Charging ahead

Firm-level optimisation strategies for sustainable and cost-effective electric vehicle workplace charging

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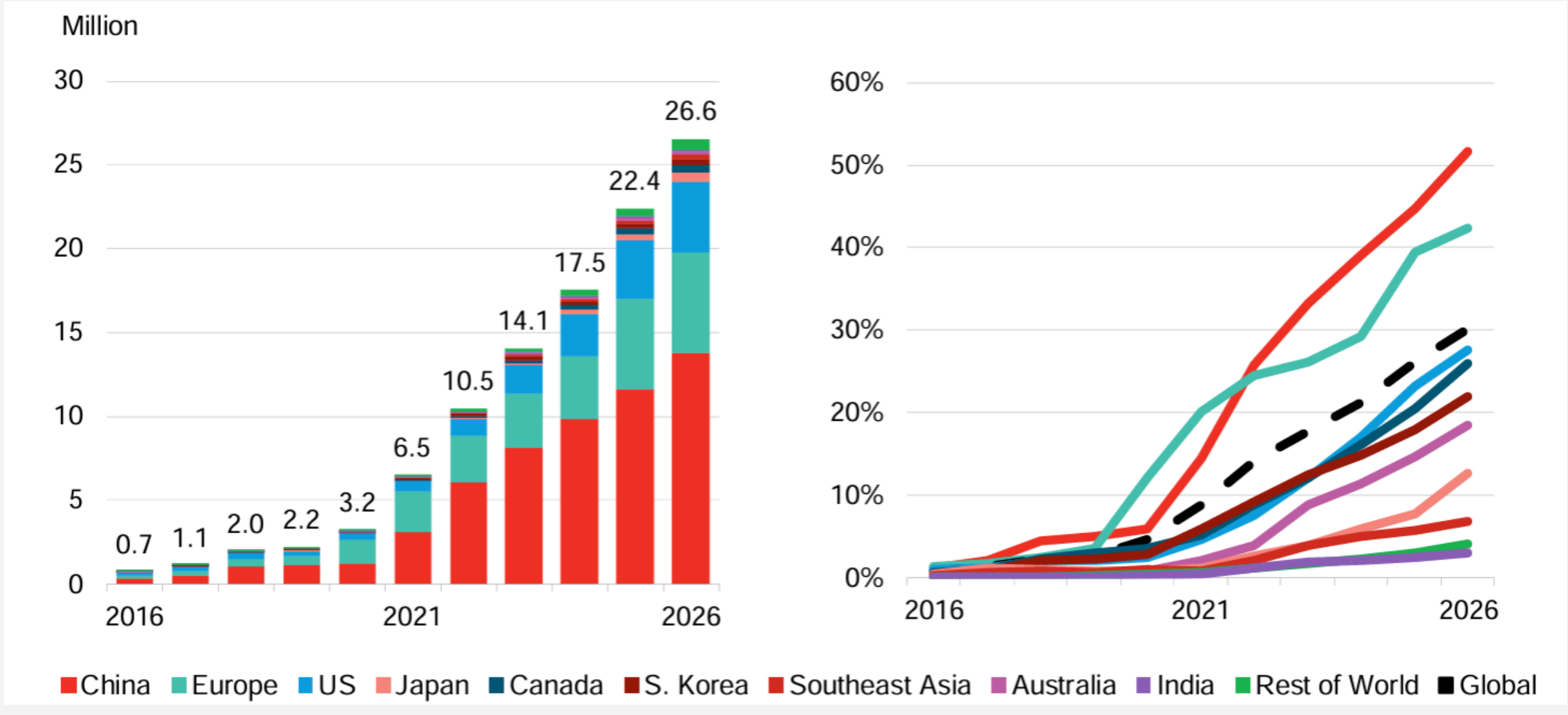
1 | Background & Motivation

