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Optimizing the deployment of chargers for electric fleet considering heterogeneous chargers and electric vehicles

Presenter: Hao Hu

Supervisors: Dr. Bo Du and Professor Haiping Du

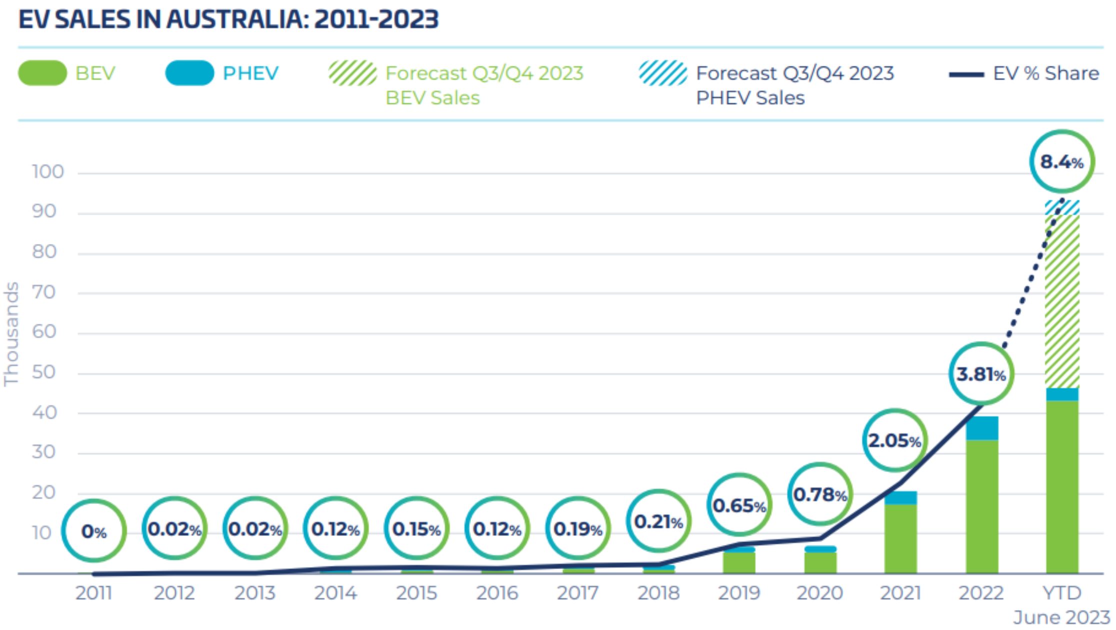
TRANSW

smart infrastructure facility

School of Civil, Mining and Environmental Engineering

UNIVERSITY OF WOLLONGONG AUSTRALIA

Background



The NSW Government will set a target to electrify its passenger vehicle fleet of 12,000 cars by 2030, which will significantly reduce CO_2 emissions.

1: https://www.nsw.gov.au/driving-boating-and-transport/nsw-governments-electric-vehicle-strategy
2: https://electricvehiclecouncil.com.au/wp-content/uploads/2023/07/State-of-EVs_July-2023_.pdf

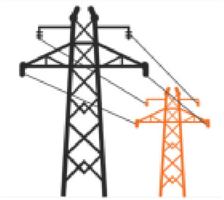
Background

Multi-type vehicles

Electric Vehicle Charging Levels and Range Chart	Power	Range added per hour	Charging time	Typical application
Level 1 single phase (domestic)	1.4-3.7kW	10-20km range/hour	5-16 hours	Home
Level 2 slow single phase (domestic or public)	7kW	30-45km range/hour	2-5 hours	Home, work, shopping centres, car parks
Level 2 fast three-phase (public)	11-22kW	50-130km range/hour	30 minutes-2 hours	Urban roadside
Level 3 Fast charge (public)	25-350kW	150-300km range/hour	10-60 mins	Highways, motorways and key routes

