A Cost-Competitiveness Analysis of Charging Infrastructure for Electric Bus Operations

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Introduction

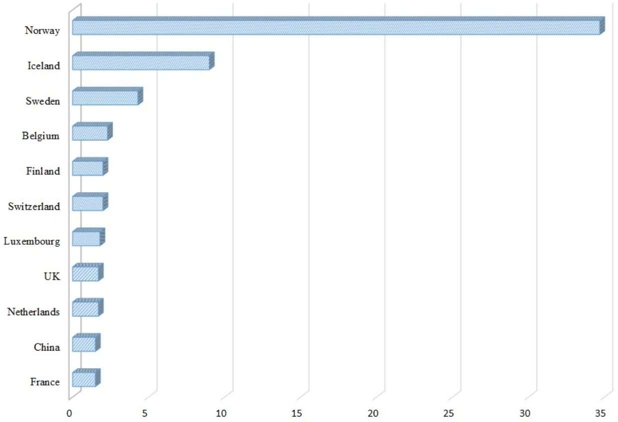

Figure: EV Market Share (%)

- limited driving range
- long charging time
- expensive battery
- shortage of charging infrastructure

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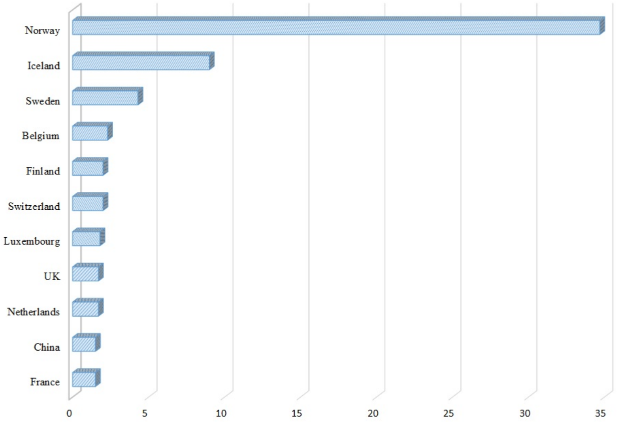

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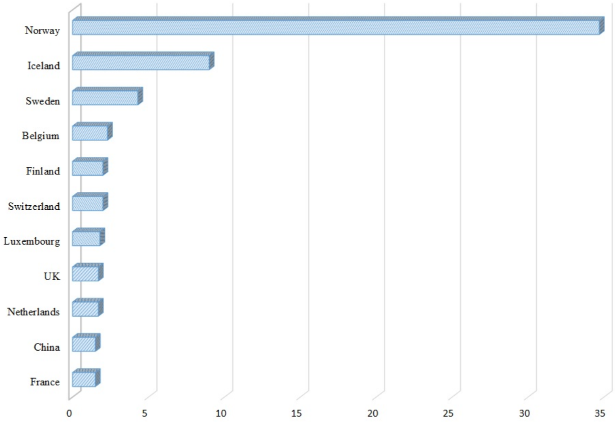

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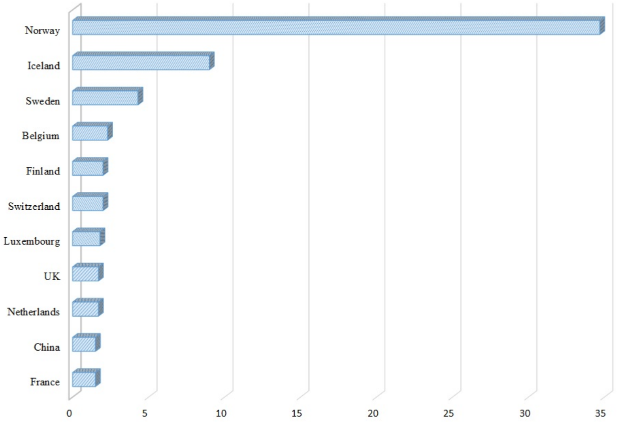

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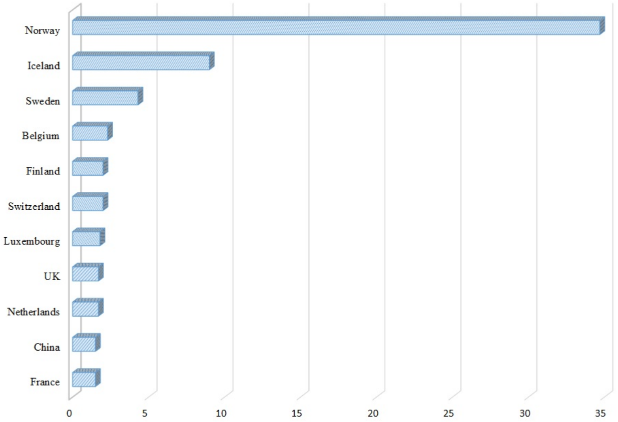

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  - Reduced charging delay and EVs battery size
  - High construction cost
- Charging Station
  - Less construction cost
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  - Short charging delay
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Which one is more economically competitive?