Problem context: Decarbonising transport



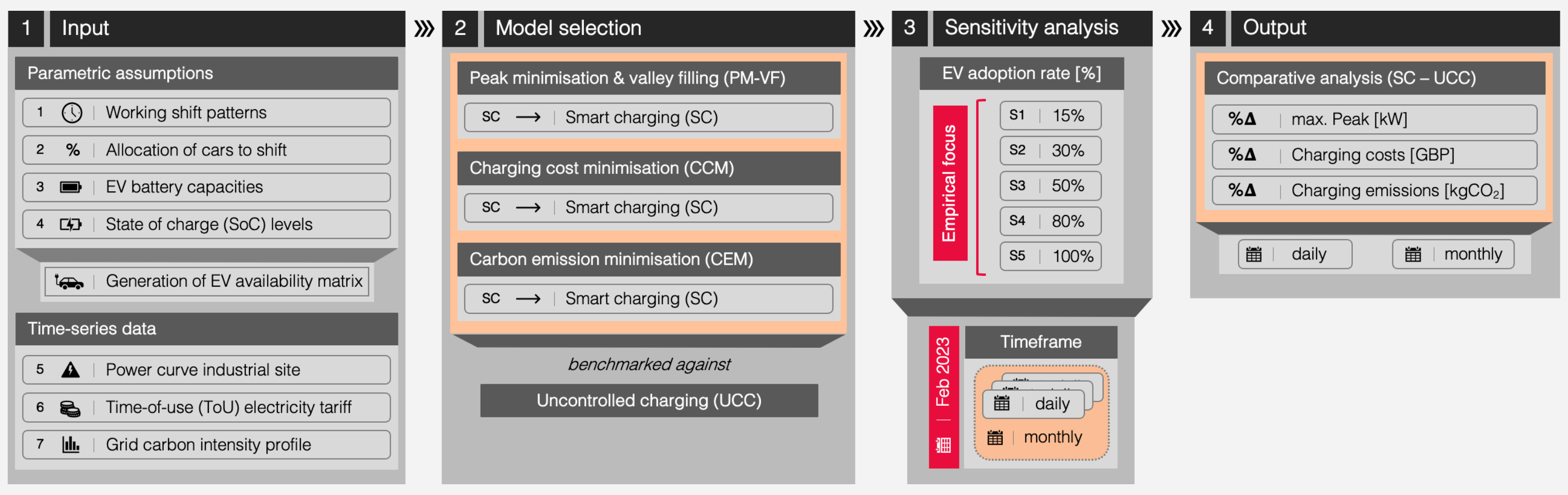
Global near-term EV sales (l.) and share of new passenger vehicle sales by market (r.) [1].

- **88%** of GHG emissions are covered by net-zero legislation as of 2023 [2].
- Mitigation efforts in transport sector feature strong focus on **road vehicle electrification**.
- **65%** of commitments in nations' revised nationally determined contributions (NDCs) as of the Glasgow Climate Pact (2021) are focused on **electrification & fuel-switching** [3].
- Helping deliver these commitments requires widespread **charging infrastructure** at **workplaces** and public places to bring 'convenience parity' between EVs and internal combustion vehicles (ICVs) [4].

2 | Model Structure

Approach: Outlining four-step structure

Topic | Leveraging **digital technologies** to unlock **demand-side flexibility (DSF)** of electric vehicles (EVs)



1 Input

Parametric assumptions
1 Working shift patterns
2 % Allocation of cars to shift
3 EV battery capacities
4 State of charge (SoC) levels
Generation of EV availability matrix

Time-series data
5 Power curve industrial site
6 Time-of-use (ToU) electricity tariff
7 Grid carbon intensity profile

2 Model selection

Peak minimisation & valley filling (PM-VF)
SC ⟶ Smart charging (SC)
Charging cost minimisation (CCM)
SC ⟶ Smart charging (SC)
Carbon emission minimisation (CEM)
SC ⟶ Smart charging (SC)
benchmarked against
Uncontrolled charging (UCC)

3 Sensitivity analysis

EV adoption rate [%]
Empirical focus
S1 15%
S2 30%
S3 50%
S4 80%
S5 100%
Feb 2023
Timeframe
daily
monthly

4 Output

Comparative analysis (SC – UCC)
%Δ max. Peak [kW]
%Δ Charging costs [GBP]
%Δ Charging emissions [kgCO$_2$]
daily
monthly

RQ | What are the benefits of **coordinated EV workplace charging** for firms?