Multi-type chargers

Time-of-use electricity tariffs

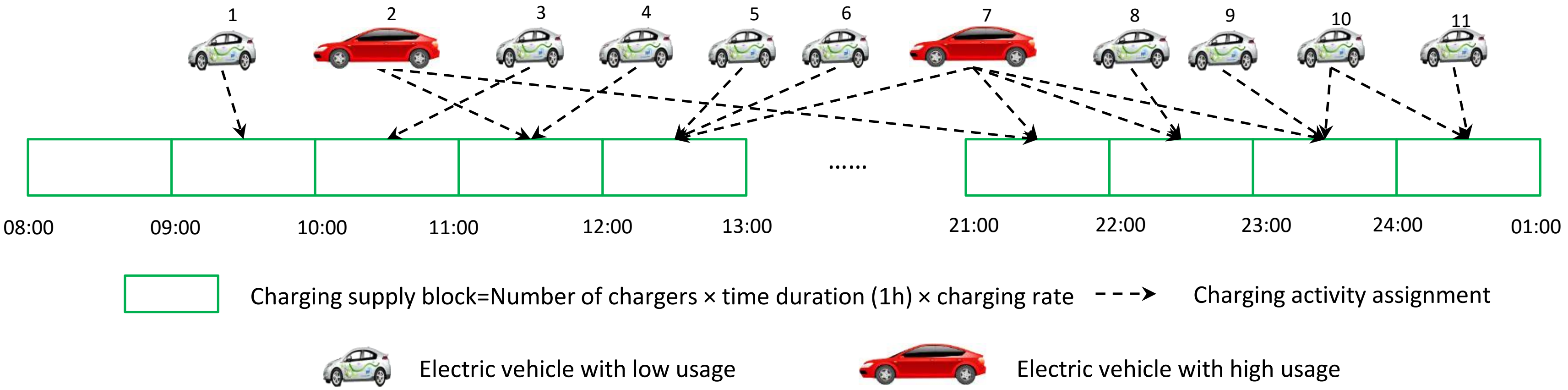


Limited power grid capacity

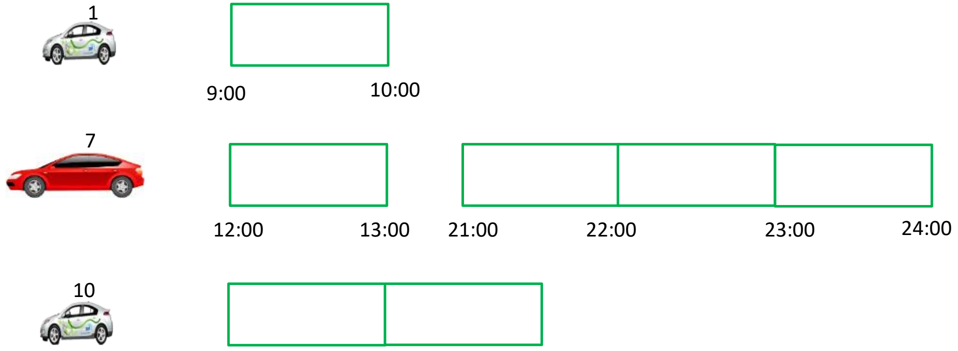
https://www.transport.nsw.gov.au/projects/electric-vehicles/charging-an-electric-vehicle

Problem description

Deployment of chargers and charging scheduling



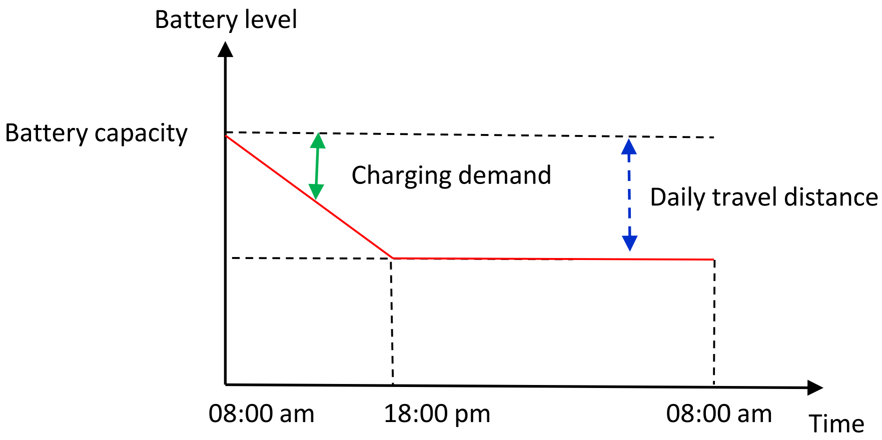
Example of charging activities



Problem description

Assumptions

- Only **a portion of electric vehicles** will return to sites for top-up charging (e.g., no driving activity in the afternoon) during daily operation
- Each electric vehicle can only return to sites **for top-up charging with limited times**, such as 1-2 times a day
- A **charging cycle** is defined based on a certain period (e.g., **one week or longer**) rather than one day
- The **energy consumption curve** during a day is **linear with time**



