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Smart and Sustainable Living Community in High Dense Asian Cities: Support from Electric Vehicle Charging Infrastructure Planning and Intelligent Charging System

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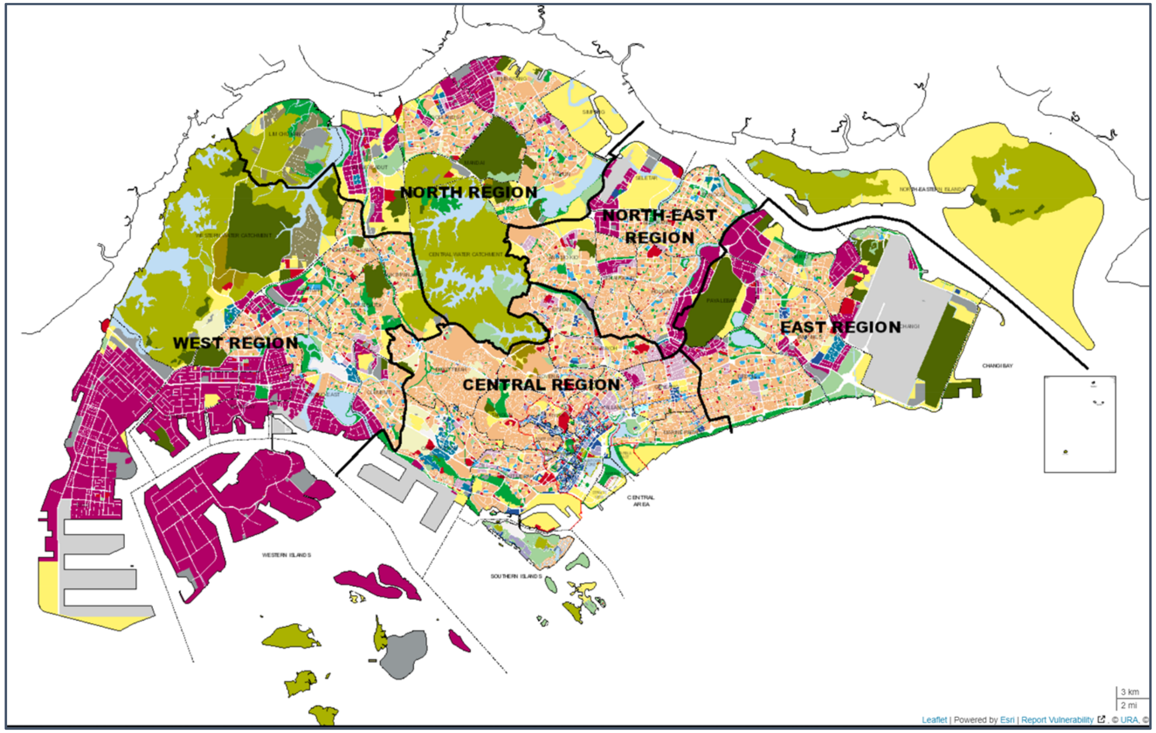
Contents

Introduction (1/5)

❑ Features of High Dense Asian City

- Singapore is a sovereign island city-state in Southeast Asia.
- Singapore has almost 5.7 million residents with the third greatest population density in the world (7,804 persons/km^2).
- Singapore has nearly one million vehicles on Singapore's roads. More than 600,000 of those (~60%) are private and rental cars.
- Roads take up 12% of the country's total land area, which is a far higher percentage than in many larger countries.

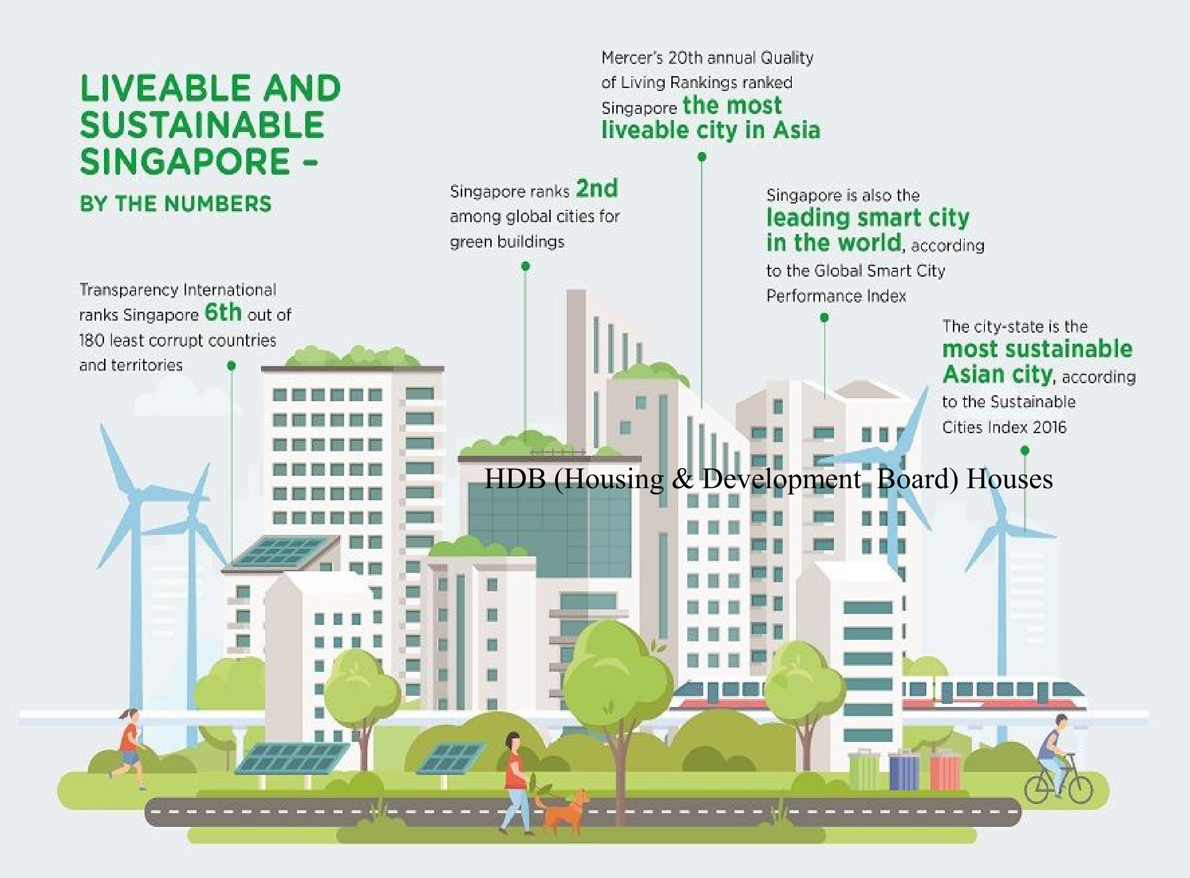
Land use master plan (2019)



