: ERI@N

Research Fields Prioritisation – Alignment to Singapore

The survey conducted for the technological fields are weighted for four major criteria: Significance/relevance to global research, benefits to Singapore, alignment to Singapore R&D interests and Investment interests. The top 5 major research fields that are selected from the outcomes are presented in Figure 26.

Major Research Field	Sub-Research Field
System Integration	Research on Holistic Concepts for New Cities and City Quarters Integrating Electromobility, zero-energy homes, renewable energies, resilience, sustainable living practices, etc.
Singapore's Transport System	Research on Electromobility and Intelligent Transport Systems
	Research on the Interface Between City and Transport Planning
Charging Infrastructure Technology and Placement	Research on Fast Charging Technologies in General
	Research on Stationary Inductive Charging
	Research on the Placement of Charging Stations in Singapore
Electrification of Singapore's Fleets	Research on the Electrification of Buses and Fleet Trials
	Research on the Electrification of Taxis and Fleet Trials
	Research on the Electrification of Freight Transport and Fleet Trials
Energy Storage Solutions for EV	Research on new Battery Materials
	Research on Lithium Ion Batteries

Figure 26: Priority Research Fields Aligned to Singapore
Source: ERIAN

Figure 27 gives an overview of the expected technology timelines of each research field.

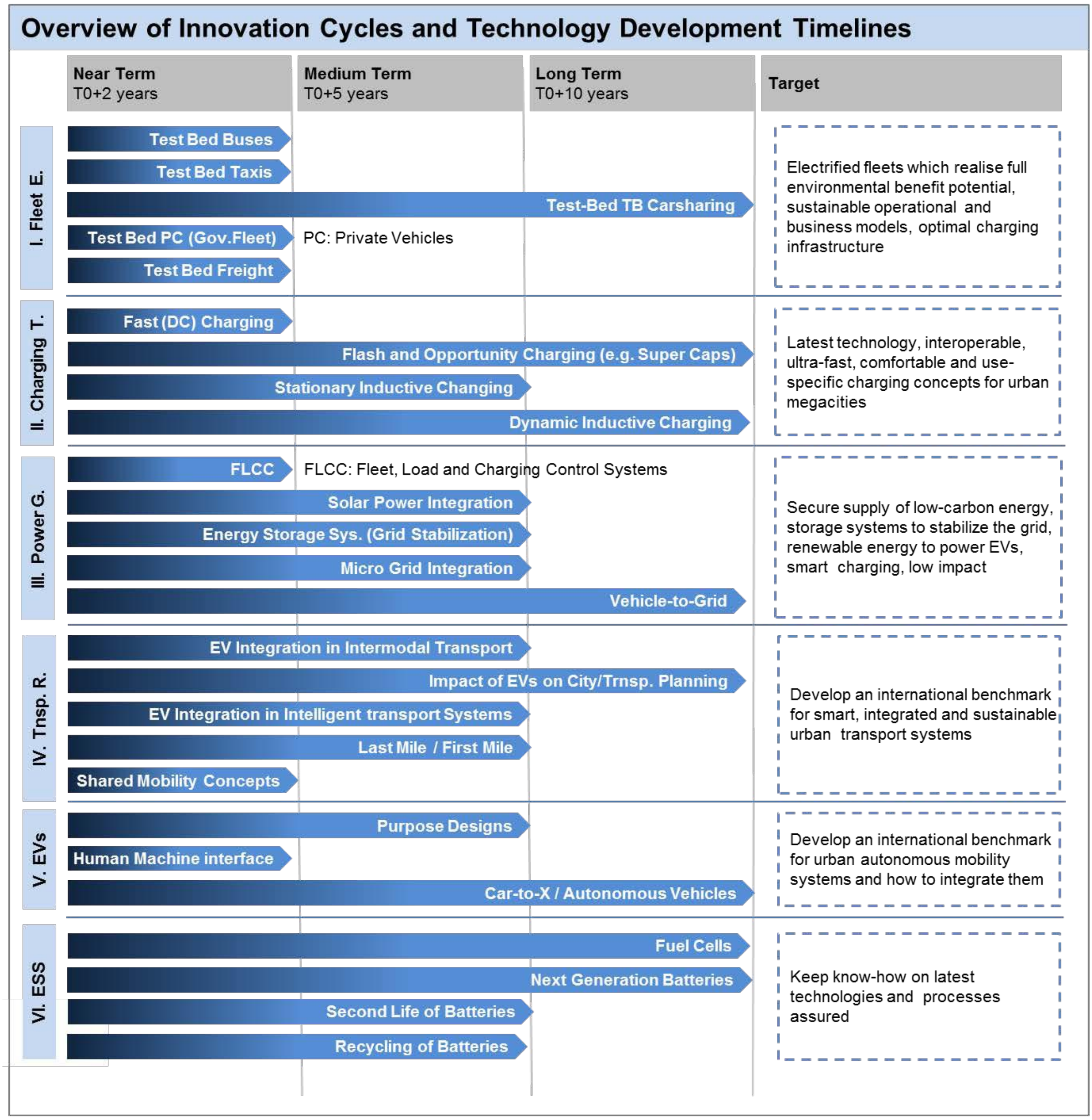


Figure 27 Overview of Innovation Cycles and Technology Development Timelines
Source: ERI@N

Integrated research projects