Battery level during 24hours

Mathematical model

Mixed-integer linear programming

Input

- **Vehicles related info**: vehicle type, historical driving distance, battery capacity, charger adaptability, etc.
- **Chargers related info**: acquisition cost, maintenance cost, installation cost, charging rate , etc.
- **Backbone site related information**: power grid, backbone upgrade cost and so on

Optimisation Model

Objective: minimise the total cost, including charger related cost (installation cost, purchasing cost and maintenance cost) + site backbone upgrade cost + charging cost

Constraints: satisfying charging demand

- Maximum power grid limitation
- State-of-charge (SOC) within certain battery levels
- Flexible charging (e.g., daytime top-up charging, overnight recharging)
- Time-varying electricity price at peak hours, non-peak hours and overnight
- Heterogeneous charging demand for different vehicle types at different time periods

Output

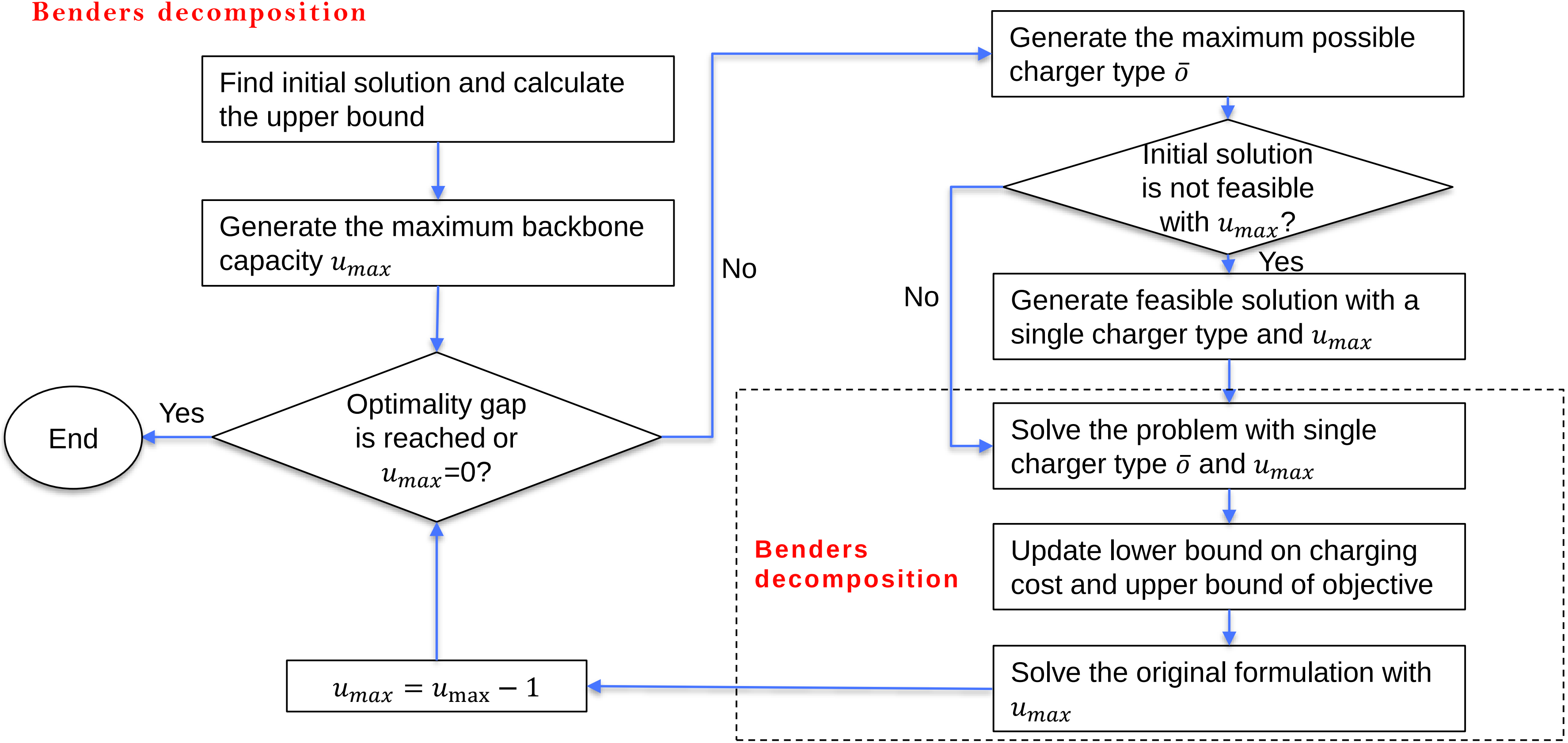
Number of chargers and types of chargers

