Evaluating the operational and economic feasibility of mobile charging pods for electric bus operations

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Rise of Electric Buses

- Technical development of electric buses has increased dramatically over the past few years.
- Reduce noise and improve energy efficiency.
- Emissions of hazardous small particles and greenhouse gases are considerably reduced.

Figure – Electric bus (credits Volvo Bus)

Major Challenges

- Huge weight and cost due to large batteries.
- Lower range compared to diesel and bio-fuel buses.
- Change existing schedule, deploy more buses.
- Lower duration for charging especially in urban contexts.

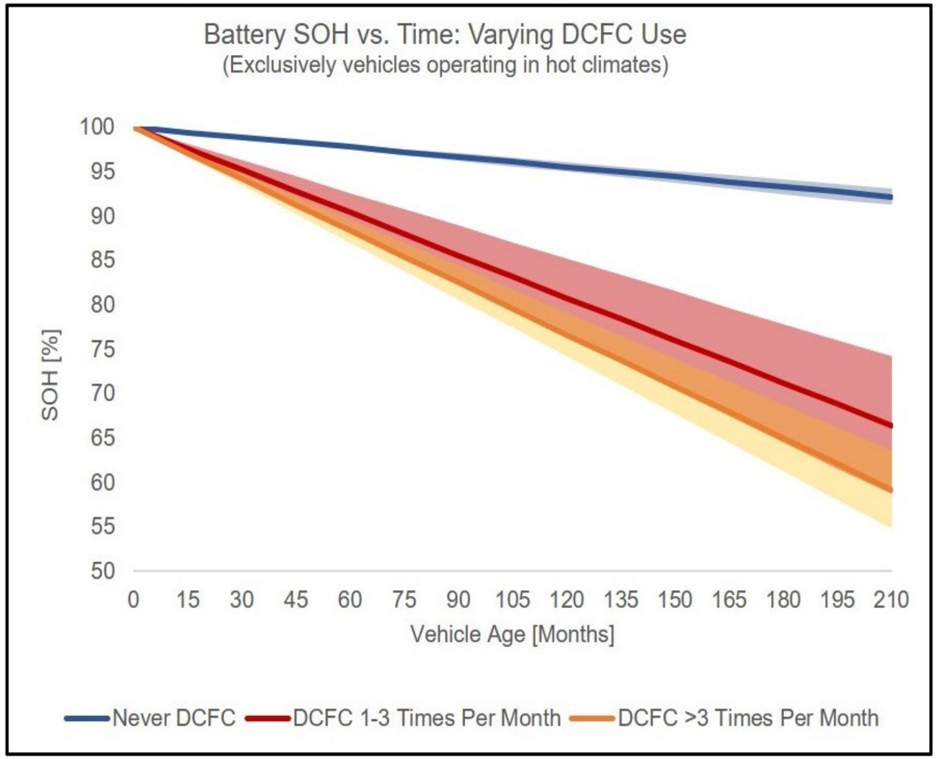


Figure- Effect of DC fast charging on battery health[1]

Current Charging Methods

Depot Charging-

- Buses Can only charge overnight at depots.
- Requires Large Battery capacity [4]

Depot + End Station Charging-

- Buses charge at depots at night and also at end terminals during operations.
- Huge Investment in End-Station Charger

Use of MAPs

- Mobile Autonomous Charging pods (MAPs)- autonomous battery on wheels.
- Can attach to bus and form a platoon with the bus.
- Can autonomously attach and detach to electric buses.
- Charges vis Vehicle-to-Vehicle (V2V) charging [5]

Figure- DIMAAG AI Battery on wheels [2]

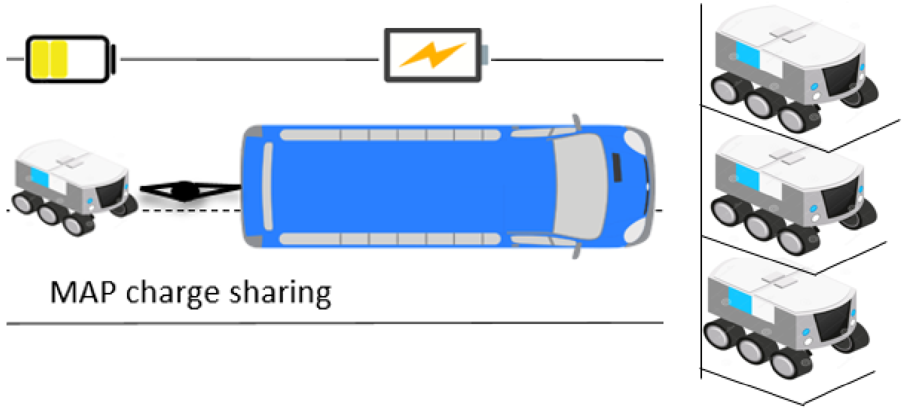


Figure- Proposed MAP solution [3]

Research Questions

- How can MAPs be leveraged to **electrify urban bus networks** ?

- What are the potential benefits in terms of **infrastructure cost reduction** and **decreased battery capacity requirements**?

Real-World Application

- Case study for **Blue bus lines** in Stockholm (**Lines 1,2,3,4 and 6**)
- Comparison with different **charging strategies.**
- Benefits in terms of **infrastructure costs** and **battery reduction**.