Introduction (2/5)

❑ Features of High Dense Asian City (cont'd)

HDB (Housing & Development Board) Tall Buildings

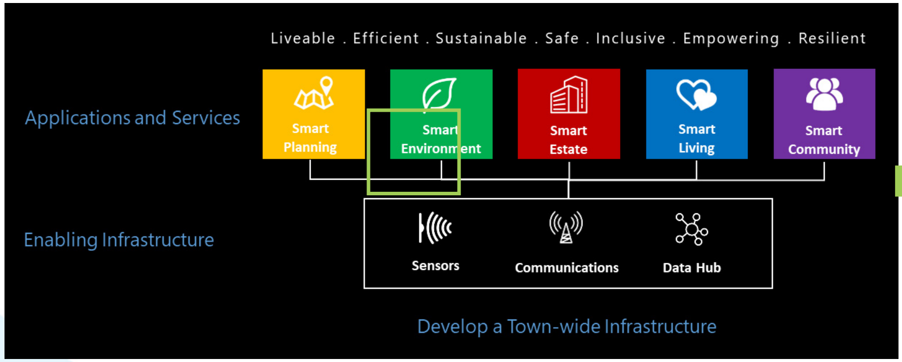


HDB (Housing & Development Board) Houses

Introduction (3/5)

❑ Smart and Sustainable Living Community

- First unveiled in 2014
- Developing estates that provide eco-friendly and smart features for a smart and sustainable living
- Creating a better living environment for residents by the use of smart technologies in the planning, development, and management of HDB towns



Smart HDB Town Framework (Source: HDB)

HDB Greenprint — A Greener Neighbourhood

- Energy-efficient management
- Water management
- Waste management
- Vehicle electrification
- …

Introduction (4/5)

❑ Current Electric Vehicle Population and Charging Facilities in Singapore

Cumulative EVs

	2015	2016	2017	2018	2019	2020
electric cars	1	12	314	560	1,120	1,217
electric taxis	-	-	-	102	133	32
electric buses	4	3	3	23	50	50
Total	5	15	317	685	1,303	1,299

2,119 EV Charging Points

Supplier/ owner	Location	Number	Price	Charger type
BlueSG	Roadsides, near HDB carparks, community clubs and schools	1,515 points (295 points open to private chargers)	S$1/h for the first 3 hours and S$2 per hour thereafter	Type 2 AC
SP Group	Commercial buildings, shopping malls, business parks and industrial sites	Over 340 points in 71 locations	S$0.46/ kWh (AC) S$0.38/kWh(DC)	Type 2 AC and Combo 2 DC
GreenLots	Especially in condominiums	121 points	S$0.5/ kWh (7.4 kW) S$ 0.55/ kWh (43/50 kW)	3.7kW/7.4kW/22kW AC 50 kW DC
BYD		122 points		AC 40kw& 80kw
Shell	Only at select Shell Stations	18 points	S$0.55/kWh	Type 2 AC and Combo 2 DC
Tesla	Orchard, Millenia walk	3 points		Tesla supercharger (250kW fast DC charging)

Introduction (5/5)

❑ EV and Charging Infrastructure Roadmap of Singapore

2020

- EV Early Adoption Incentive (EEAI) was introduced
- Road taxi/pricing schemes were revised
- EV mobility initiatives are officially started

2025

- Cease new diesel car & taxi registrations
- The price of EV and ICE to be similar
- COE structure for EVs and other vehicles
- Funding &incentives for open EV carparks using solar power
- Eight EV-ready Towns

2030

- All new car & taxi registrations to be of cleaner-energy
- Fully electric and plug-ins taking up 33% of overall cars
- 50% COE for EVs
- 50% COE for EV taxi
- 60000 EV charging points
- all towns EV ready
- New building plans to have 80% EV-ready car parks

2035

- All new buildings under construction are designated EV-ready

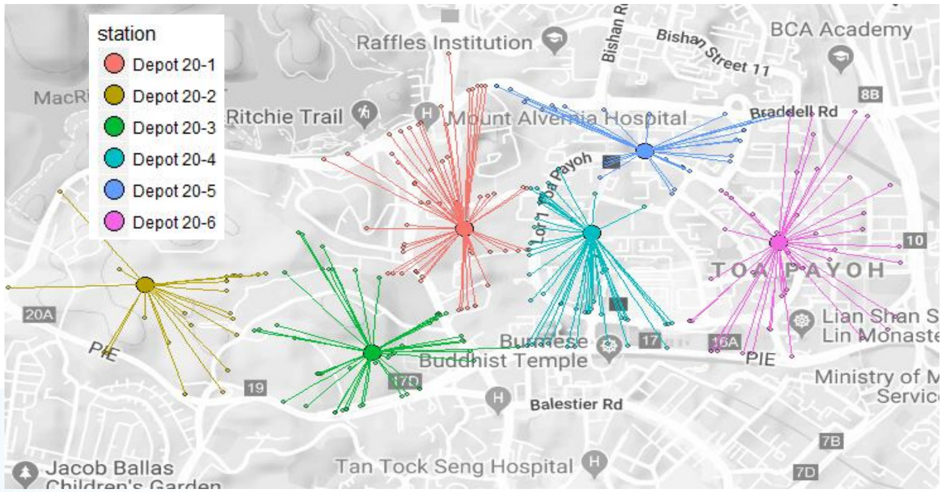
2040

- Phase out ICE vehicles
- All vehicles run on cleaner energy
- 100% cleaner energy bus fleet

Electric Vehicle Charging Infrastructure Planning (1/19)

- **EV Charging Facility Deployment Problem To fully satisfy the EV charging demand for urban mobility**

  - 1st issue: Where to build charging stations?
  - 2nd issue: What type of charging infrastructure should be deployed?
  - 3nd issue: How much capacity should be allocated at each station?