Cost component, including charger related cost, backbone upgrade cost , and charging cost

Charging scheduling

Solution algorithm

Benders decomposition



Basic parameters

Vehicle types and corresponding specifications

Vehicle type	Model	Number of vehicles	Battery capacity (kWh)	Driving range (km)	On-board AC charger capacity (kW)	DC quick charger capacity (kW)
Passenger Light	Hyundai Kona	480	39.2	305	7.2	100
Passenger Small	Nissan Leaf	3602	39	270	6.6	100
Passenger Medium	MG MGZS	1344	50.3	320	22	150
Passenger Large	Hyundai Ioniq 5 EPIQ	259	77.4	454	10.5	100
SUV	Volvo XC40	2345	78	420	11	150
People mover	Ford E-transit 420 L	300	68	317	11.5	150

Charger price and services cost

Type of charger	Price	Annual maintenance per charger	Installation cost
3.8kW AC charger	$1,200	$150	$750
7.7kW AC charger	$1,700	$150	$900
22kw AC charger	$2,300	$150	$900
50kW DC charger	$35,000	$375	$4,500
100kW DC charger	$58,000	$450	$4,500
150kW DC charger	$68,000	$450	$4,500

Annual driving distance and corresponding number of vehicles

Annual distance (km)	Number of vehicles
<5000km	1453
5001-10000km	2951
10001-20000km	3152
20001-30000km	674
30001-40000km	11
40001-50000km	5
50001-60000km	68
60001-70000km	36
70001-80000km	5
80001-90000km	4
90001-100000km	5
>100000km	2
Total	8330

Provided by NSW treasury

Numerical experiments

Efficiency of proposed method

Comparison of computational time between the proposed method and Gurobi

Number of vehicles	Number of instances	Proposed method Min	Proposed method Mean	Proposed method Max	Gurobi Min	Gurobi Mean	Gurobi Max	Gap
(0, 10]	710	4.6	24.5	289.7	0.3	15.0	1436.7	38.66%
(10, 20]	97	86.1	242.9	961.5	23.0	260.4	1900.5	-7.23%
(20, 30]	40	240.0	440.0	1064.3	77.4	721.3	3626.8	-63.94%
(30, 40]	23	313.6	706.0	2208.9	92.7	1493.2	6349.5	-111.51%
(40, 50]	15	895.3	11891.1	18097.3	5539.1	16224.3	18008.1	-36.44%
(50, 60]	8	2109.9	14029.5	18093.6	14823.9	17610.5	18010.1	-25.52%
(60, 70]	4	1952.3	10117.8	18056.6	18009.3	18009.6	18010.1	-78.00%
(70, 80]	1	2317.4	2317.4	2317.4	18011.1	18011.1	18011.1	-677.21%
(80, 90]	1	3573.3	3573.3	3573.3	18011.7	18011.7	18011.7	-404.07%
(90, 100]	2	5630.8	5777.8	5924.8	18012.9	18013.1	18013.4	-211.77%
(100, 110]	2	4102.5	6580.3	9058.1	18014.5	18014.5	18014.5	-173.77%
(170, 180]	2	18083.7	18085.9	18088.2	18023.9	18024.1	18024.3	0.34%
(180, 190]	1	18078.7	18078.7	18078.7	18026.4	18026.4	18026.4	0.29%
>200	1	18035.0	18035.0	18035.0	18055.4	18055.4	18055.4	-0.11%

