

For your convenience, the impact of EV penetration level π^{ev} on the performance of the proposed uniform carbon pricing scheme is analyzed as the supplementary file provided online. Specifically, the analysis is conducted on *Test System 2*. Before delving into the analysis, the EV penetration level is introduced first. The constraint (3) of **Cons-Flow** should be modified as given below

$$\begin{aligned} \sum_{ke \in K_e^{rs}} f_{ke}^{rs} &= Q_e^{rs}, f_{ke}^{rs} \geq 0, \sum_{kg \in K_g^{rs}} f_{kg}^{rs} = Q_g^{rs}, f_{kg}^{rs} \geq 0, \forall rs \in \Gamma & (3) \\ \Downarrow \\ \sum_{ke \in K_e^{rs}} f_{ke}^{rs} &= \pi^{\text{ev}} Q^{rs}, f_{ke}^{rs} \geq 0, \sum_{kg \in K_g^{rs}} f_{kg}^{rs} = (1 - \pi^{\text{ev}}) Q^{rs}, f_{kg}^{rs} \geq 0, \forall rs \in \Gamma & (3\text{mod}1) \\ Q^{rs} &= Q_e^{rs} + Q_g^{rs}, \forall rs \in \Gamma & (3\text{mod}2) \end{aligned}$$

The results for three different EV penetration levels ($\pi^{\text{ev}} = 0.1, 0.3$ and 0.5), both without and with the carbon price (i.e., the proposed uniform carbon pricing scheme), are presented in Table I. It is evident that the adoption of the carbon price leads to a significant reduction in emissions with a slight increase in consumption. Specifically, when there is a higher proportion (expressed with a lower π^{ev}) of gasoline vehicles (GVs), the effectiveness of the proposed method in reducing carbon emissions in the transportation network (TN) becomes more pronounced. Conversely, with a higher proportion of electric vehicles (EVs), the proposed method demonstrates a more intuitive reduction in carbon emissions in the power distribution network (PDN). Since GV engage in scheduling by directly applying carbon emission fees through a carbon emission model, while EVs participate through the energy-carbon integrated price (ECIP), our focus will be on the charging price (i.e., the ECIP) of EVs. The charging price for each fast-charging station (FCS) at different EV penetration levels is illustrated in Fig. 1.

TABLE I
Carbon emissions and costs w.o. & w. the carbon price of test system 2 at different EV penetration levels

		W.o carbon price		W. carbon price		Gap	
		Emission (t)	Cost (\$)	Emission (t)	Cost (\$)	Emission (t)	Cost
$\pi^{\text{ev}} = 0.1$	TN	22.73	50992.35	17.559	52300.38	-5.171	2.57%
	PDN	43.73	5497.74	41.298	5536.79	-2.432	0.71%
	Total	66.46	56490.09	58.857	57837.17	-7.603	2.38%
$\pi^{\text{ev}} = 0.3$	TN	13.653	59067.89	10.366	60574.55	-3.287	2.55%
	PDN	68.95	10915.05	65.923	10993.82	-3.027	0.72%
	Total	83.603	69982.94	76.289	71718.37	-6.314	2.26%
$\pi^{\text{ev}} = 0.5$	TN	7.386	71162.04	5.08	72841.3	-2.306	2.3%
	PDN	105.964	16306.59	99.79	16427.96	-6.174	0.074%
	Total	113.35	87468.63	104.87	89269.26	-8.48	2.06%

It is evident that, in the absence of the carbon price, the charging price at each FCS is lower compared to that considering the carbon price. With the inclusion of the carbon price, each FCS exhibits an elevated charging price. Generally, a greater increase in the charging price of FCS corresponds to a higher node carbon intensity (NCI). The EV penetration level has an impact on the charging price, meaning that as the penetration level rises, the charging price increases. This is

attributed to the higher penetration level of EVs, which results in increased energy consumption. The elevated energy consumption implies a greater amount of power injection, leading to an inevitable rise in line losses and carbon emissions caused by power losses. Consequently, this contributes to an increase in power grid costs, which are then distributed among end-users, including EV users.