Methodology

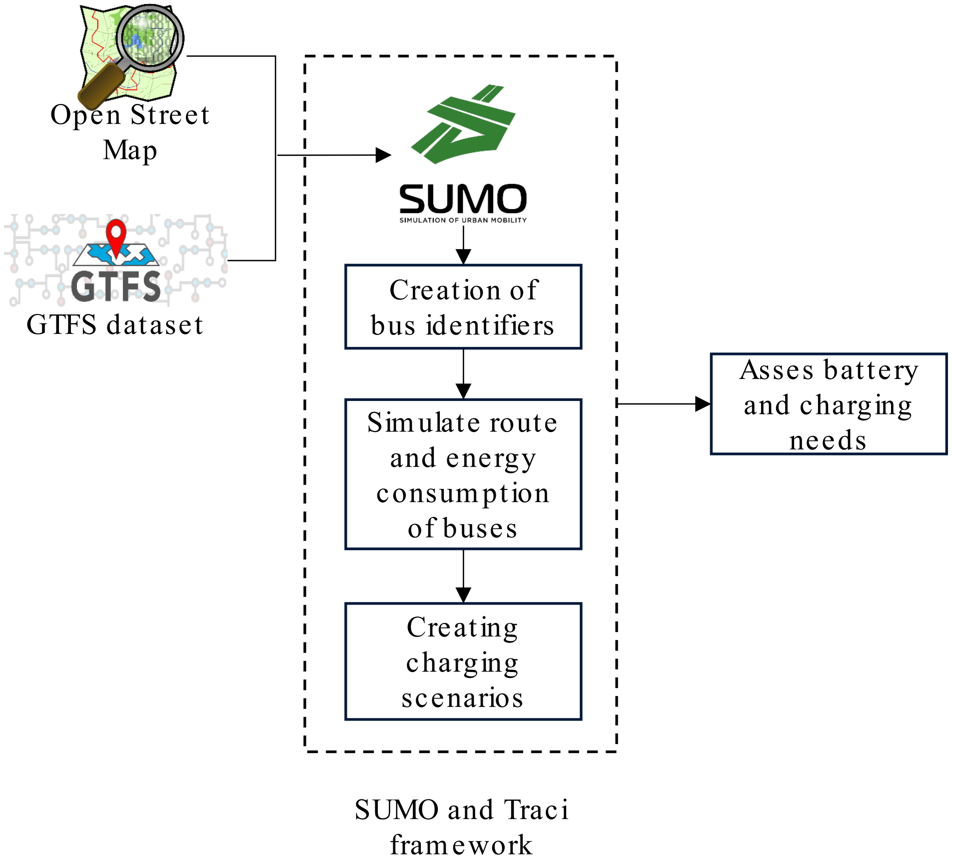
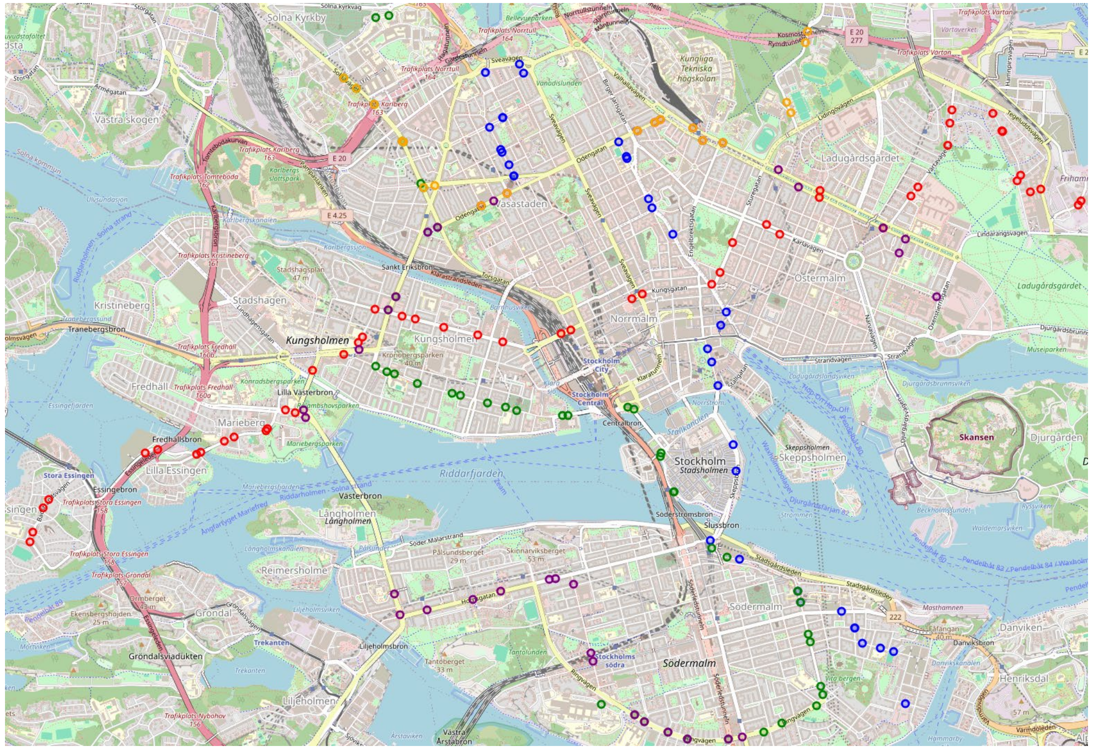


Figure- Simulation-based approach for electrifying bus networks

Case Study for Blue lines

- We employ **SUMO**, using road network data imported from **OpenStreetMap**.
- Bus routes and schedule were taken from **GTFS** and **AVL** datasets provided by the Region Stockholm.