While research in each of the above mentioned priority research fields should be supported, the development of integrated research projects systematically integrating aspects of research fields should be pursued.

7 Policy Recommendations

The challenges of developing an urban electromobility system in Singapore can only be addressed if they are seen as political challenges, requiring political consultation, decision and implementation, as opposed to seeing them as purely technical challenges requiring the 'right' technical solutions. The primary purposes of such frameworks should be to remove obstacles to the effective participation of all stakeholders in the decision-making process. [21]

A transformation of Singapore's complex and interlinked transportation system to electromobility requires a high level of coordination and collaboration between stakeholders. To realise the systemic change required to reduce carbon emissions and to accelerate the transition to transportation, it is necessary to establish a common set of guidelines or principles for how the specific challenges of each stakeholder should be addressed (Figure 28).

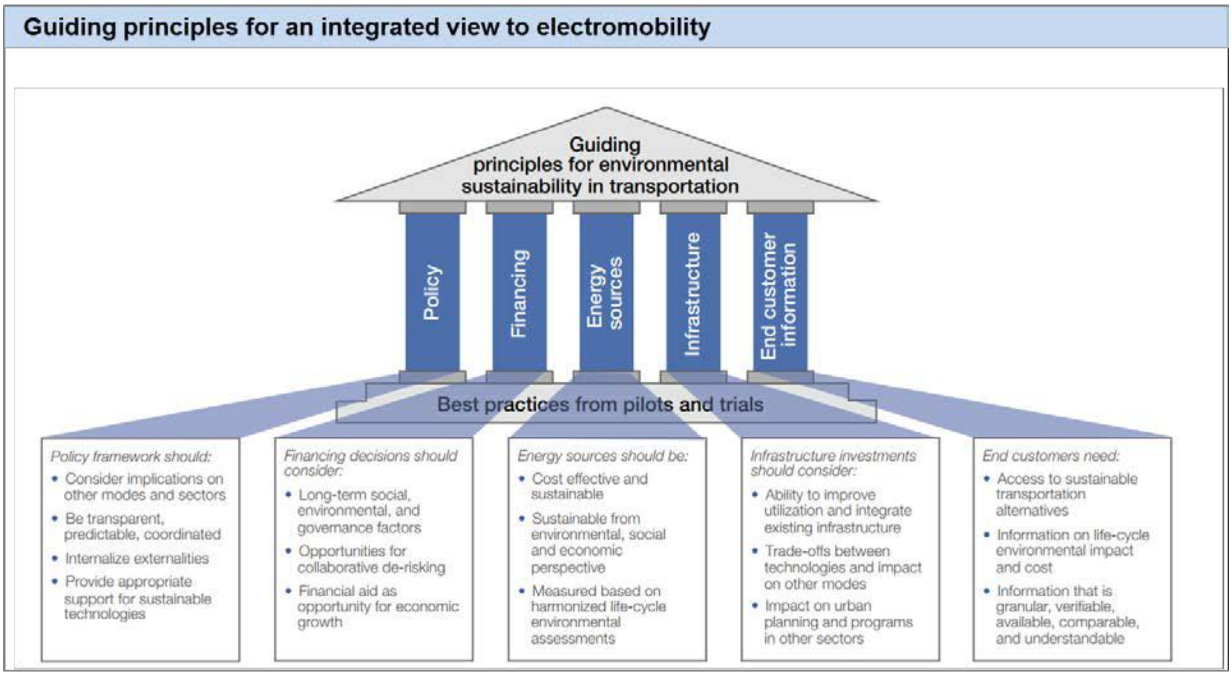


Figure 28 Guiding principles for an Integrated View to Electromobility
Source: World Economic Forum, 2012

Transport systems need to support economic growth, improve urban environmental quality, increase safety and improve quality of life. The negative externalities of today's transport system (e.g. increased air pollution, road injuries, fatalities and congestion) highlight the need to approach transport from a perspective that considers the multiple motivators, outcomes and co-benefits (Figure 29).