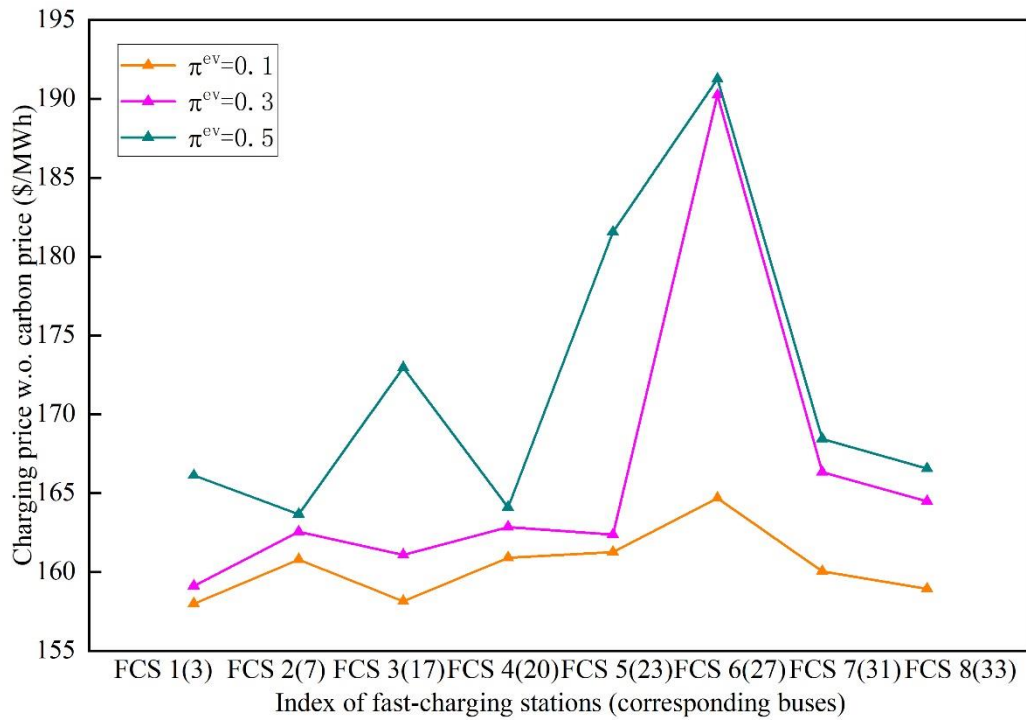


Fig. 1a. Charging price of each FCS w.o. the carbon price at different EV penetration levels.

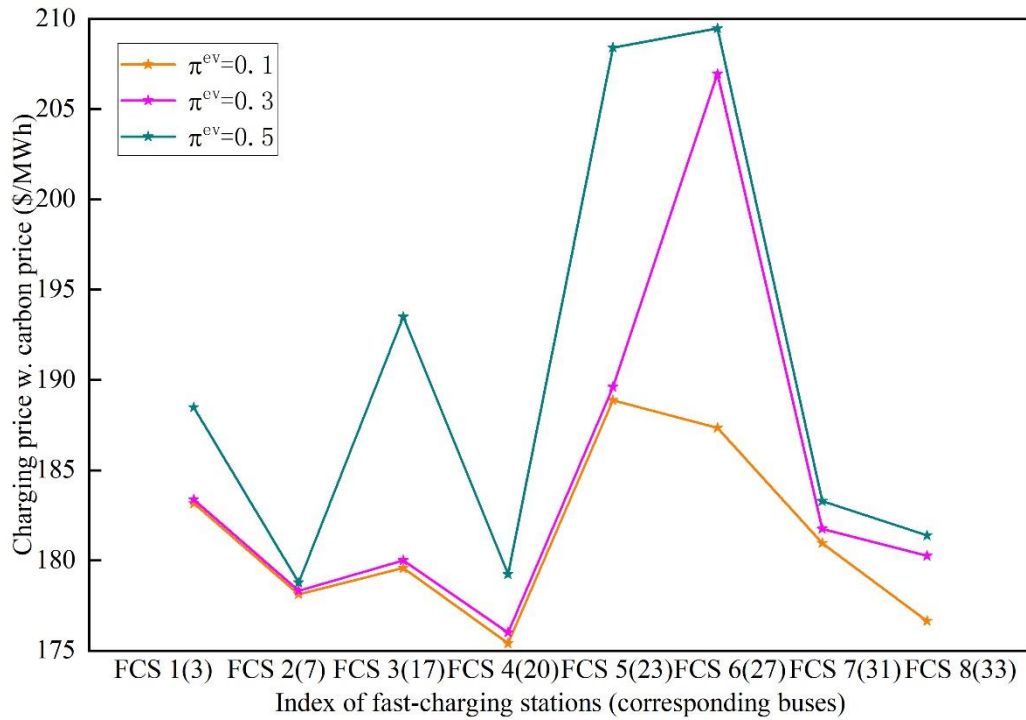


Fig. 1b. Charging price of each FCS w. the carbon price at different EV penetration levels.