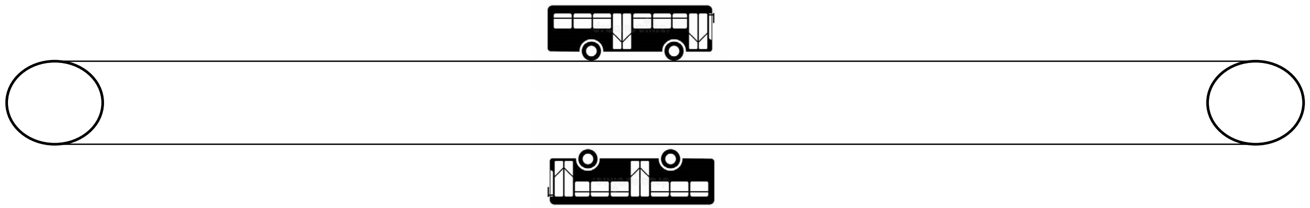


No. of buses per line

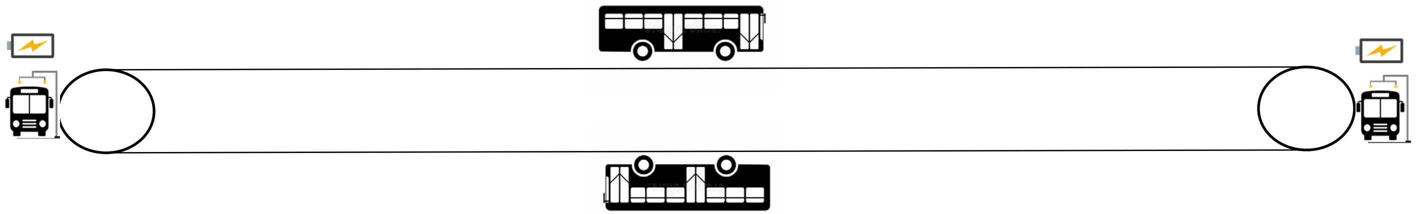
- We consider a **turn-around** time of **5 minutes** based on **AVL** dataset.

Bus Line	No. of Buses	Max trips per bus	Total distance travelled (Km)	Total energy consumed (MWh)	Energy per trip (kWh)
Line 1	21	15	2715	8.06	30.3
Line 2	15	19	1613.95	5.16	22.9
Line 3	16	18	2286.56	7.6	28.43
Line 4	23	16	3469.83	9.48	31.64
Line 6	10	26	1189.51	3.46	17.81
Total	**85**	**94**	**11274.85**	**33.76**	**131.08**

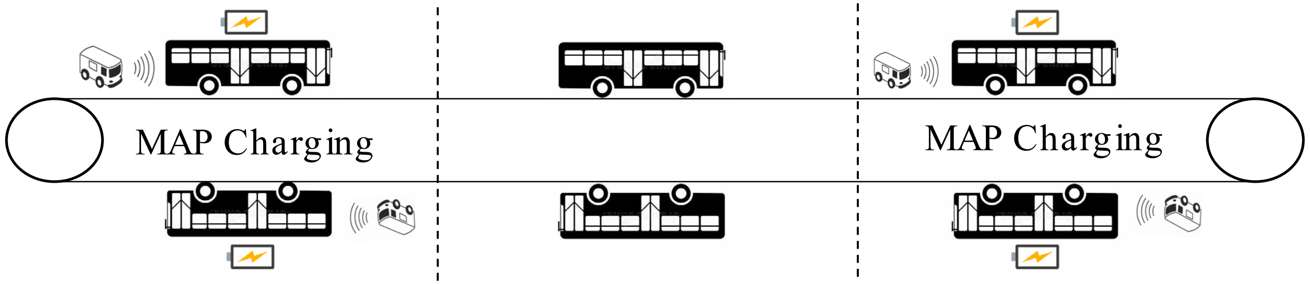
Scenarios



A) Only Depot (overnight) charging



B) Depot Charging + End station charging

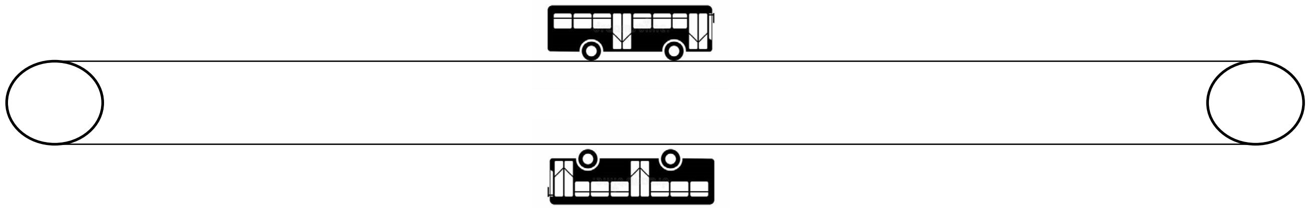


C) Depot Charging + MAP charging

Electric bus characteristic

Parameter	Value
Baseline battery capacity of e-buses	470 kWh
Operational weight of e-buses	30,000 Kg
Average speed of e-buses	20 Km/h
Energy consumption e-buses	3.0 kWh/Km
Minimum turn-around time	5 minutes

Only Depot Charging

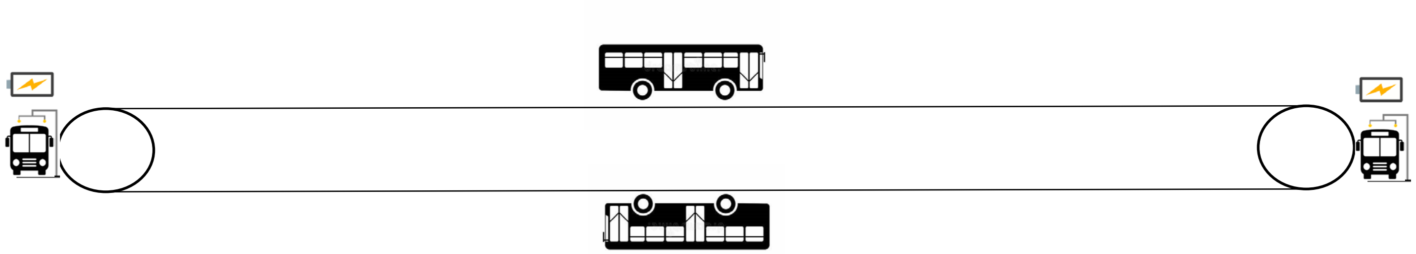


A) Only Depot Charging

Bus Line	Required battery capacity (kWh)	Total battery capacity per line (kWh)
Line 1	620	13020
Line 2	530	7950
Line 3	720	11520
Line 4	620	14260
Line 6	550	5500
Total	**3040**	**52250**