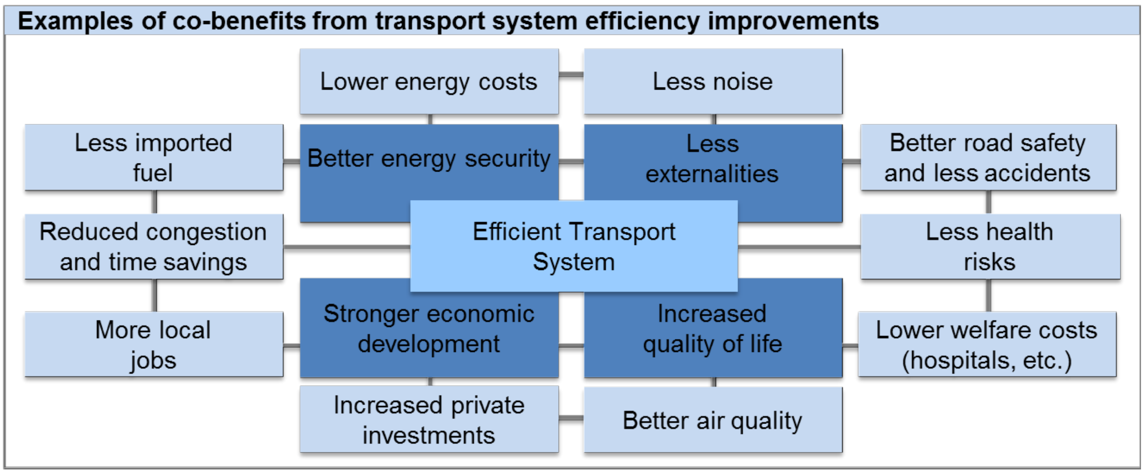


Figure 29 Examples of Co-Benefits from Transport System Efficiency Improvements
Source: ERI@N based on IEA

[21] Based on Mobility Reports from UN, 2014

Steps taken by the government will help to accelerate the transition towards more EVs in Singapore's transport system. Singapore has a variety of policy levers at its disposal to influence the deployment of EVs and EV charging infrastructure.

Create a cycle of market growth: The government's role in accelerating the EV market
When it comes to market development, the major question, federal and local governments are dealing with today is what many describe as the "chicken-and-egg" nature of EV ownership and charging station installation: Whether a higher availability of charging infrastructure will lead to more EVs on the roads, or more EVs will lead to a further expansion of charging stations (Figure 30).