3 | Methodology

Methods: Drawing from operations research (OR) [5, 6]

Peak min. & valley filling (PM-VF):

$$min \;\; z_{PM-VF} = \sum_{t \in T} (P_t + y_t - C)^2$$

Charging cost min. (CCM):

$$min \;\; z_{CCM} = \sum_{t \in T} y_t * \lambda_t$$

Carbon emission min. (CEM):

$$min \;\; z_{CEM} = \sum_{t \in T} y_t * \gamma_t$$

[1] $s.t. \quad y_t = \sum_{m \in M} x_{mt} f_{mt} \qquad \forall\, t \in T$ Total charging load

[2] $-p_{max} \leq x_{mt} \leq p_{max} \qquad \forall\, t \in T;\ m \in M$ Charging power restrictions

[3] $0 \leq E_m^{ini} + \sum_{k \in T \mid k \leq t} x_{mt} f_{mt} \leq E_m^{cap} \qquad \forall\, t \in T;\ m \in M$ Battery capacity restrictions

[4] $E_m^{fin} = E_m^{ini} + \sum_{k \in T \mid k \leq t} x_{mt} f_{mt} \geq E_{T+1} \qquad \forall\, t \in T;\ m \in M$ Minimum state-of-charge (SoC) requirement

[5] $0 = x_{mt}(1 - f_{mt}) \qquad \forall\, t \in T;\ m \in M$ Logical operator ensuring car availability

$$C = \frac{max(P_t) + min(P_t)}{2}$$

Constant *C*

$$f_{mt} = \begin{cases} 1, if\ EV\ m \in M\ is\ parked\ at\ workplace\ at\ time\ t \in T, \\ 0, \qquad otherwise \end{cases}$$