30% increase in **battery capacity** compared to Baseline of **470 kWh**

Depot Charging + End station

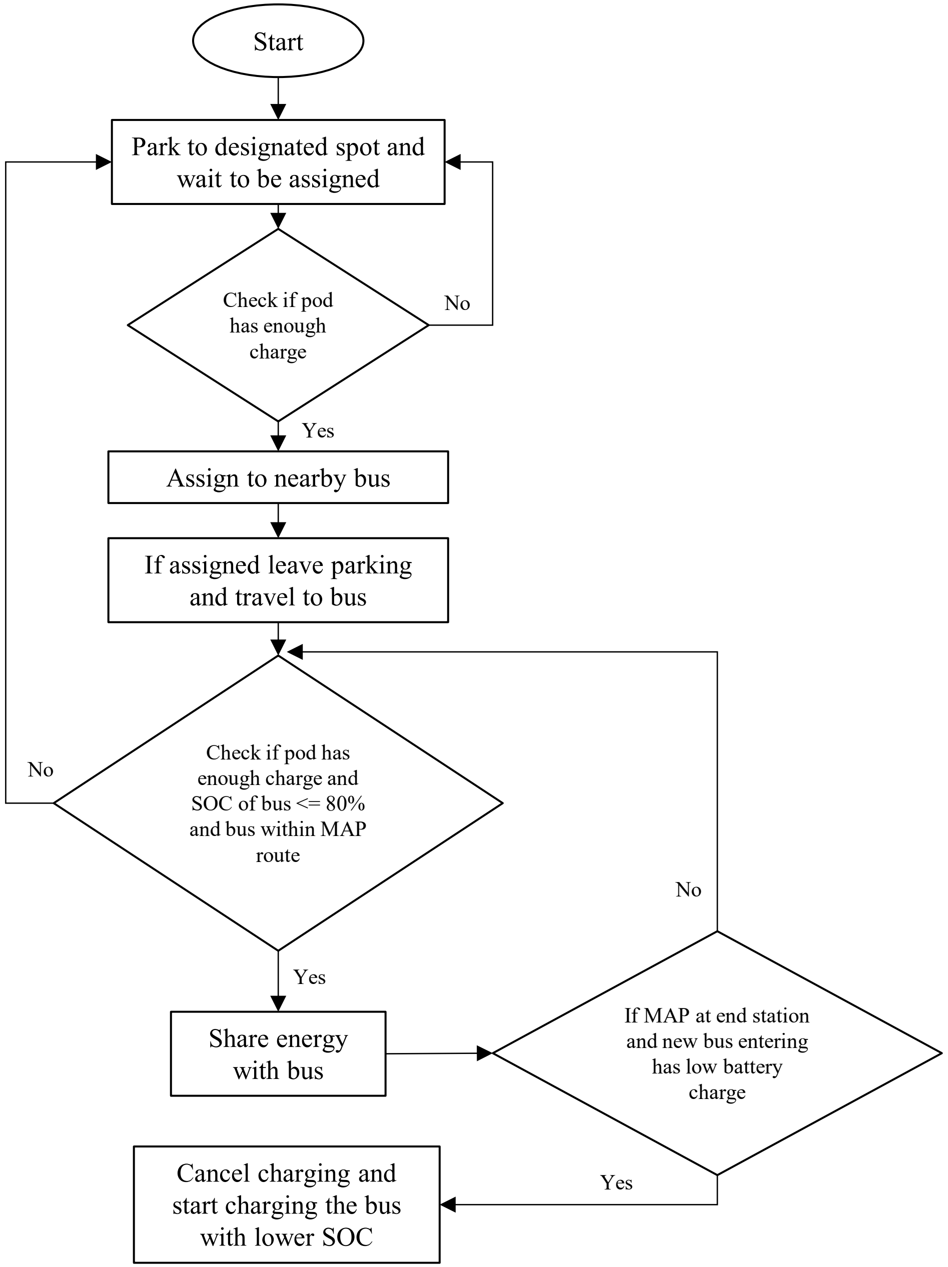


B) Depot Charging + End station charging

Bus Line	Required battery capacity (kWh)	Number of chargers (150 kW)	Energy Charged (MWh)	Total battery capacity per line (kWh)
Line 1	350	6	3.85	7350
Line 2	180	6	3.88	2700
Line 3	380	7	4.40	6080
Line 4	360	8	4.73	8280
Line 6	100	6	3.00	1000
Total	**1370**	**33**	**19.86**	**25410**