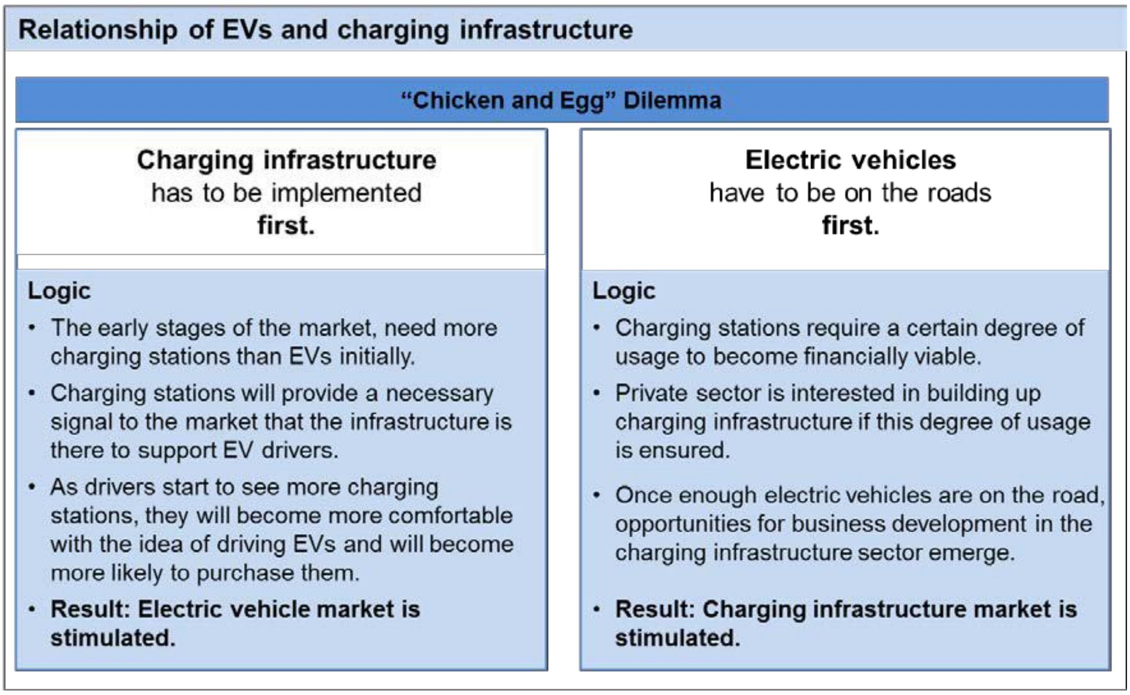


Figure 30 Relationship of EVs and Charging Infrastructure
Source: ERI@N

It suggests that the best way for policymakers to facilitate the growth of the overall market is to grow EV purchases and allow the private sector to provide charging (Figure 31).

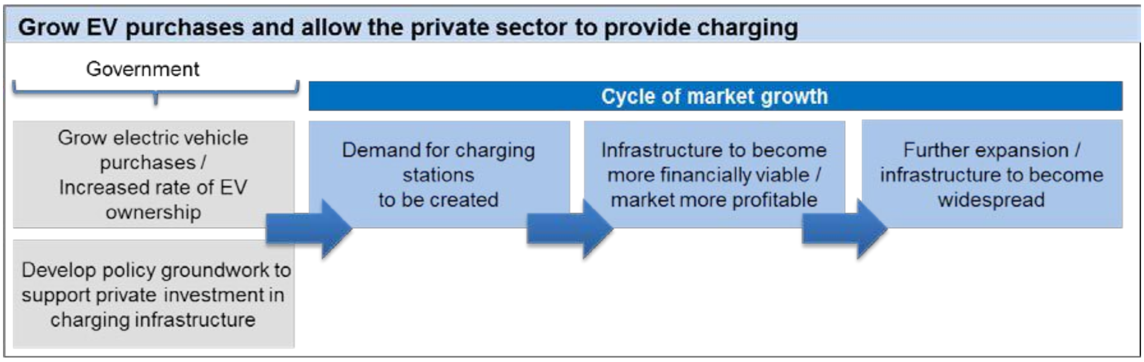


Figure 31 Cycle of Market Growth
Source: ERI@N Analysis based on Yale School of Management

Rather than directly financing charging infrastructure governments should facilitate EV market growth through supporting policy levers and set a regulatory framework conducive for private investment in charging infrastructure. Current market examples include Tesla investing in charging stations around the world, and recent announcements by BMW and VW to invest in charging stations in the U.S. "Singapore could use a mix of regulatory, financial, non-financial policy levers to support the growth of EV purchases in Singapore".

The lack of clarity on policy regarding investment and subsidies from the government, can be a barrier to investment in charging infrastructure by private investors and it is recommended that Singapore release policies in this regard as early as possible.

Framework matching policy levers to adoption barriers

	Barrier / Policy lever	Barriers to EV deployment						Barriers to CI					
		Availability of EV models	Upfront costs / TCO of EVs	Range anxiety	Availability of charging infrastructure	Technological uncertainty	Lack of information	Lack of standard	Policy uncertainty regarding investment	Permitting of EV charging equipment	Demand uncertainty	Economics of CI	Technological uncertainty
Groundwork to support private investment in CI	Deciding technical standards				✓			✓				✓	✓
	Streamlining permitting		✓							✓			
	Zoning & building codes				✓					✓		✓	
	Prepare real estate for CI				✓								
	Investment / Production tax credits for CI				✓							✓	
	Subsidies for CI				✓							✓	
	Low-Financing for CI				✓							✓	
Grow EV purchases	Streamlining of the EV registration process	✓	✓				✓						
	Update Homologation Process	✓					✓				✓	✓	
	Subsidies / tax credits for EVs	✓	✓								✓	✓	
	Waivers on registration / taxes on EVs	✓	✓										
	Free parking for EVs		✓										
	Waiving ERP charges for EVs		✓										
	Signage for charging stations & EV parking lots			✓	✓							✓	
R&D & Promotion	Demonstration projects / Applied Research			✓		✓	✓						✓
	Advocacy by public figures / info campaigns			✓			✓						
	Procurement of EVs for public fleets			✓			✓				✓		