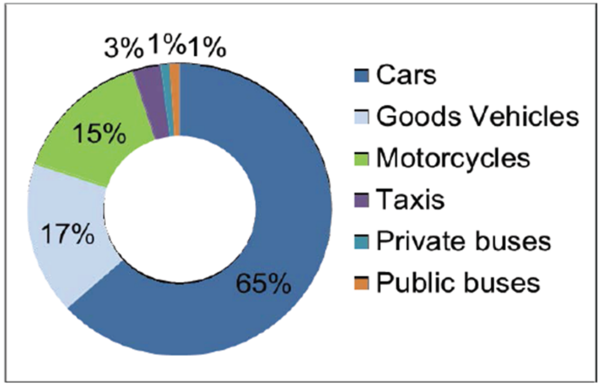


Electric Vehicle Charging Infrastructure Planning (2/19)

❑ Existing Approaches in the Literature

- Bi-level programming models: computational intractable for large-scale network and may be problematic (travel demand!= charging demand)
- Single-level optimization models: acceptable in computation efficiency, but SO may not reach due to different EV stakeholders
- Micro-level data-based method: appealing but time-consuming and labor-intensive

A tangible approach is needed for EV charging infrastructure planning for a dense city



2014:
- Car fleet size: 616,609 cars
- Taxi; 125,000 km/taxi/year

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Electric Vehicle Charging Infrastructure Planning (3/19)

Key EV & Charging Infrastructure Profiles for Modelling	
❖ How many types of EVs in a city?	Private EVs, 1-shift and 2-shift EV taxis
❖ EV charging frequency depends on EV driving range	
❖ How many types of charging modes?	Normal (level-2) charging & Fast charging
❖ Different charging efficiencies ⇨ two charging schemes	
❖ Candidate charging sites	Residential carparks and petrol stations

❑ Prevailing EV Brands and Vehicle Profiles

EV Brand (model year)	Battery capacity	Range^	Price*
Renault Zoe (2017)	22 kWh	149 miles^^	£14,245
Mitsubishi i-MiEV (2017)	16 kWh	59 miles	$23,845
Volkswagen e-Golf (2016)	24.2 kWh	83 miles	$28,995
Ford Focus Electric (2017)	**33.5 kWh**	**115 miles**	**$29,995**
Nissan Leaf (2017)	**30 kWh**	**107 miles**	**$31,545**
Fiat 500e (2017)	24 kWh	84 miles	$32,780
Chevrolet Bolt EV (2017)	60 kWh	238 miles	$37,495
Mercedes-Benz B250e (2017)	28 kWh	87 miles	$40,825
BMW i3 (2017)	**33 kWh**	**114 miles**	**$43,395**
Tesla Model S (2017)	60-100 kWh	210-315 miles	$69,200-$135,700
Tesla Model X (2017)	75-100 kWh	238-289 miles	$90,000-$140,000

- 30-35 kWh batteries are often used and their driving range are between 110 and 115 miles
- **32 kWh battery with 180 km of driving range (Assumption)**

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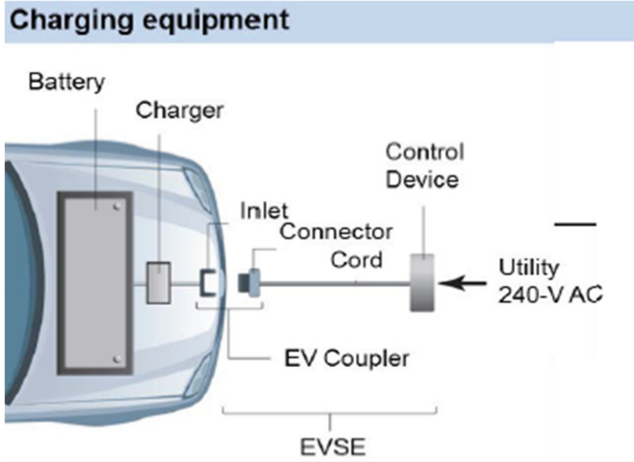
Electric Vehicle Charging Infrastructure Planning (4/19)

❑ Comparison of Charging Modes (Hydro-Québec, August 2015)

	Level 1	Level 2	Fast charge
Voltage	120 V	208 or 240 V	200 to 450 V
Current type	AC	AC	DC
Useful power	1.4 kW	7.2 kW	50 kW
Maximum output	1.9 kW	19.2 kW	150 kW
Charging time[a]	12 h[a]	3 h[a]	20 min[b]
Connector	J1772	J1772	J1772 Combo, CHAdeMO and Supercharger

a. Charging time of a completely discharged 16-kWh battery at useful power.
b. Charging time to 80% charge, i.e., 12 kWh. Fast charging cannot be sustained to a full charge.



Reamrk: Very few batteries can support the maximum power at 100 kW. J1772 Combo standard sets limit the rated power to 50 kW for the fast charge

❑ Charging efficiency for a 32 kWh-battery:

- Level-2 charging mode: about 6 hours to make a full charge
- Fast charging (FC) mode: about 40 minutes to get 80% State of Charge (SoC)

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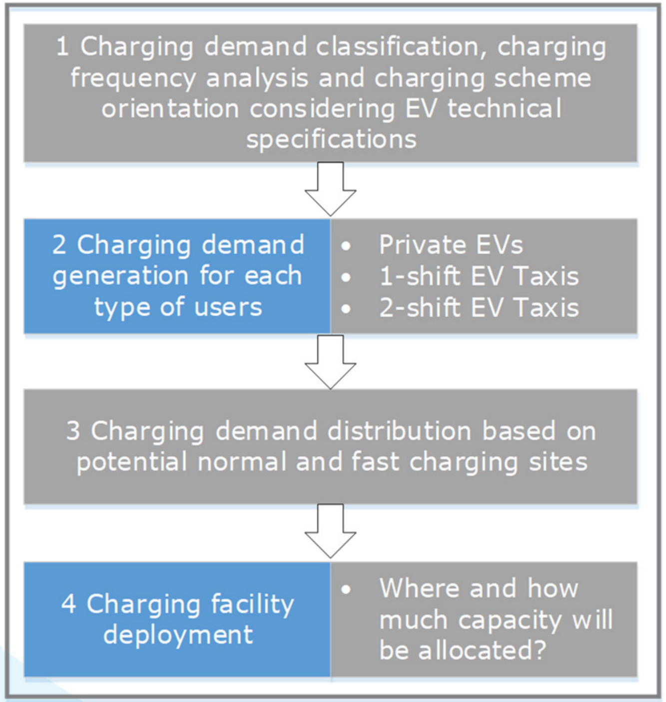
Electric Vehicle Charging Infrastructure Planning (5/19)