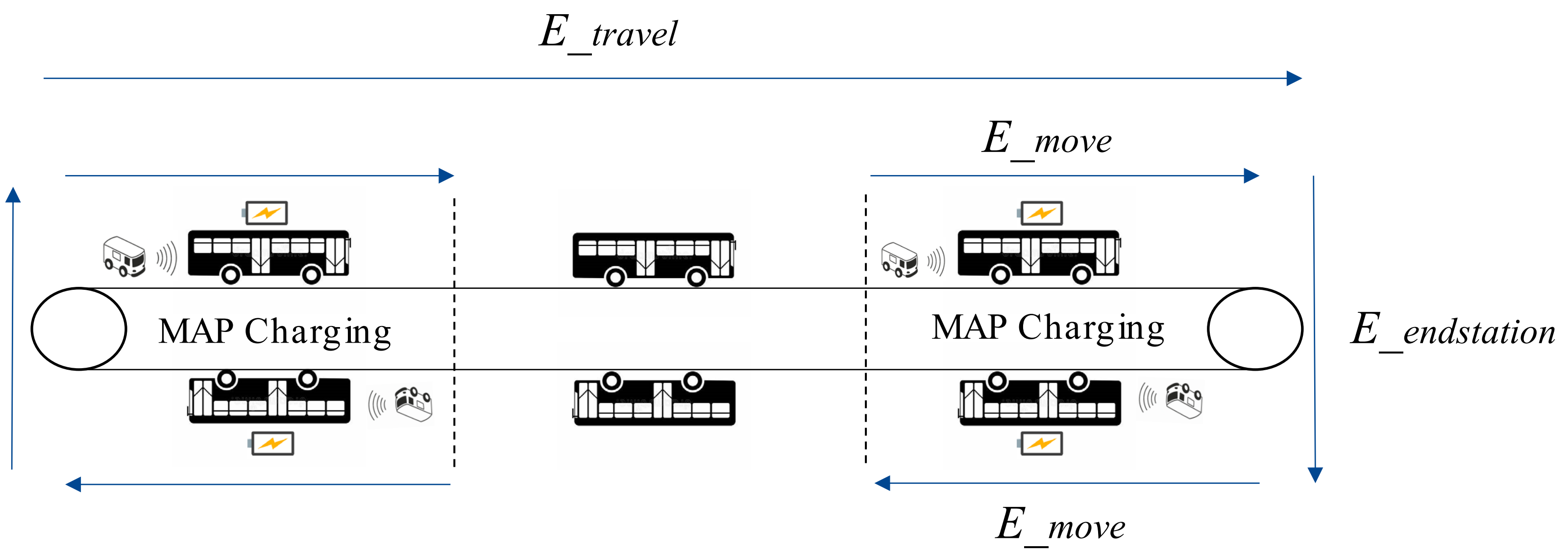
50% decrease in **battery capacity** compared to only **depot charging**

MAP charging algorithm



Depot Charging + MAP charging

- Based on previous studies [3], the efficiency of MAP is around **75% to 80%**.
- MAP are placed so to provide enough charge for the bus to complete the trip.



Distance for MAP placement

- MAP are placed so to provide enough charge for the bus to complete the trip.

$$E\_endstation + E\_move \geq E\_travel, \quad (1)$$

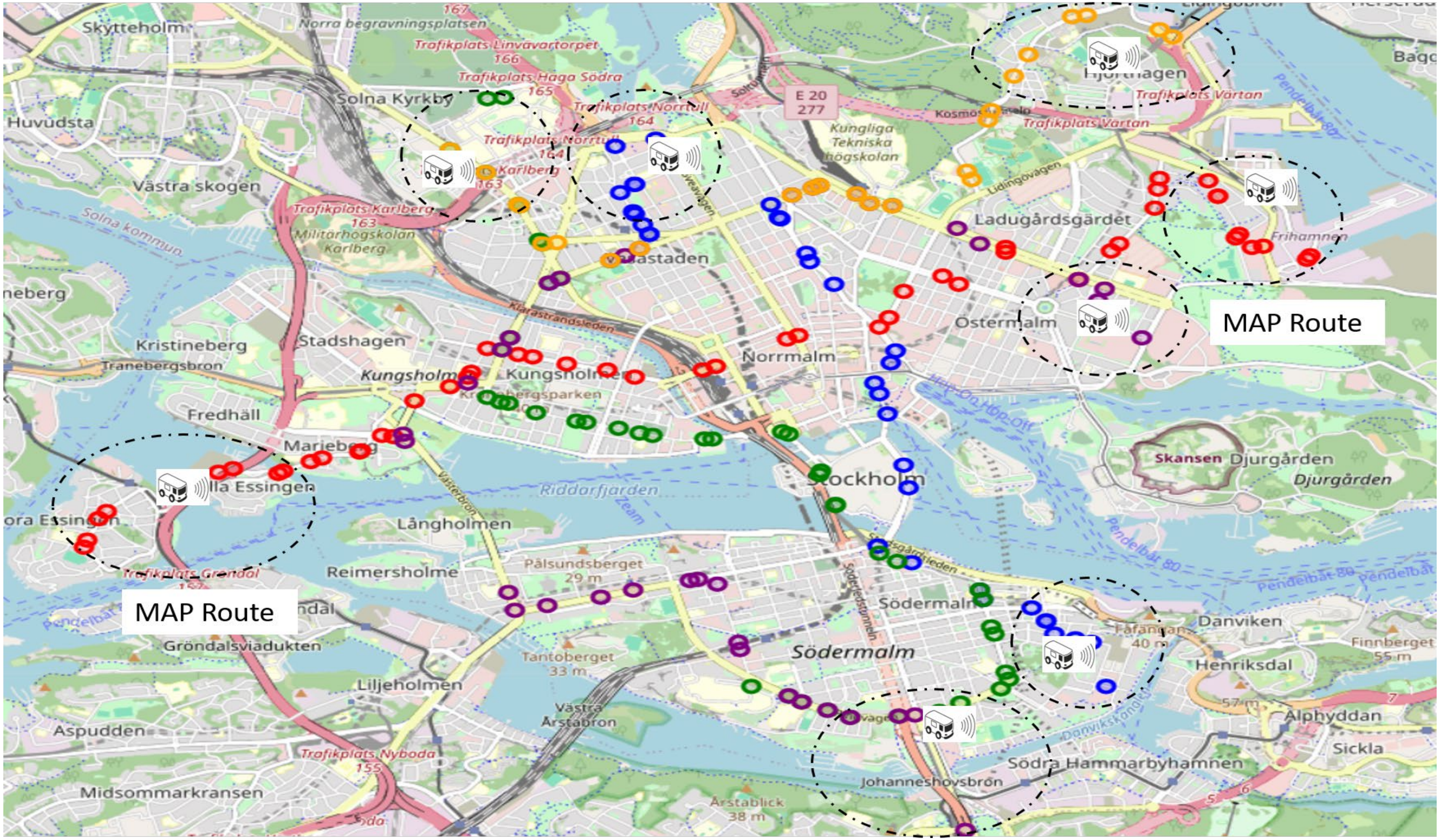
$$(c\_rate \times t\_turn) + 2\,(c\_rate \times tm) \geq E\_travel \quad (2)$$