✓ Policy lever to overcome barrier; Regulatory Levers (grey: Deciding technical standards, Streamlining permitting, Zoning & building codes, Streamlining of the EV registration process, Update Homologation Process, Signage for charging stations & EV parking lots); CI: Charging Infrastructure

Figure 32 Framework Matching Policy Levers to Adoption Barriers
Source: ERI@N Analysis based on Harvard Kennedy School

Singapore's government can create policies that encourage EV adoption and use, since they are the most efficient way to ensure a sustainable and profitable charging infrastructure ecosystem

Modified Homologation Process

A recently published paper by German companies in Singapore draws on the experiences in the Singaporean car-market and recommends the introduction to a modified homologation process to support the introduction of EV models into the market (Figure 33).

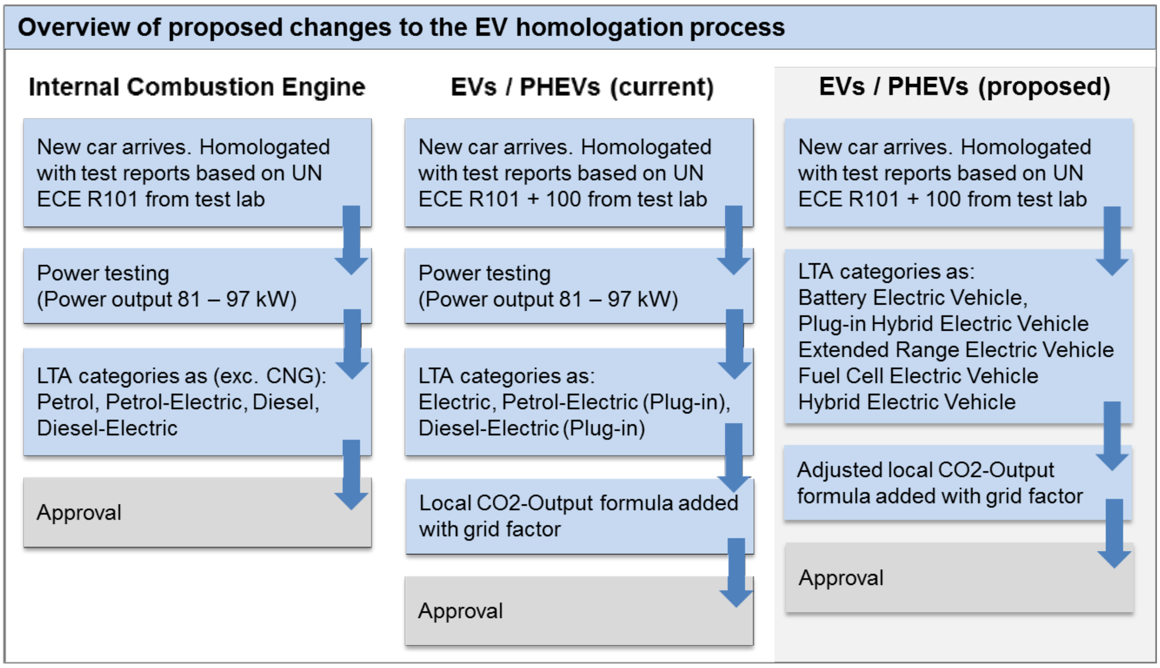


Figure 33 Overview of Proposed Changes to the EV Homologation Process[22]

Financial incentives for potential EV buyers

Nowadays under the CEVS, pure battery EVs are granted a tax rebate of S$ 30,000.[23] A reconsideration of the COE of EVs could also help to make EVs more attractive to customers than their conventional equivalents. Another lever for enhancing EVs could be to rethink the ARF calculation mechanism which is currently based on the OMV. E.g., excluding the battery from the EV's OMV could help to bring the ARF significantly down.

In general, studies indicate that initial purchase incentives have a much higher impact on consumers' buying decisions than benefits which will lower the TCO at a later point of time.[24]

Set a regulatory framework conducive for private investment in charging infrastructure

Deciding technical standards

The decision on one standard for charging infrastructure in Singapore is crucial to ensure a long-term large-scale deployment of EVs. Adherence to standards helps ensure safety, reliability as well as environmental care and this in turn raises user confidence. A common standard is needed to ensure the interoperability of charging systems and the ability of devices to work together.[25]