❑ 4-step Method

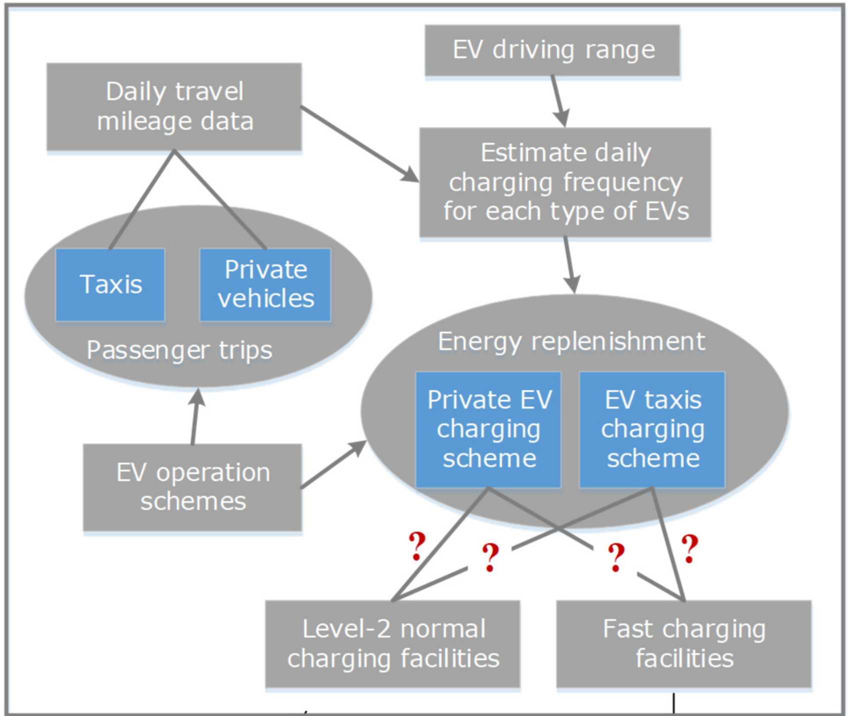


$$f_{private\ vehcile} = \frac{48.8\ km/day}{180\ km(1-0.2)} = 0.34/day$$

Charging frequency: $f_k = \frac{d_k}{R(1-\rho_k)}, \forall k \in \mathcal{K},$

the division of driving range and daily travel mileage

Step 1:



Residential Carparks

Petrol stations

Electric Vehicle Charging Infrastructure Planning (6/19)

❑ 4-step Method (cont'd)

1 Charging demand classification, charging frequency analysis and charging scheme orientation considering EV technical specifications

2 Charging demand generation for each type of users
- Private EVs
- 1-shift EV Taxis
- 2-shift EV Taxis

3 Charging demand distribution based on potential normal and fast charging sites

4 Charging facility deployment
- Where and how much capacity will be allocated?

Step 2:

to generate total normal/fast charging demand

occupancy rate

daily travel mileage

$$D_k = \alpha_k \times Q_k \times d_k, \ \forall\, k \in \mathcal{K}.$$

The number of the kth type of EVs

The total charging demand measured in hours for each type of charging mode:

$$S_k = \begin{cases} 6 \times \dfrac{D_k}{R}, & \text{if the Level-2 charging mode is used,} \\ \dfrac{2}{3} \times \dfrac{D_k}{80\%R}, & \text{if the fast charging mode is used.} \end{cases}$$

A more realistic case considering users' charging preferences: $S_k = 6\sum_{j\in\mathcal{J}} \left(1 - \dfrac{\gamma_{j-1}+\gamma_j}{2}\right) \times Q_k^j \times M_j,$

Electric Vehicle Charging Infrastructure Planning (7/19)

❑ 4-step Method (cont'd)

1 Charging demand classification, charging frequency analysis and charging scheme orientation considering EV technical specifications

⇩

2 Charging demand generation for each type of users	• Private EVs • 1-shift EV Taxis • 2-shift EV Taxis

⇩

3 Charging demand distribution based on potential normal and fast charging sites

⇩

4 Charging facility deployment	• Where and how much capacity will be allocated?

Step 3:

Spatial distribution of two types of charging demand

$$S^i_{\text{level2}} = S_{\text{level2}} \times \frac{N_i}{\sum_i N_i},$$

the number of private EVs (including1-shift taxis) at carpark *i*

Based on demographic statistics

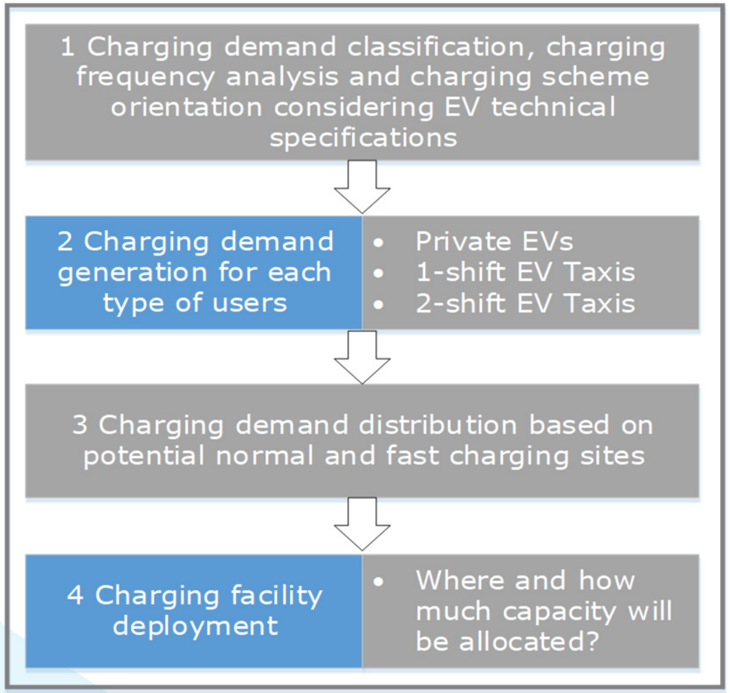
$$S^i_{\text{fast}} = S_{\text{fast}} \times \frac{\tilde{N}_i}{\sum_i \tilde{N}_i},$$

the petrol throughput or count of energy replenishment at petrol station *i*

- ❖ access the commercial information from petrol operators,
- ❖ estimate the count of energy replenishment based on vehicles' temporal-spatial distribution (e.g., trajectories)

Electric Vehicle Charging Infrastructure Planning (8/19)

❑ 4-step Method



Step 4:

Charging facility deployment: the number of chargers at each site

$$N_i^* = \begin{cases} \left\lceil \dfrac{S^i_{\text{level2}}}{\Phi_{\text{level2}}} \right\rceil, & \text{for Level-2 normal charging station,} \\ \left\lceil \dfrac{S^i_{\text{fast}}}{\Phi_{\text{fast}}} \right\rceil, & \text{for fast charging station.} \end{cases}$$

the average daily engaged working hours for a Level-2 charging slot and a fast charging slot

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Electric Vehicle Charging Infrastructure Planning (9/19)