Objective

- Conduct a cost analysis of different types of charging facilities in a transit system to serve the charging needs of electric buses.
- Identify factors that may have a great impact on the cost competitiveness of different charging infrastructure.
- Assess the cost competitiveness of charging lanes on the worldwide BRT corridors.

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Setting & Assumption

- A single loop bus line is considered.
- Stationary charging infrastructure is only deployed at the bus terminal.
- Charging lanes are uniformly deployed along the bus line.

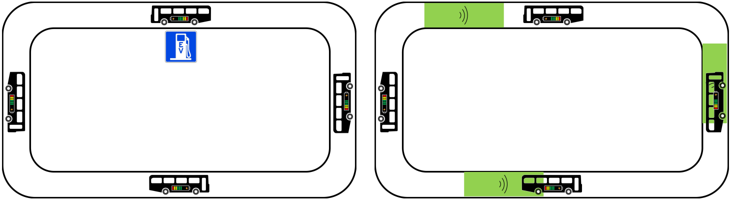

Figure: Bus line with charging stations (left) and charging lanes (right)

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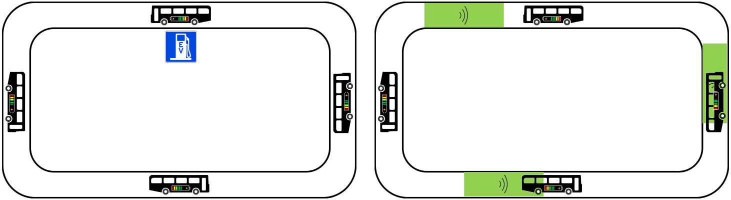

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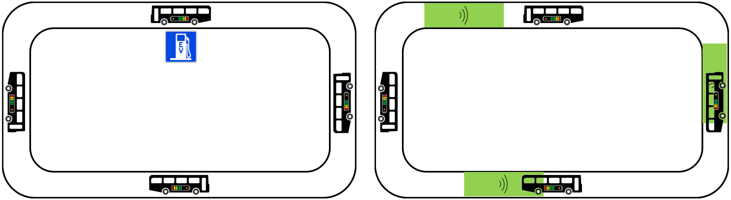

Figure: Bus line with charging stations (left) and charging lanes (right)

Setting & Assumption

- All buses are identical and are operated by the same bus company.
- All charging facilities are constructed and operated by the bus company.
- The bus service frequency is fixed.
- The average operating speed of buses, considering dwelling times at bus stations, is constant along the bus line.
- Buses do not need to slow down to recharge on charging lanes.
- The bus company aims to minimize the total capital cost for both the infrastructure and fleet.

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Model

- Variables
  - Bus fleet size
  - Battery size
  - Configuration of charging infrastructure:
    - charging station
      - # chargers
    - swapping station
      - # chargers
      - # batteries
    - charging lane
      - total length
      - # segments
      - # inverters
- Constraints
  - Guaranteeing the service frequency
  - Satisfying the charging need
- Objective
  - Infrastructure + Fleet cost

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- Objective is to minimize
  - Infrastructure + Fleet cost

Tradeoff

	Charging Station	Swapping Station	Charging Lane
Charging Delay	Large	Medium	0
Fleet Size	Large	Medium	Small
Battery Size	–	–	–
Infrastructure Cost	Low	Medium	High

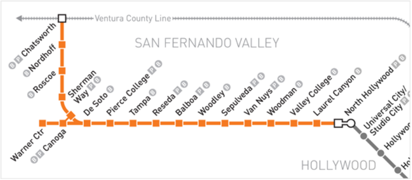
Parameter

Infrastructure Parameter	Value
Recharging efficiency for charging or swapping stations	0.9
Recharging efficiency for charging lanes	0.85
State of charge range (SOCR)	0.6
Electric power of charging or swapping station	120 kW
Electric power of charging lane	80 kW
Fixed construction area for each charging station	2,000 ft^2
Construction area required for one charger	900 ft^2
Unit construction cost	\$104/ft^2
Installation cost per unit of charging power	\$444/kW
Unit manufacturing cost for battery	\$570/kWh
Unit manufacturing cost for bus (excluding battery)	\$315,320/veh
Construction cost for battery swapping system without chargers	\$562,400
Construction cost for building one mile of charging lane	\$321,800/mi
Inverter cost per unit of charging power	\$250/kW
Fixed cost of constructing power transmitter	\$20,000

Parameter

- The nominal scenario is based on the Metro Orange Line, a bus rapid transit (BRT) corridor in Los Angeles.