The proposed method outperformed commercial solver, Gurobi on both small and large-scale instances regarding the computational time

Numerical experiments

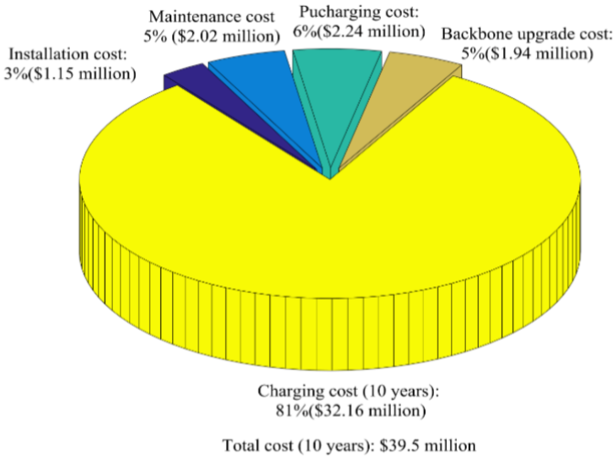
Efficiency of proposed method

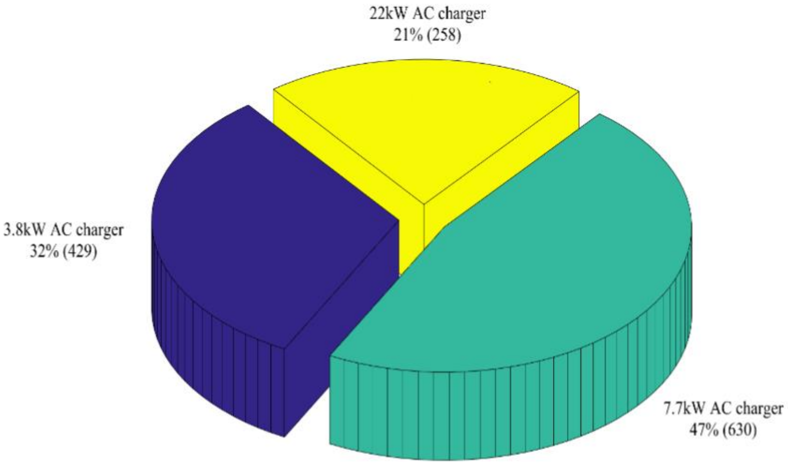
Number of vehicles	Proposed method Obj	Proposed method Bound	Proposed method Gap	Gurobi Obj	Gurobi Bound	Gurobi Gap	Gap
41	159859.9	158380.4	**0.93%**	160224.8	158273.1	1.22%	-0.23%
41	203331.1	196651.9	3.28%	203713.5	191852.6	5.82%	-0.19%
43	156548.8	155004.9	**0.99%**	156558.6	154992.5	1.00%	-0.01%
45	185468.8	180847.1	2.49%	188076	179792.8	4.40%	-1.39%
45	144784.5	143133.9	1.14%	144459.9	142444.9	1.39%	0.22%
46	177827.3	173485.7	2.44%	181664.3	171574.7	5.55%	-2.11%
48	181165.6	177084.7	2.25%	181217.4	176504.8	2.60%	-0.03%
48	188224.1	184275.2	2.10%	196216.8	173941	11.35%	-4.07%
49	196313.3	190449.6	2.99%	199047.9	189243.9	4.93%	-1.37%
49	215716.2	211494.6	1.96%	215123.8	193080.3	10.25%	0.28%
49	161307	159781.7	**0.95%**	163039.9	159212.1	2.35%	-1.06%
50	212309.9	207386.1	2.32%	216821.7	193915.5	10.56%	-2.08%
53	203140.7	197953	2.55%	206854.7	184294.7	10.91%	-1.80%
54	201614.8	195012.8	3.27%	208953.9	186039.9	10.97%	-3.51%
56	209249.9	205340.4	1.87%	208902.7	186672.7	10.64%	0.17%
56	199670.8	193506.4	3.09%	206038.8	182725.6	11.31%	-3.09%
58	174157.6	167860.3	3.62%	202238.6	164358.1	18.73%	-13.89%
59	233683.9	231415.8	**0.97%**	233395.3	211196.8	9.51%	0.12%
59	120470.9	119278.8	**0.99%**	120682.1	119206	1.22%	-0.17%
66	203511.7	197459.4	2.97%	211672.9	187781.9	11.29%	-3.86%
67	254335.9	251812.1	**0.99%**	253598.3	240772	5.06%	0.29%
68	257745.1	255209.8	**0.98%**	257463.9	236490.2	8.15%	0.11%
68	217379	211733.9	2.60%	217140.6	194538.9	10.41%	0.11%
80	253092.8	250572.9	**1.00%**	252675.5	231926.5	8.21%	0.17%
84	250356.1	247862.2	**1.00%**	250078.2	229217.3	8.34%	0.11%
92	259301.4	256692	1.01%	258915.2	239165.9	7.63%	0.15%
95	276610.3	274390.7	**0.80%**	276155.3	266219.1	3.60%	0.16%
105	296623.9	293703.8	**0.98%**	296649.7	291899.4	1.60%	-0.01%
107	271269.1	268564.5	**1.00%**	271622.6	266510.3	1.88%	-0.13%
173	427059.2	392020	8.20%	581916.5	398979.8	31.44%	-26.61%
176	357319.2	320845.6	10.21%	510773.7	328004.4	35.78%	-30.04%
192	429475.5	391848.3	8.76%	541239.8	393016.8	27.39%	-20.65%
392	752593.8	613325	18.51%	857727.2	604278.4	29.55%	-12.26%
Average			3.01%			9.85%	-3.84%