❑ Case Study

- **Data Sources and Data Preparation**

  - Official databases released by Land Transport Authority (LTA) and Housing & Development Board (HDB) in Singapore

- **Two scenarios with different driving ranges**

  - Scenario A with driving range of 180 km (current situation)
  - Scenario B with driving range of 320 km (near future)

Data item	Specification	Data source	Usage/purpose
HDB car park information	car park location and hourly available parking lots	https://api.data.gov.sg/v1/transport/carpark-availability	Candidate sites for Level-2 charging facilities & to estimate the number of private EVs at each residential community
Taxi Availability	real-time locations of available taxis across the island (updated every 15 seconds)	https://api.data.gov.sg/v1/transport/taxi-availability	To estimate the count of taxi energy replenishments at each petrol station
Petrol station information	locations of petrol stations	http://www.sgcarmart.com/news/carpark_index.php?LOC=all&TYP=petrol	Same as the above one
Transport statistics in Singapore (2017)	private vehicle population, average annual kilometers traveled per private vehicle, taxi fleet, average daily number of taxi trips, average engaged mileage per trip	https://www.lta.gov.sg/content/ltaweb/en/publications-and-research.html	For the charging frequency analysis, demand generation and distribution
Other taxi operational data	taxi utilization rate with engaged passengers, two-shift occupancy rate	https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=766364af-eb2f-4d2a-9575-1499d862777f https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=8d105be4-5fa5-4837-b346-300533288a03	For the determination of the fleets of one-shift and two-shift EV taxis

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Electric Vehicle Charging Infrastructure Planning (10/19)

❑ Input Data and Remarks

EV fleet size:

$$N_{\text{EVcar}} = 0.1 \times 502,187 = 50,218.7,$$

$$N_{\text{EVtaxi1}} = 0.3 \times 23,140 \times (1 - 68\%) = 2,221.44$$

$$N_{\text{EVtaxi2}} = 4,720.56$$

The average number of occupied parking lots at HDB car park *i* (the hourly available parking lots during 11pm to 4am) to estimate the spatial distribution of private EVs, N_i

Parameter	Value
the penetration rate of EVs in planned year	0.1 for private EVs 0.3 for EV taxis
the vehicle fleet	502,187 private cars 23,140 taxis
the driving range	R = 180 km for Scenario A (Year 2020) R = 320 km for Scenario B (Year 2030)
average daily number of taxi trips	17.72 for the one-shift taxi 26.19 for the two-shift taxi
average engaged mileages per trip	10.28 km/trip for the one-shift taxi 10.01 km/trip for the two-shift taxi
average daily engaged working time	Φ_{level2} =15 hours for a Level-2 charging slot Φ_{fast} = 20 hours for a fast charging slot
taxi utilization rate with engaged passengers	75%
the proportion of taxis on a two-shift system	68%
average annual kilometers traveled per private car	17,800 km
the one-shift EV taxis groups with different charging preference {'γ_{j-1}, γ_j': percentage }	{'5%-10%': 0.15, '10%-15%': 0.25, '15%-20%': 0.25, '20%-25%':0.25, '25%-30%':0.05, '30%-35%':0.03, '35%-40%':0.02}

The better way to estimate the count of taxi energy replenishment is based on taxi trajectories. Due to lack of such data, we use taxi proximity (real-time taxi availability) to petrol stations (i.e., occurrence frequency that a taxi mo$\tilde{N}_i$es near a petrol station, within 25m range) to approximate the results of .

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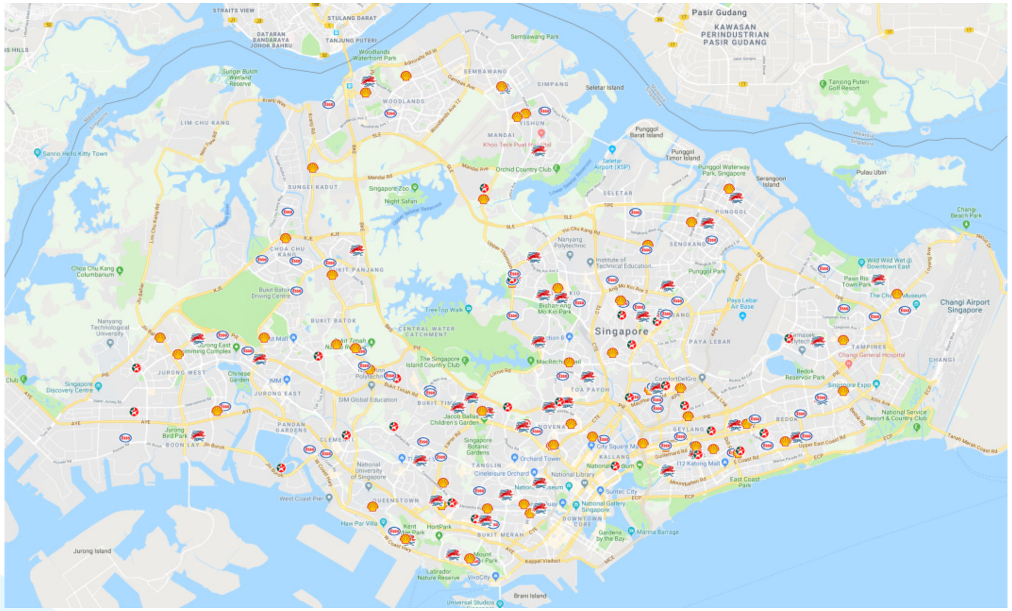
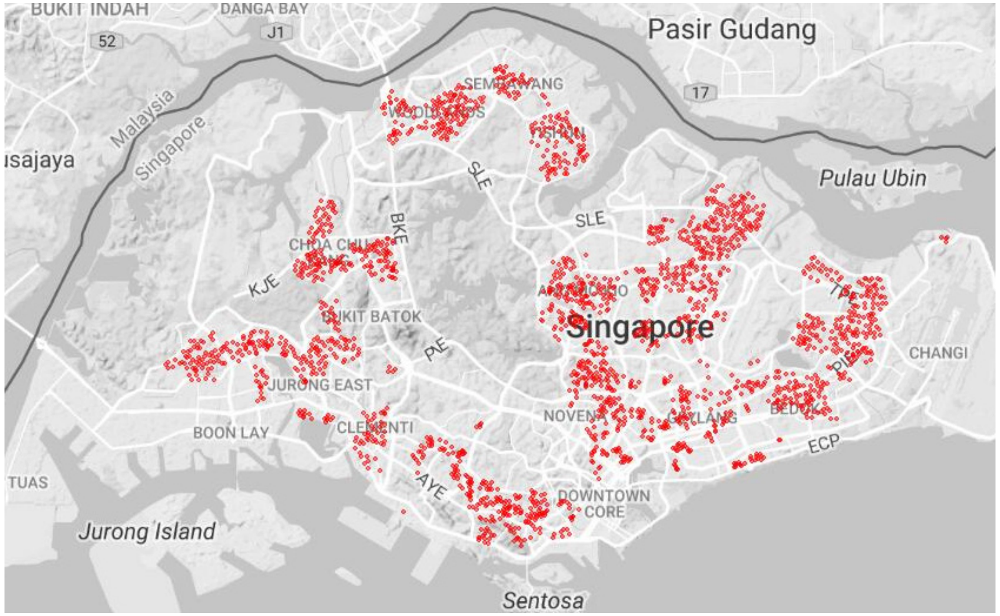
Electric Vehicle Charging Infrastructure Planning (11/19)