Bus Line Parameter	Value
Service frequency	16 veh/h
Operating hours	22.2 h
Circulation length	35.2 mi
Average speed	19.9 mph



Basic Result

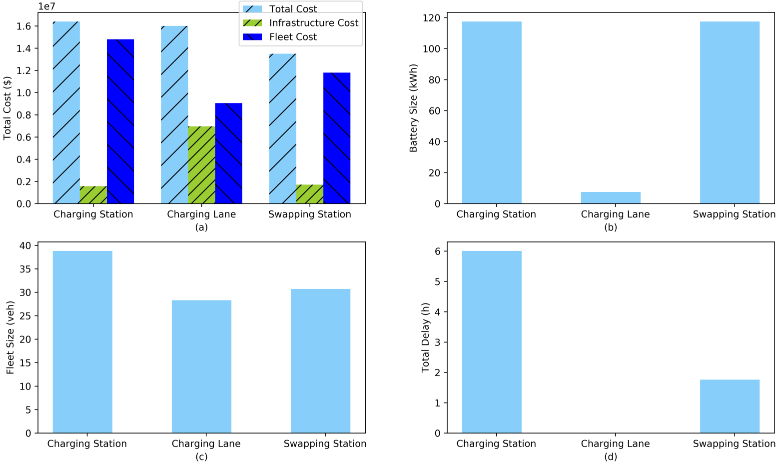


Figure: Results in the nominal scenario

Sensitivity Analysis

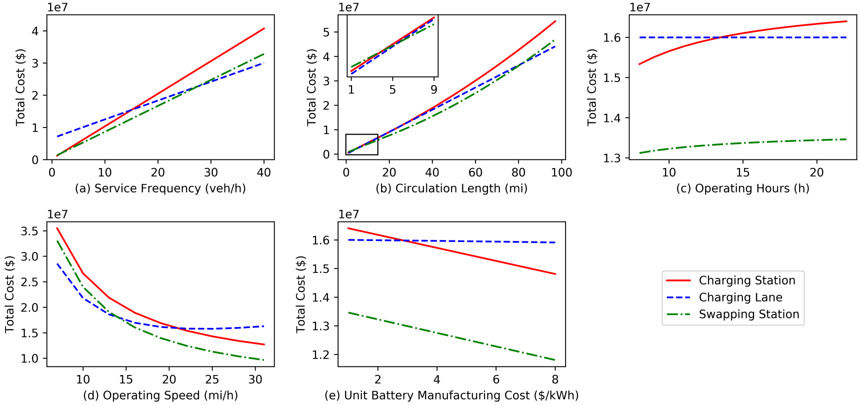


Figure: Sensitivity analysis

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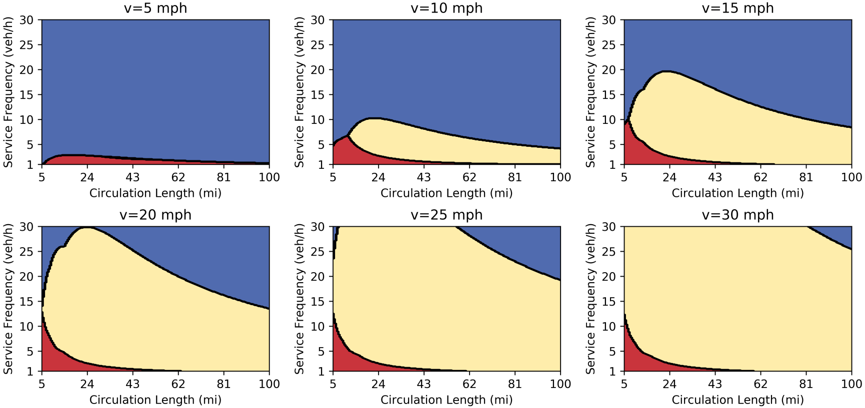