Definition of car availability matrix

Modelling assumptions

- Relative allocation of cars

AM	PM	OFFICE	#CARS
63%	27%	10%	1,100

- EV battery capacity

kWh	kWh	kWh
48	71	100

uniformly distributed

- State of Charge (SoC) levels

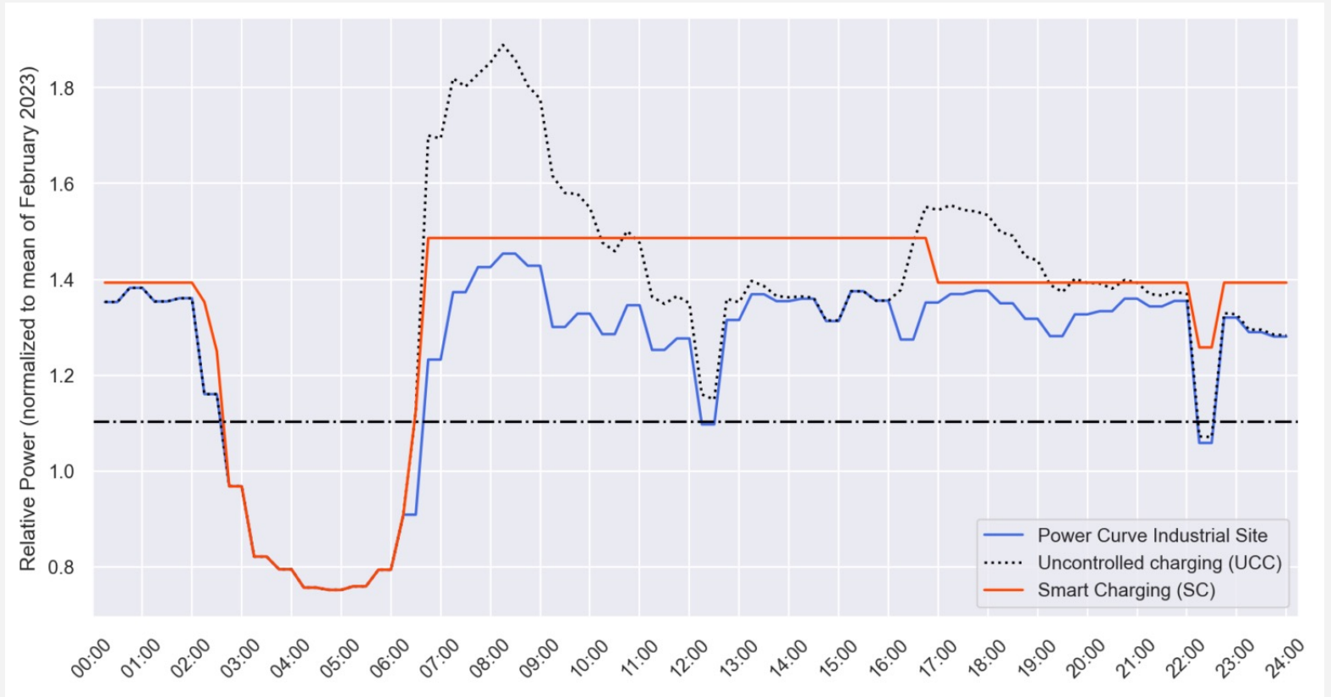
	LB	UB
E_{ini}	10%	80%
E_{fin}	80%	100%

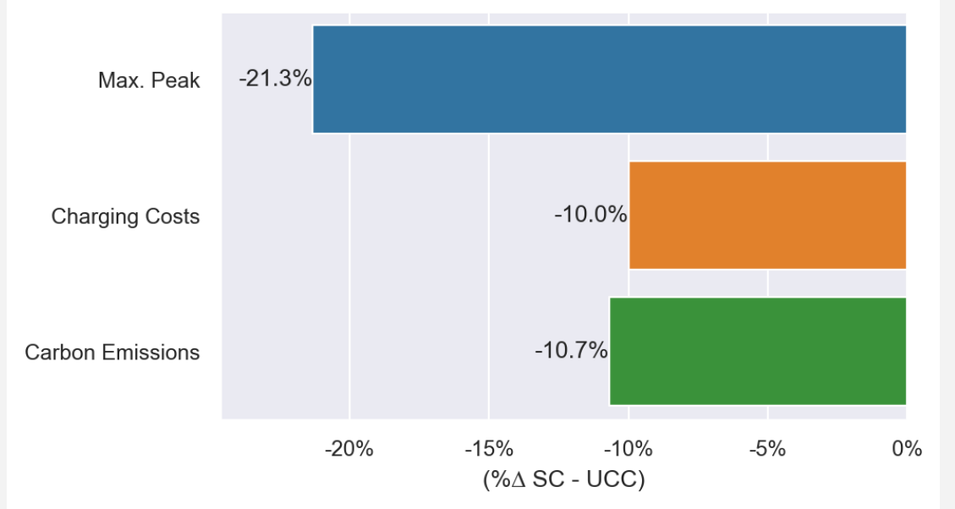
[1] BloombergNEF (2023). Electric Vehicle Outlook 2023.
[2] UN Environment Programme (2023). Emissions Gap Report.
[3] SLOCAT (2021). Climate Strategies for Transport. An analysis of NDCs and Long-Term Strategies.