❑ Candidate Sites



186 Petrol stations across the island



2,068 HDB car parks in Singapore

Electric Vehicle Charging Infrastructure Planning (12/19)

❑ Charging Frequency Analysis

Daily mileage of private vehicles

17,800 km ÷ 365 days = 48.8 km/day

A full-charge private EV can serve

180 km ÷ (48.8 km/day) = 3.69 days

MOTOR VEHICLE POPULATION

		2013	2014
[4]	All Vehicles	974,170	972,037
	Private Cars	540,063	536,882
	Other Cars	83,625	82,141
	Taxi	27,695	28,736
	Buses	17,509	17,554
	Goods & Other Vehicles	160,344	161,698
	Motorcycles	144,934	145,026

ANNUAL AVERAGE QUOTA PREMIUM OF COE

		2013	2014
[5]	Category A (Cars ≤ 1600cc & Taxis)	$74,690	$67,675
	Category B (Cars >1600cc)	$78,712	$73,282
	Category C (Goods Vehicles & Buses)	$60,342	$50,764
	Category D (Motorcycles)	$1,757	$4,027
	Category E (Open Category)	$80,278	$73,436

PRIVATE VEHICLE ANNUAL MILEAGE

		2013	2014
[6]	Average Annual Kilometres Travelled per Vehicle		
	Cars	17,800	17,500
	Private Hire Buses	51,800	54,400
	School Buses	54,100	53,400
	Light Goods Vehicles (≤ 3.5 tons)	30,000	30,500
	Heavy Goods Vehicles (> 3.5 tons)	38,100	39,900
	Motorcycles	12,900	12,800

❑ Assumptions

- Car owners re-charge their vehicles when SOC <= 20% and make a full charge

❑ Average charging frequency for private EVs:

48.8 ÷ (180 ×80%) = 0.34 times per day (charge once for near three days)

Electric Vehicle Charging Infrastructure Planning (13/19)

❑ Daily Mileages of Two Kinds of Taxis

One-shift taxi	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Average daily number of taxi trips	18.0	18.4	18.1	17.5	17.1	17.6	17.8	17.7	18.0	17.5	17.6	17.3
Average engaged mileage per trip (km)	10.0	9.9	10.0	10.2	10.2	10.2	10.4	10.3	10.3	10.4	10.7	10.8
Two-shift taxi												
Average daily number of taxi trips	27.2	27.7	27.2	25.6	25.2	25.9	26.0	25.9	26.3	25.9	25.7	25.7
Average engaged mileage per trip (km)	9.4	9.3	9.3	10.1	10.0	10.2	10.3	10.1	10.2	10.3	10.4	10.5

Consider a taxi utilization rate of 75% (with passengers)

- **The average daily accumulative mileage:**

  One-shift taxi: 17.72 trips/day × 10.28 km/trip ÷ 75% = 243 km/day

  Two-shift taxi: 26.19 trips/day × 10.01 km/trip ÷ 75% = 350 km/day

❑ Average charging frequency for two types of EV taxis:

One-shift EV taxis: 243 ÷ (180 × 80%) = 1.69 times per day

Two-shift EV taxis: 350 ÷ (180 ×80%) = 2.43 times per day

Every day, 1-shift EAV taxi needs to charge twice and 2-shift EAV taxi needs to charge three times.

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Electric Vehicle Charging Infrastructure Planning (14/19)

❑ One-shift EV Taxi Scenario

- **Taxi drivers would**

(1) hope to make a full charge at night (off-work time),

(2) and take an extra energy replenishment during their working time when the SOC is low, e.g., 20%.

- **1st type charging activities:** could be done at night at residential carparks (Level-2 charging facilities).

- **Charging in day** could be fulfilled by fast charging

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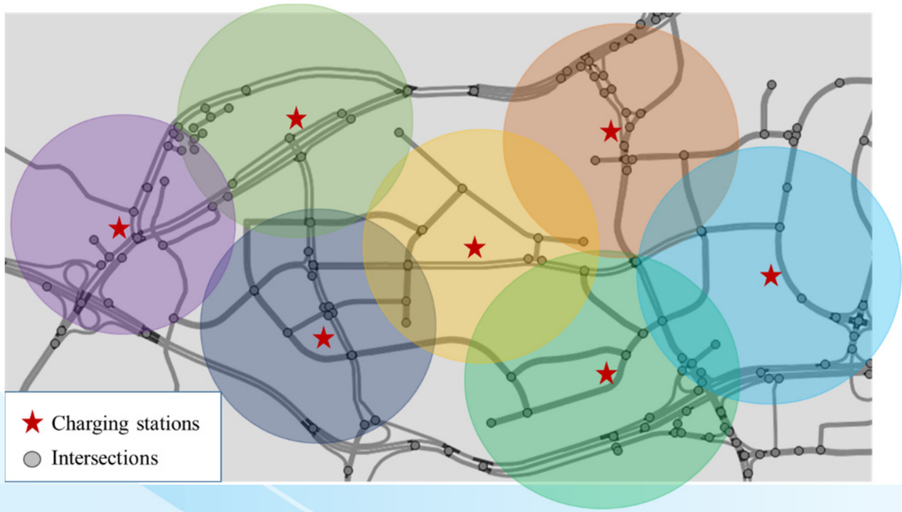
Electric Vehicle Charging Infrastructure Planning (15/19)

❑ **Two-shift EV Taxi Scenario: EVs charge 3 or more times every day**

- Impossible to make a long time charging at the off time (night time)
- Two-shift EV taxis always seek the fast charging.



- **Two issues to be solved:**

  Where are these fast charging (FC) stations?

  What capacity for each FC station?