Figure: Competitive domain of charging infrastructure

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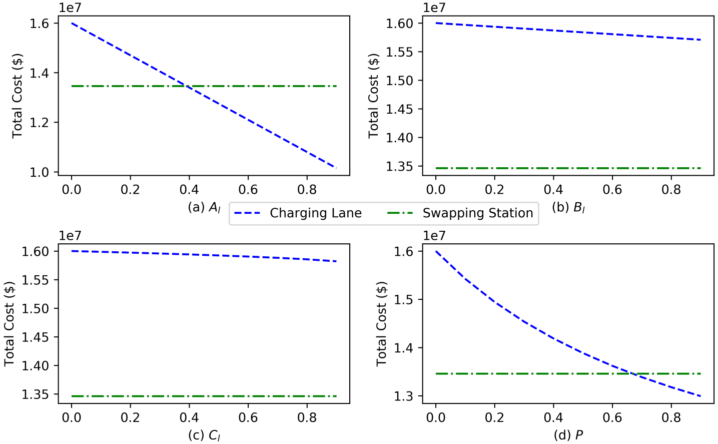

Figure: Sensitivity analysis of charging-lane parameters

BRT Corridors

Table: BRT corridors and their corresponding competitive charging infrastructure

City	Circulation Length (mi)	Service Frequency (veh/h)	Operating Speed (mph)	Competitive Infrastructure
Amsterdam	55.3	18	**21.1**	**Swapping Station**
Bangkok	8.2	15	16.2	Charging Lane
Beijing	73.3	30	11.8	Charging Lane
Bogota	130.5	312	14.3	Charging Lane
Brisbane	33.9	232	15.5	Charging Lane
Bunous Aires	79.7	193	11.5	Charging Lane
Cali	42.3	164	9.0	Charging Lane
Changde	23.5	27	19.3	Charging Lane
Changzhou	64.5	43	10.6	Charging Lane
Chengdu	35.8	101	18.6	Charging Lane
Dalian	11.2	86	12.0	Charging Lane
Guangzhou	28.0	320	11.2	Charging Lane
Hangzhou	35.3	67	7.6	Charging Lane
Hefei	8.9	80	10.6	Charging Lane
Istanbul	60.8	137	21.7	Charging Lane
Jakarta	166.5	40	12.4	Charging Lane
Jinan	51.7	49	10.9	Charging Lane
Kuala Lumpur	6.6	16	13.1	Charging Lane
Lanzhou	10.7	90	13.7	Charging Lane

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City	Circulation Length (mi)	Service Frequency (veh/h)	Operating Speed (mph)	Competitive Infrastructure
Leon	18.6	20	10.6	Charging Lane
Lianyungang	42.3	25	11.2	Charging Lane
Lima	33.7	101	15.5	Charging Lane
Los Angeles	35.3	**16**	19.9	**Swapping Station**
Mexico City	101.3	56	11.2	Charging Lane
Nagoya	8.3	12	15.5	Charging Lane
Nanning	14.0	51	9.6	Charging Lane
Nantes	7.7	9	11.8	Charging Lane
Seoul	53.4	210	9.9	Charging Lane
Shaoxing	14.3	15	9.3	Charging Lane
Urumqi	34.8	93	8.1	Charging Lane
Xiamen	64.7	107	16.8	Charging Lane
Yancheng	19.9	39	11.2	Charging Lane
Yichang	16.2	94	12.4	Charging Lane
Yinchuan	26.1	44	10.7	Charging Lane
Zaozhuang	80.8	23	**24.5**	**Swapping Station**
Zhengzhou	62.5	129	10.6	Charging Lane
Zhongshan	15.7	26	14.9	Charging Lane
Zhoushan	28.6	47	11.8	Charging Lane

Finding

- The **service frequency**, **circulation length**, and **operating speed** of a transit system are discovered to have a great impact on the cost competitiveness of different charging infrastructure.

- Charging lanes supported by the current inductive CWD technology are **cost competitive** for most of the existing BRT corridors, and their superiority becomes more remarkable for the transit systems with **high service frequency** and **low operating speed**.

- Upgrading the **charging power** and reducing the **unit-length construction cost** for charging lanes show great promise on making charging lanes more cost competitive for transit systems with low service frequency.

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Lab for Innovative Mobility Systems (LIMOS)

- Economic Analysis
  1. A Cost-Competitiveness of Charging Infrastructure for Electric Bus Operations. *Transportation Research Part C* (2018).
  2. Deployment of Stationary and Dynamic Charging Infrastructure for Electric Vehicles along Traffic Corridors. *Transportation Research Part C*, 77 (2017), 185-206.
- Operational Planning
  1. Integrated Planning of Dynamic and Static Charging Infrastructures for Electric Vehicles. *International Journal of Sustainable Transportation* (2018).
  2. Optimal Deployment of Charging Lanes for Electric Vehicles in Transportation Networks. *Transportation Research Part B*, 91 (2016), 344-365.
  3. Integrated Pricing of Roads and Electricity Enabled by Wireless Power Transfer. *Transportation Research Part C*, 34 (2013): 1-15.

Thank You!