[22] Source: Singaporean-German Chamber of Industry and Commerce, Automotive Committee Singapore
[23] Revised CEVS LTA 2015
[24] Report by International Council on Clean Transportation, 2014
[25] Based on Electromobility in Germany: Vision 2020 and Beyond by Germany trade & invest; Electromobility Standards by PricewaterhouseCoopers; E-mobility and smart grids at the JRC by European Commission

Streamline permitting - Introduce standardised permitting processes for installations
Policies that ease the permitting and installation process are relatively straightforward and low-cost measures that have proven to be beneficial in first-mover states, e.g. in the U.S.[26] The installation of charging stations in Singapore currently requires organisational and coordination efforts which are hard to calculate in time and costs. The installation process often requires the coordination with multiple agencies as carparks and surroundings consist of a variety of micro zones controlled by different agencies and companies.[27] Standardised guidelines and permitting processes as well as the consolidation of stakeholders to one contact agency would significantly reduce time and cost efforts and help to accelerate the island-wide build-up of charging infrastructure.

Zoning and Building codes - Avoid retrofitting efforts by higher transparency and early planning of building's electrical packages
The easiest access to the power supply for charging stations lies in the carpark. Consultants involved in the building planning stage usually only plan for small electrical packages which are intended to serve the needs of a normal carpark (lighting, etc.). This makes it later complicated for charging infrastructure providers to find a close and sufficient power source, especially for a 3-phase power supply. Stakeholders preparing these guidelines should at least include M&E consultants (in BCA's Public Sector Panels of Consultants PSPC), BCA, LTA and the charging infrastructure provider. German private sector stakeholders recommend that future carparks should be equipped with min. 63A power supply to cater future generations of EVs and PHEVs. Furthermore 10 EV ready lots for every 100 parking lots are recommended with a possible scale up according to the EV growth rate.[28]

Provide low-cost financing for charging infrastructure
A variety of studies list subsidies, investment tax credits and/or production tax credits for charging infrastructure accelerating measures.[29] However if the financial focus of a government is on growing the EV purchase market rather than investing in charging infrastructure development, a systematic approach to low-cost-financing is recommended. Lowering costs of charging infrastructure can have a significant impact on long-term profitability. Low-cost financing not only can help grow the market and increase profitability to installers, it can also help establish a market for the financing of these investments.

Ensure financial stakeholder involvement
As mentioned above, to support the market growth of EVs in Singapore financial institutions have to be aware of the nature of the electromobility technology and market. Buyers need to turn to a financial institution who understands the ins and outs of this emerging market - financing for the purchase of EVs as well as the purchase and installation of supportive charging stations and solar panel arrays. Thus banks can help to make financing of EVs more easily accessible and affordable.

Ensure a holistic approach
The importance of having "one face to the customer" for the success of the introduction of electromobility systems to Singapore's consumers was stressed multiple times by roadmap stakeholders. From a charging infrastructure perspective, it is important that customers are able to just plug and play. A future established customer service which helps in case of questions or problems has to be fast in response and easily to contact.

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[26] Based on The Wall Street Journal; 2014
[27] Interview with OEM based in Singapore
[28] Source: Singaporean-German Chamber of Industry and Commerce, Automotive Committee Singapore
[29] Based on Report on EV policies by Harvard Kennedy School; 2010; Supercharging the Development of Electric Vehicles in China by McKinsey, 2015; Energy Policy report from Elsevier , 2013

Promote Electromobility

Consumers have to be educated about the TCO structure of EVs and how low EV's operational costs and government incentives can make EVs a cost-competitive choice. Community-based marketing programs for electromobility help to spread the word. Furthermore the government can support legislation that requires Singapore Power to provide information about EVs to potential EV drivers. Finally education institutes and industry OEMs should work towards educating and training employees along the value chain like electricians, real estate developers, and facility managers.

Support Applied Research

Electromobility covers a broad spectrum of technology and engineering, ranging from materials to information and communication technology and energy and the environment, etc. The government should dedicate budgets to the research fields explained before, carefully monitoring tangible outcomes and constantly performing a global benchmark to control investments and to realise fruitful research collaborations on a world-class research level.

Create standardised testing procedures

Currently, there is no technical acceptance test in Singapore which could help to test prototypes. Licences to test prototype EVs on the street, which are capable of being operated on public and private roads, are not granted. This makes testing difficult as experiences have shown that standardised test procedures with input from industry and other stakeholders are necessary to accurately measure real-world prototype performance.[30] For example, testing has to be done for the total system's performance of an EV as well as the determination of its energy consumption and range. These test procedures may then also help to test production and pre-production of advanced technology prototypes.

30 Interview with research institution based in Singapore

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