Electric Vehicle Charging Infrastructure Planning (16/19)

- **The EV driving range will achieve >= 200 miles in near future**

  E.g., the 2018 Nissan Leaf adds 40% more driving range than the EV model last year, up to 151 miles

Planned Year	EV driving range	Estimated charging frequency		
		Private EVs	1-shift EV taxis	2-shift EV taxis
2017	112 miles (180km)	0.34 times/day	1.69 times/day	2.43 times/day
2020	**200 miles (320km)**	**0.19 times/day**	**0.95 times/day**	**1.37 times/day**
2025/2030?	300 miles (480km)	0.13times/day	0.63 times/day	0.91 times/day

Electric Vehicle Charging Infrastructure Planning (16/18)

- **If so, the charging frequency for 1-shift EAV taxis drops to once per day (charging at night like private EVs)**
- **Charging frequency of 2-shift EV taxis declines from 3 times to 2 times per day**

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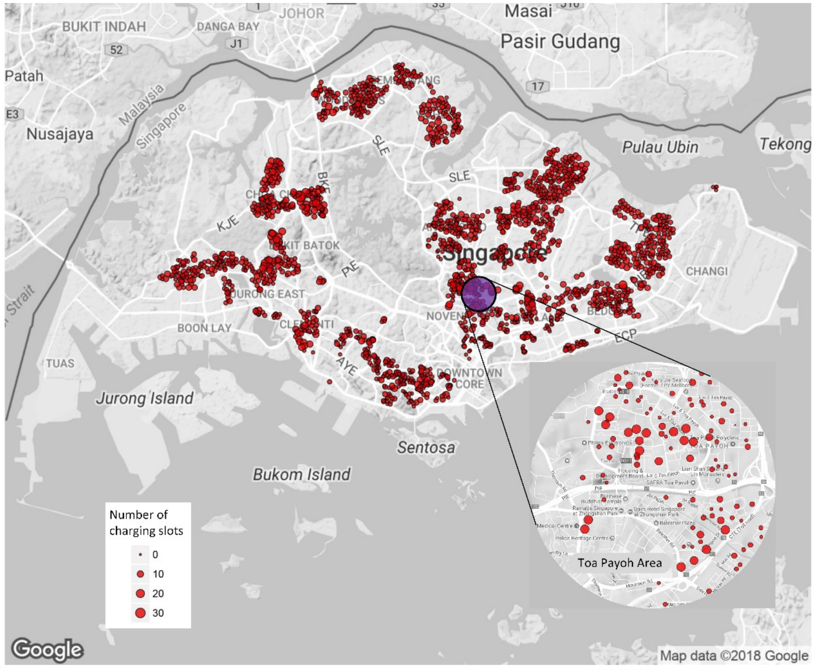
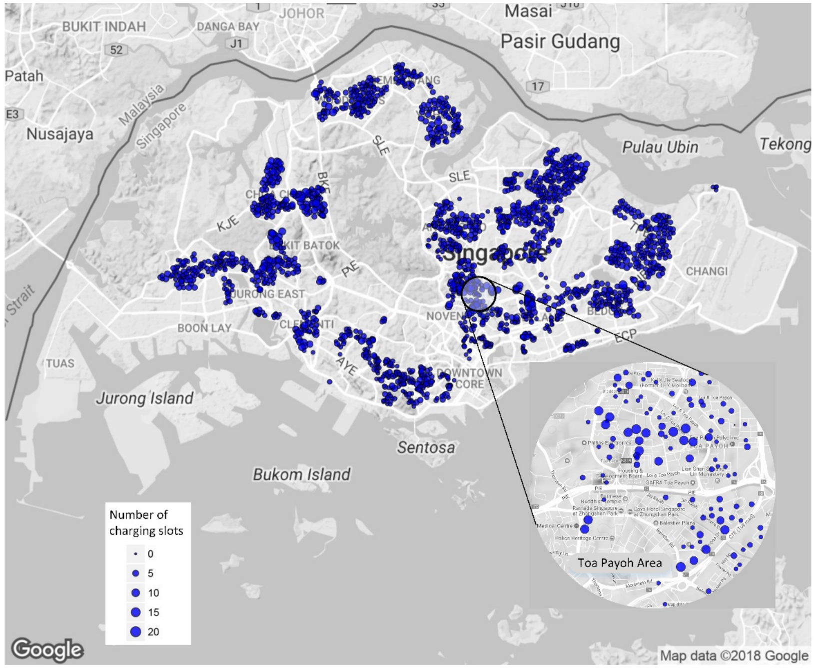
Electric Vehicle Charging Infrastructure Planning (17/19)

❑ Level-2 Normal Charging Facility Distribution



Scenario A with R = 180km



Scenario B with R = 320km

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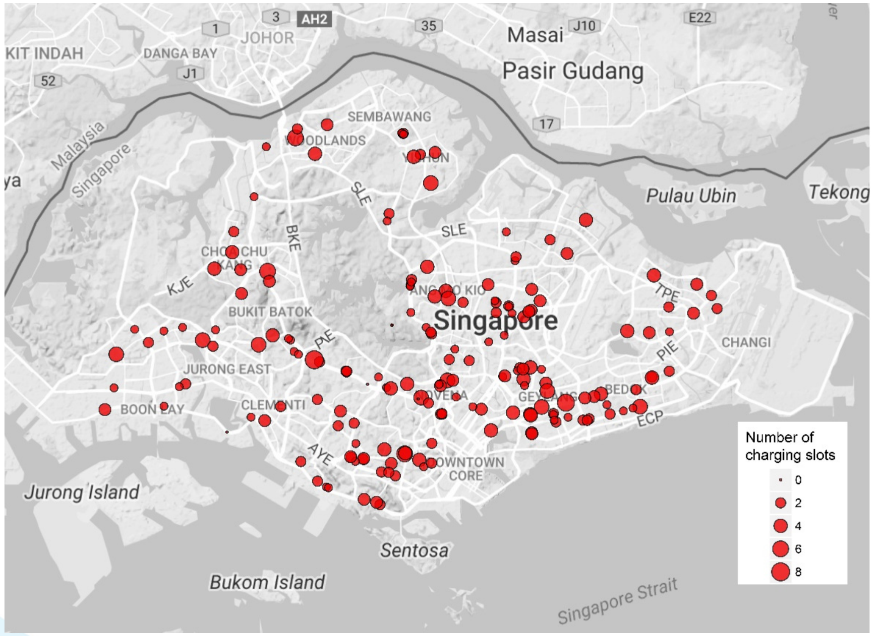
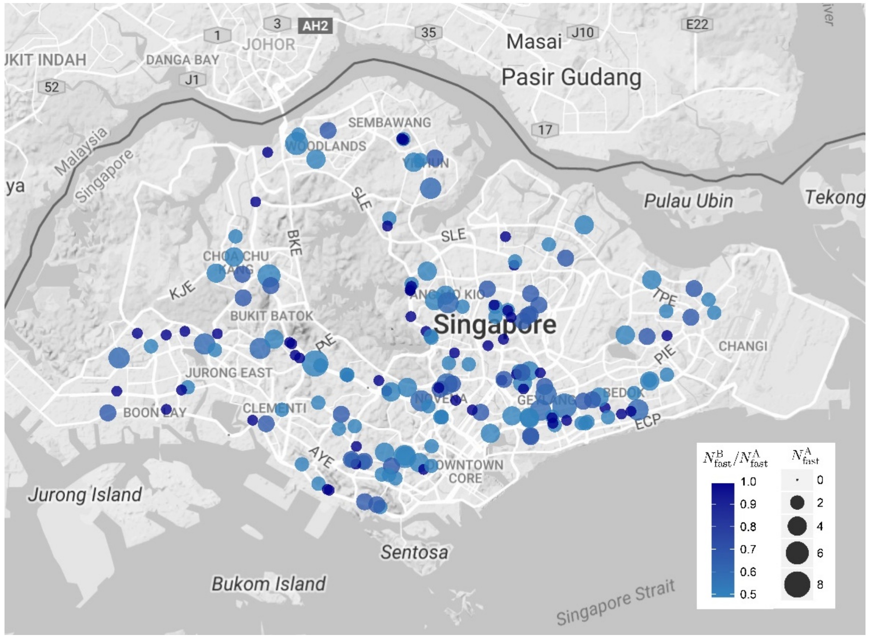
Electric Vehicle Charging Infrastructure Planning (18/19)