4 | Results

Analysis: Sensitivity analyses (exemplarily for EV adoption rate = **50%)**

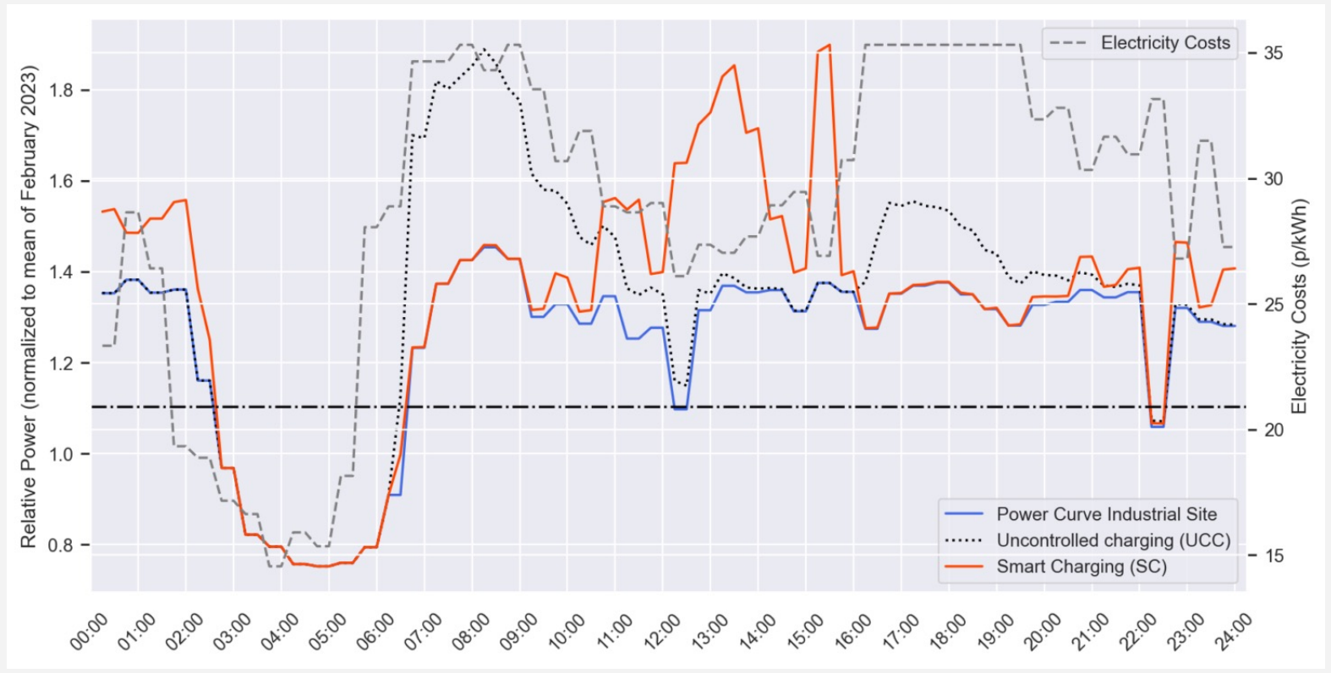
Peak minimisation & valley filling (PM-VF):