The proposed method outperformed commercial solver, Gurobi on both small and large-scale instances regarding the quality of solution

Numerical experiments

Cost breakdown and Components of installed chargers



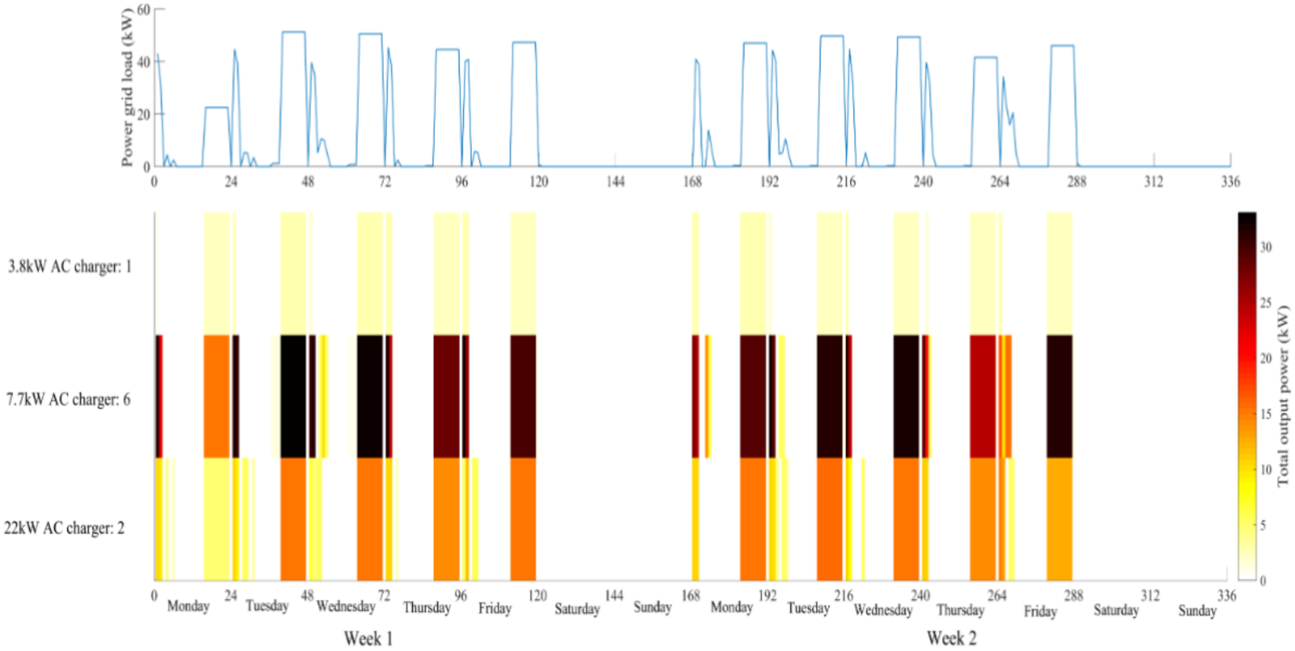


Cost breakdown **Components of installed chargers**

Charging cost is the majority, accounting for more than 81%.
The main chargers are 7.7kW AC charger and no fast DC charger is needed.