$$tm \geq E\_travel/c\_rate - t\_turn/2 \quad (3)$$

$$dm \geq tm/sbus, \quad (4)$$

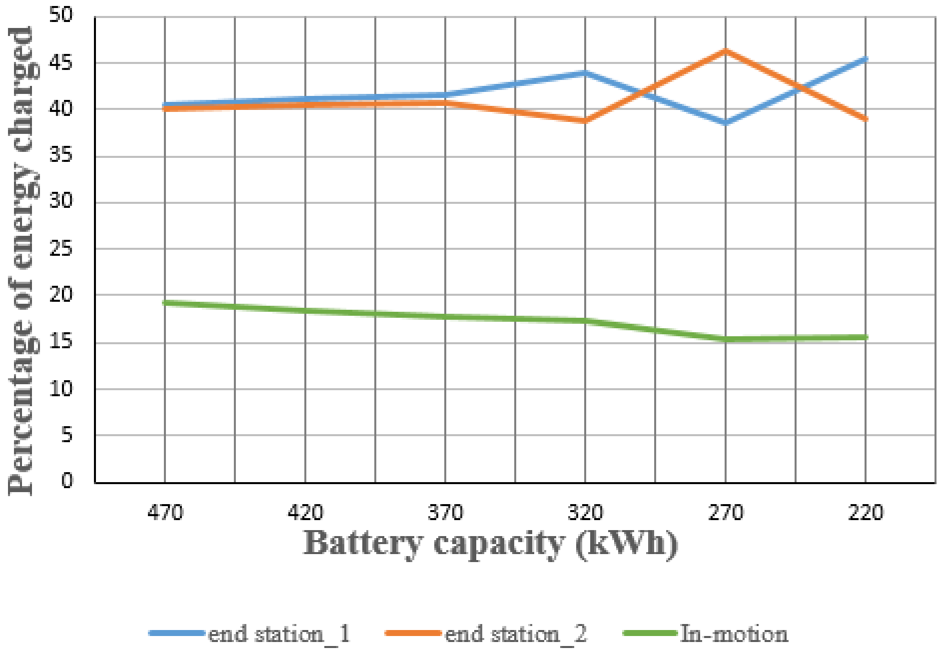
- Where, *c_rate* is the charging rate of MAPs
- *T_turn* is the minimum turnover time
- *dm* is the minimum distance that MAP needs to travel with bus
- *tm* is the minimum time that MAP needs to charge the bus
- *sbus* is the speed of the bus

Depot Charging + MAP charging



Depot Charging + MAP charging

Bus Line	Required battery capacity (kWh)	Total energy charged (kWh)	Total battery capacity per line (kWh)
Line 1	270	4.22	5670
Line 2	130	4.24	1950
Line 3	280	5.25	4480
Line 4	200	5.8	4600
Line 6	50	3.22	500
Total	**930**	**22.73**	**17200**