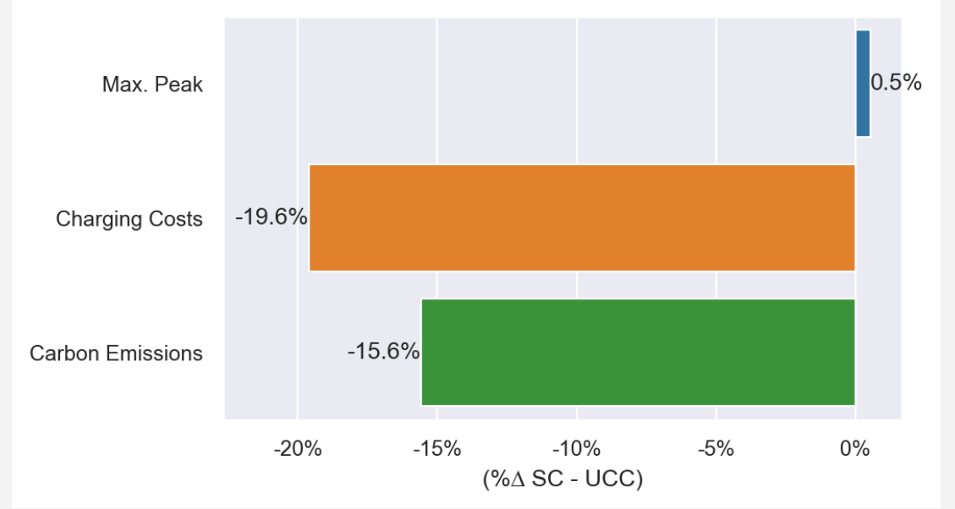




Relative performance of **PM-VF**
(change in output (SC - UCC [**%**Δ])*

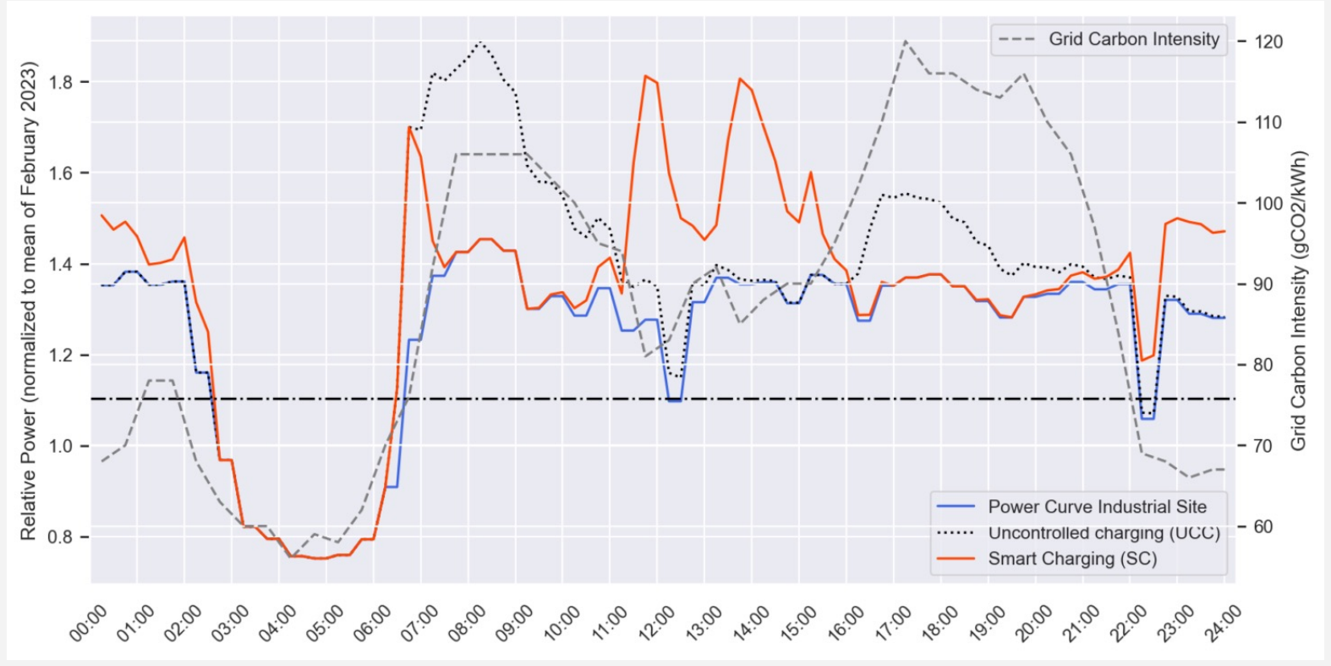
Charging cost minimisation (CCM):