Numerical experiments

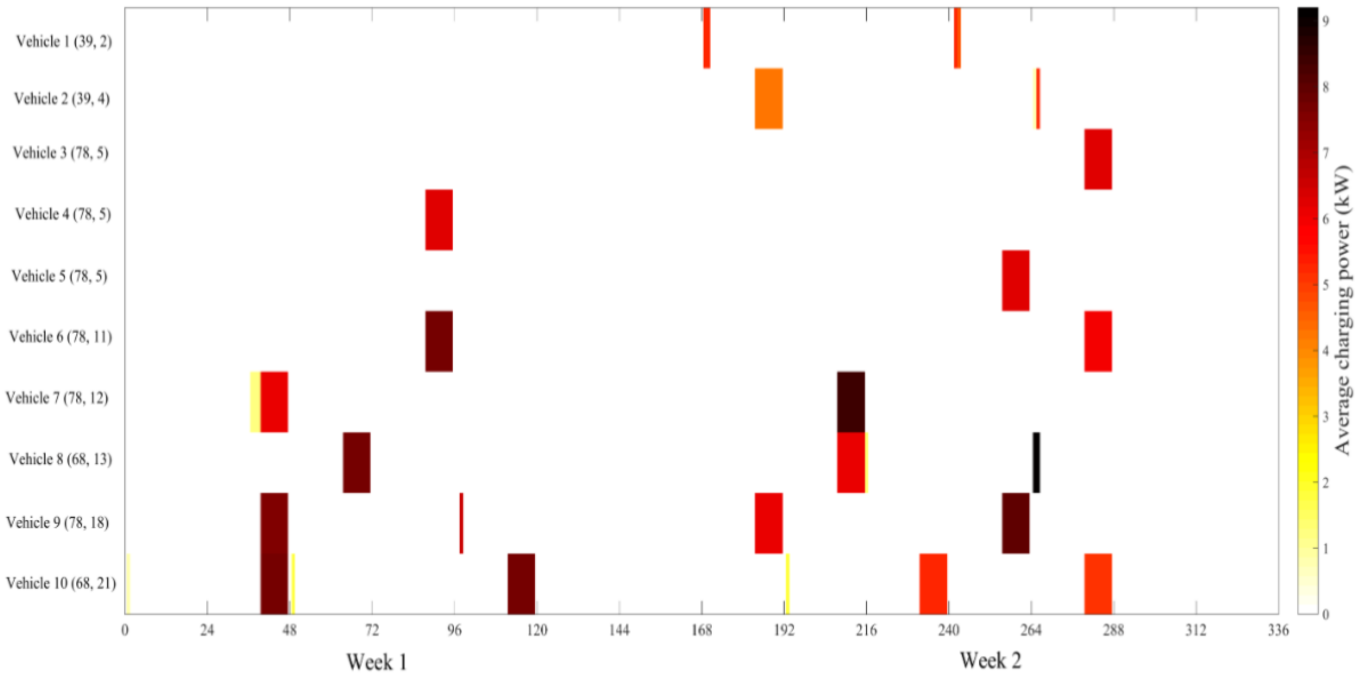
An example of the output power of chargers and power grid load at a site



Three types of chargers are in high usage during the morning and overnight periods. No charging activity occurs between peak hours (from 14 pm to 20pm) each day due to peak-hours electricity prices

Numerical experiments

An example of charging activities



When the daily energy consumption ranges from 4 to 21kWh, both the frequency of overnight charging and the charging power during overnight increases gradually.

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Conclusion and future work

- The joint optimisation problem of deployment of chargers and charging scheduling at a backbone site was investigated
- Multiple practical considerations was considered, such as time-varying electricity, power grid limitation and electric vehicles' adaptability to different chargers
- The proposed method outperformed the Gurobi in both finding better solutions and saving computational time.
- Stochastic energy consumption and charging demand of electric vehicles should be taken into account

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Thank you !

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