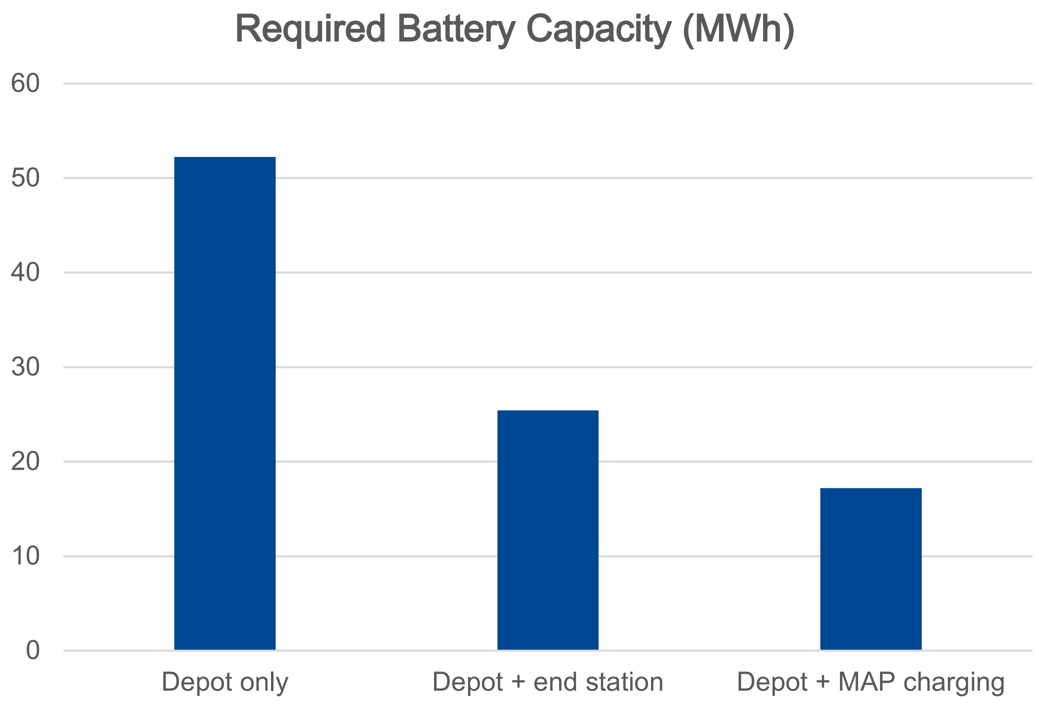


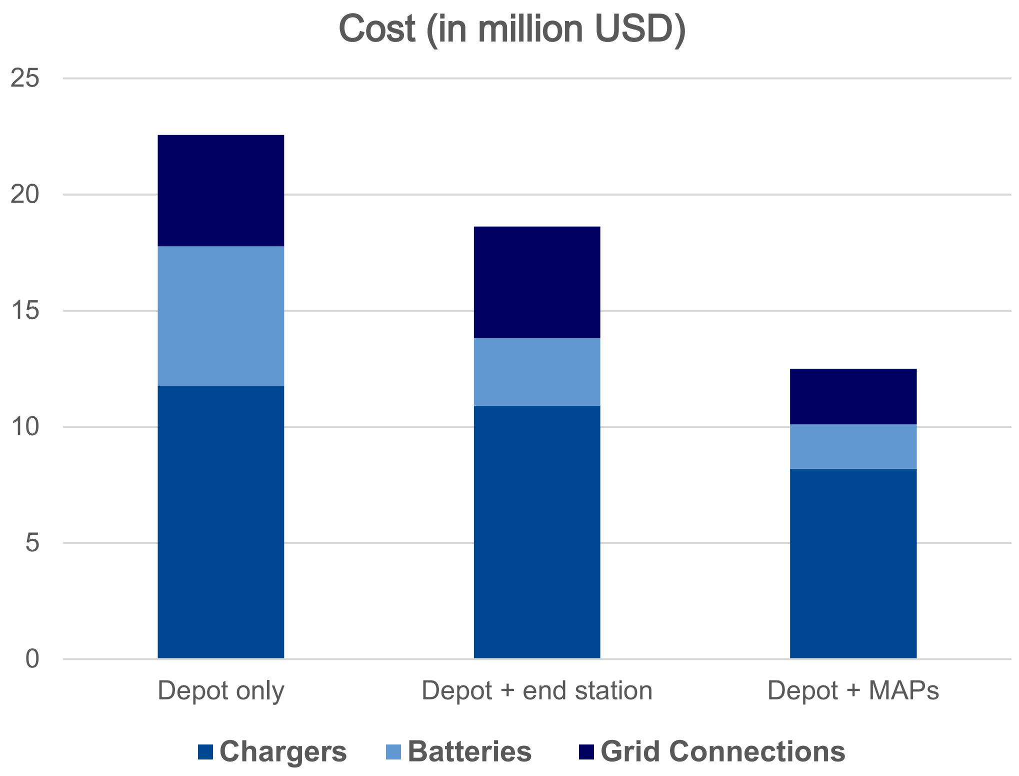
Total number of MAPs- **10 (2 MAP per line)**

67% decrease in **battery capacity** compared to **only depot charging**

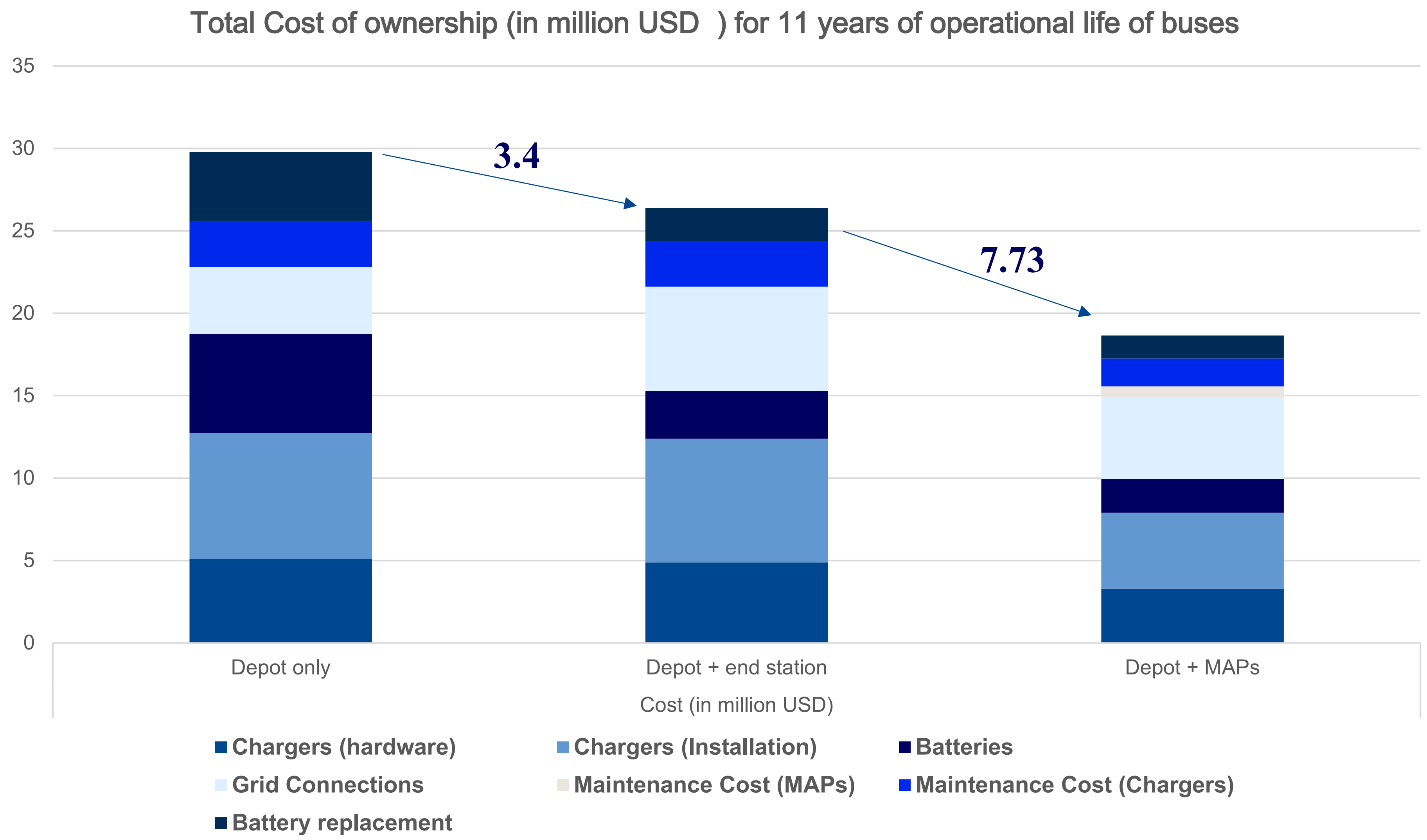
32% decrease in **battery capacity** compared to **depot + end station charging**