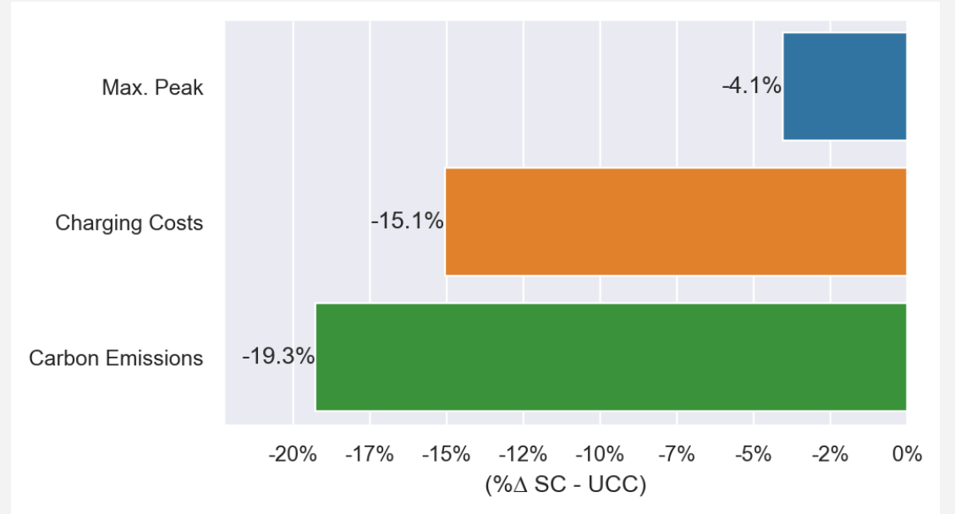




Relative performance of **CCM**
(change in output (SC - UCC [**%**Δ])*

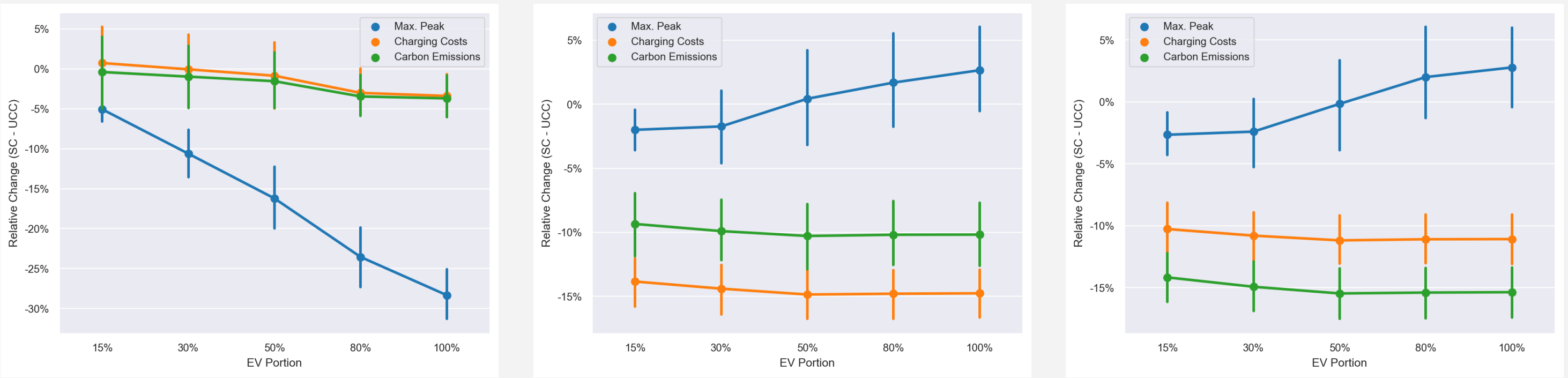
Carbon emission minimisation (CEM):