❑ Fast Charging Facility Distribution





Scenario A with R = 180km

Comparison between 2 Scenarios

Electric Vehicle Charging Infrastructure Planning (19/19)

❑ Comparison Between Two Scenarios

System indicators	Normal charging facilities		Fast charging facilities	
	Scenario A	Scenario B	Scenario A	Scenario B
Total number of chargers	7,249	4,853	519	303
Average chargers per station	3.51	2.35	2.81	1.64
Maximum chargers at station	37	22	10	5

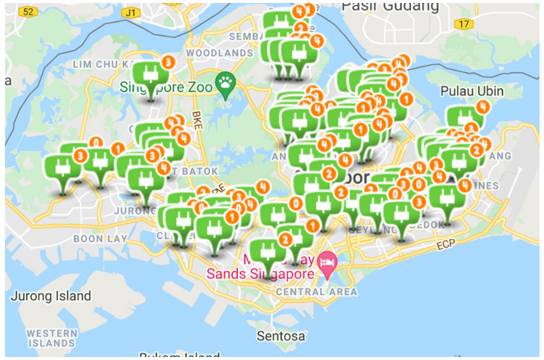
❖ When driving range increases, the infrastructure requirement is decreased in all three measures:

- total number of charging slots,
- average number of slots per site,
- maximum number of slots at site

❖ This indeed poses a problem for the implementation agency of how many charging slots to allocate in Phase 1 when EV driving range is relatively low.

Intelligent EV Charging Systems (1/4)

- With the massive deployment of EV chargers, these chargers may belong to different providers which include both public and private stakeholders
- EV users may need multiple EV charging service providers as they travel from one place to another.
- If providers use their own APP, finding an idle charger will be complicated
- A centralized and intelligent EV charging system will be needed to give customers access to the entire EV charging network



BlueSG charging network in Singapore

Known electric car charging networks around the world

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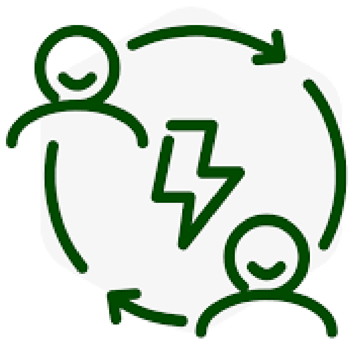
Intelligent EV Charging Systems (2/4)

❑ Technology Development



Peer to peer charging → Universal payment method → Roaming

Peer to peer charging

P2P charging is a system where individuals publicly share their private EV charge points with other EV drivers.

Universal payment method

mandatory payment options to allow any user to access a charging point (e.g., via credit card)

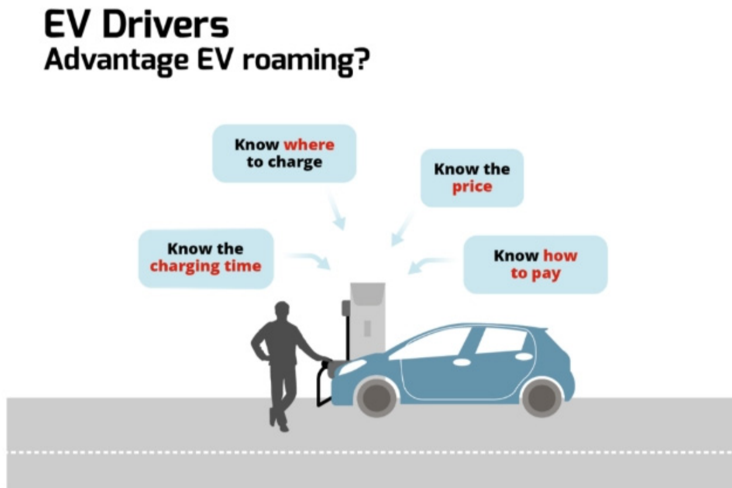
Roaming

a cloud-like system that allows any player to join the entire system, offering services on any charger

Intelligent EV Charging Systems (3/4)

❑ Advantage of intelligent EV charging systems

- Reduce their connection costs
- Use centralized data to optimize the charging network
- Foster competition by removing barriers to entry;
- Create simpler, standardized B2B interactions and transaction settlements
- Create a better customer experience



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Intelligent EV Charging Systems (4/4)

❑ Applications

- **Korea (2020)**

  KEPCO developed an open roaming platform called ChargeLink for the first time in Korea to allow EV drivers to use all charging stations in the alliance which consists of 13 charging service providers.

CHARGE LINK

EV Roaming Alliance

- **Netherlands (2015)**

  Gathering leading e-mobility service providers in Europe, GIREVE helps ease drivers' charging by connecting Charge Point and Mobility operators. GIREVE has already gathered over 150,000 charging points from different networks across Europe.

Conclusions

- ❑ **Analyzes the Unique Features of High Dense Asian Cities**

- ❑ **Propose A Tangle 4-step Approach for EV Charging Infrastructure Planning**

- ❑ **Introduce Intelligent EV Charging Systems**

Thanks & Questions!

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