Infrastructure Cost Analysis





Total cost of ownership (TCO)



Limitations

- No **sensitivity** analysis.
- No changes in **bus schedules.**
- No **urban traffic** in simulation.
- No optimisation of **MAP deployment**.

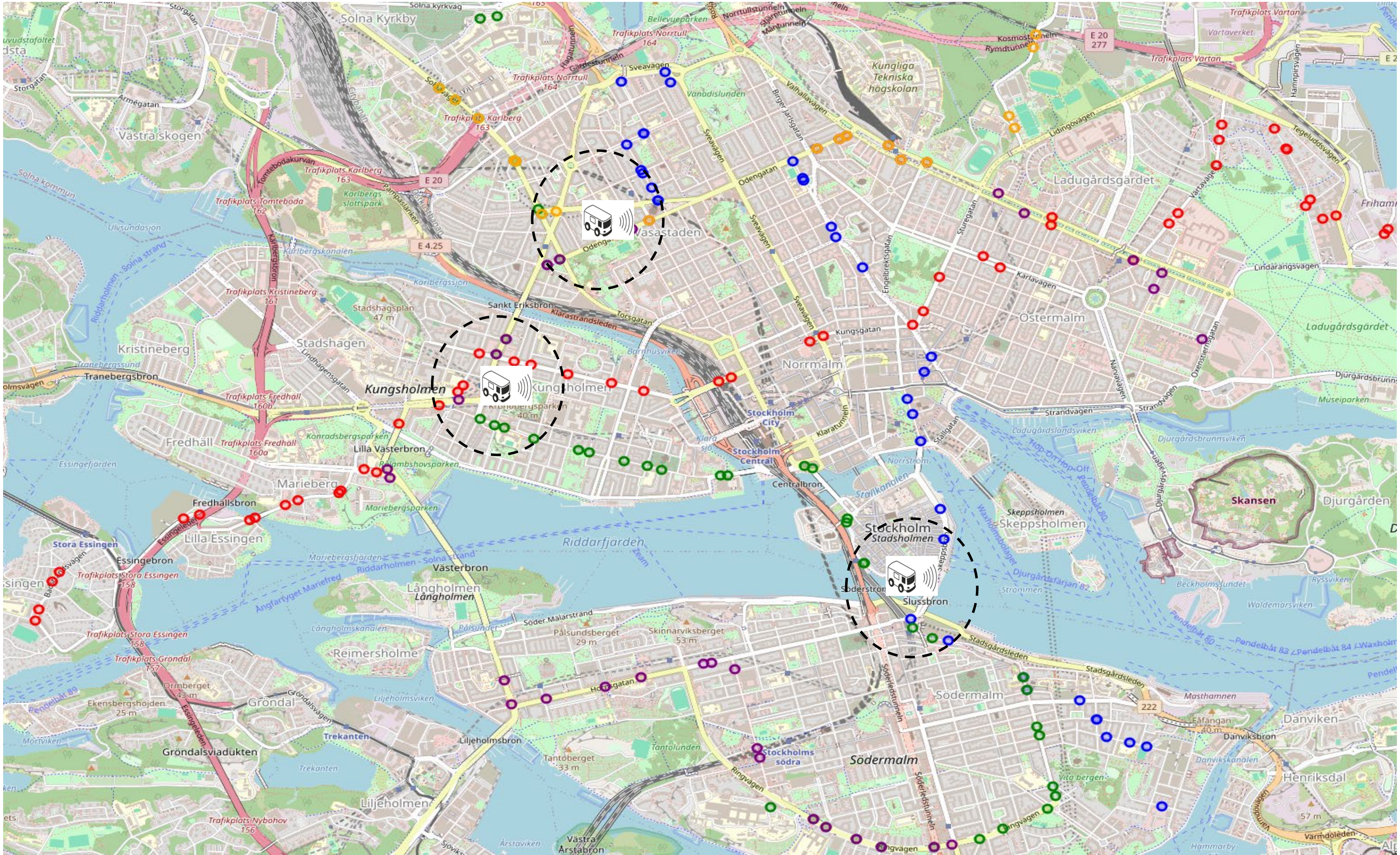
Results

- Deployment of MAPs can reduce **battery capacities by 67 %** and **infrastructure costs** by up to **10 million USD.**

- Improve **flexibility** and **reliability** of electric bus networks.

- When considering **TCO** for **11 years**, MAPs save about **11.13 million USD** compared to depot charging.

- Future works will consider the **optimal assignment** of MAPs to **lower infrastructure costs** and **improve efficiency**.



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Thank you for listening