Relative performance of **CEM**
(change in output (SC - UCC [**%**Δ])*

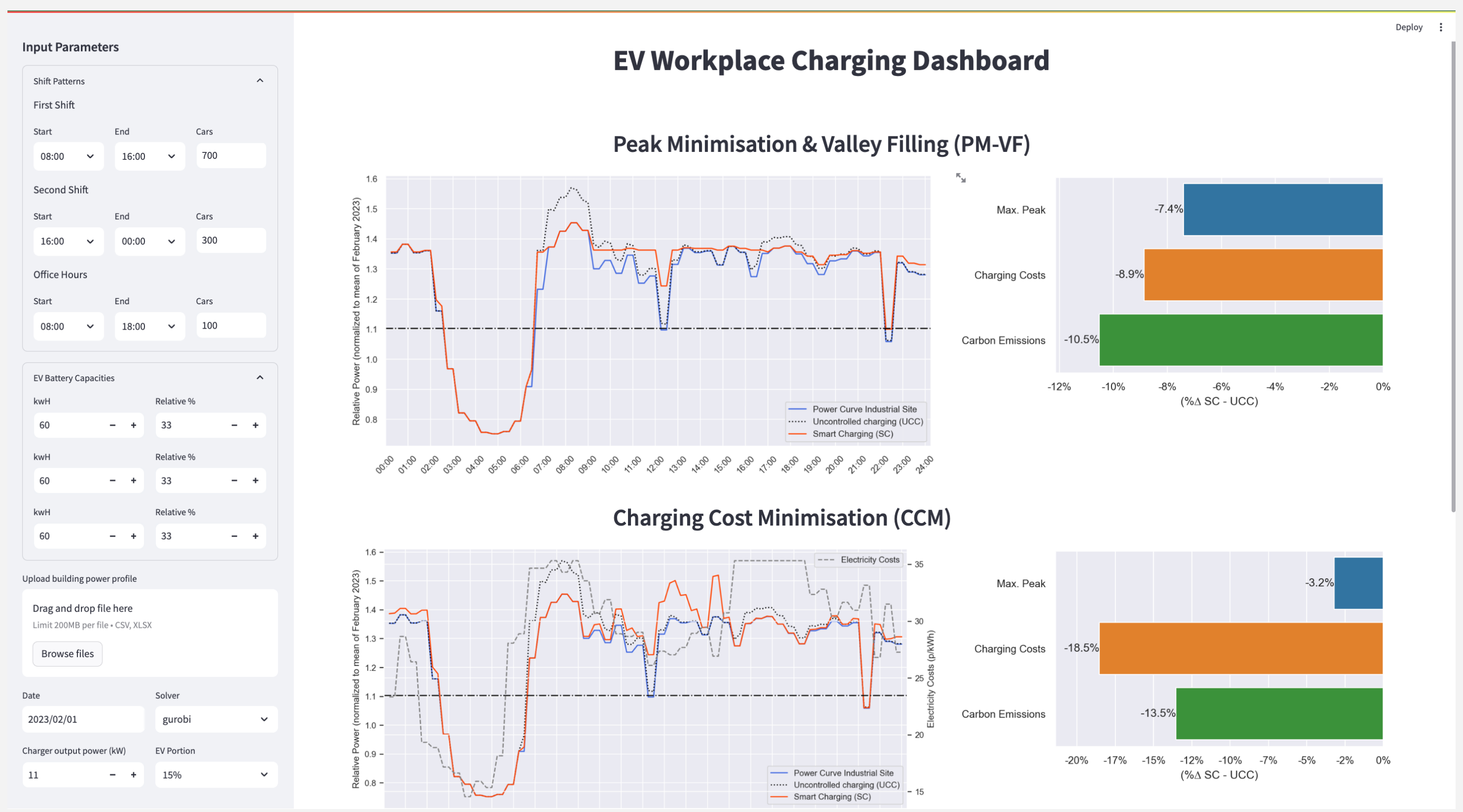
* smart charging (SC) / uncontrolled charging (UCC)



Visual summary of key metrics max. peak, charging costs and carbon emissions differentiated by model type | EV rates [S1-5: 15–100%]. Quantitative assessment of output changes [in **%**Δ], measured against UCC, for **PM-VF** (l.), **CCM** (m.), and **CEM** (r.), exemplarily for 01 February, 2023.

5 | Web Application

Development of interactive open-source tool



Input Parameters

Shift Patterns
First Shift
Start 08:00 | End 16:00 | Cars 700
Second Shift
Start 16:00 | End 00:00 | Cars 300
Office Hours
Start 08:00 | End 18:00 | Cars 100

EV Battery Capacities
kwH 60 | Relative % 33
kwH 60 | Relative % 33
kwH 60 | Relative % 33

Upload building power profile
Drag and drop file here
Limit 200MB per file • CSV, XLSX

Date 2023/02/01 | Solver gurobi
Charger output power (kW) 11 | EV Portion 15%

EV Workplace Charging Dashboard

Peak Minimisation & Valley Filling (PM-VF)
Max. Peak -7.4%
Charging Costs -8.9%
Carbon Emissions -10.5%

Charging Cost Minimisation (CCM)
Max. Peak -3.2%
Charging Costs -18.5%
Carbon Emissions -13.5%

Data pipeline	python
Model formulation	PYOMO
Optimisation	GUROBI OPTIMIZATION
Visualisation	Streamlit

GitHub
anticipated release **Q4/2024**
github.com/segermarcel

try it **yourself**

[4] Dixon et al. (2020). On the ease of being green. Applied Energy **258**.
[5] Ioakimidis et al. (2018). Peak shaving and valley filling. Energy **148**.
[6] Zheng et al. (2019). Integrating plug-in EVs into power grids. Renewable and Sustainable Energy Reviews **112.**

To cite

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Case study involving

OXFORD SDG IMPACT LAB · BMW · MINI · ROLLS-ROYCE MOTOR CARS LTD

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