*Sensitivity analysis*

*1) Sensitivity analysis of the EV penetration level:* The impact of EV penetration level $\pi^{\text{ev}}$ 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

$$\sum_{ke \in K_e^{rs}} f_{ke}^{rs} = Q_e^{rs}, f_{ke}^{rs} \ge 0, \sum_{kg \in K_g^{rs}} f_{kg}^{rs} = Q_g^{rs}, f_{kg}^{rs} \ge 0, \forall rs \in \Gamma \tag{3}$$

$$\Downarrow$$

$$\sum_{ke \in K_e^{rs}} f_{ke}^{rs} = \pi^{\text{ev}} Q^{rs}, f_{ke}^{rs} \ge 0, \sum_{kg \in K_g^{rs}} f_{kg}^{rs} = (1-\pi^{\text{ev}}) Q^{rs}, f_{kg}^{rs} \ge 0, \forall rs \in \Gamma \tag{3mod1}$$

$$Q^{rs} = Q_e^{rs} + Q_g^{rs}, \quad \forall rs \in \Gamma \tag{3mod2}$$

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 $\pi^{\text{ev}}$) 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 GVs 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 incorporating 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.

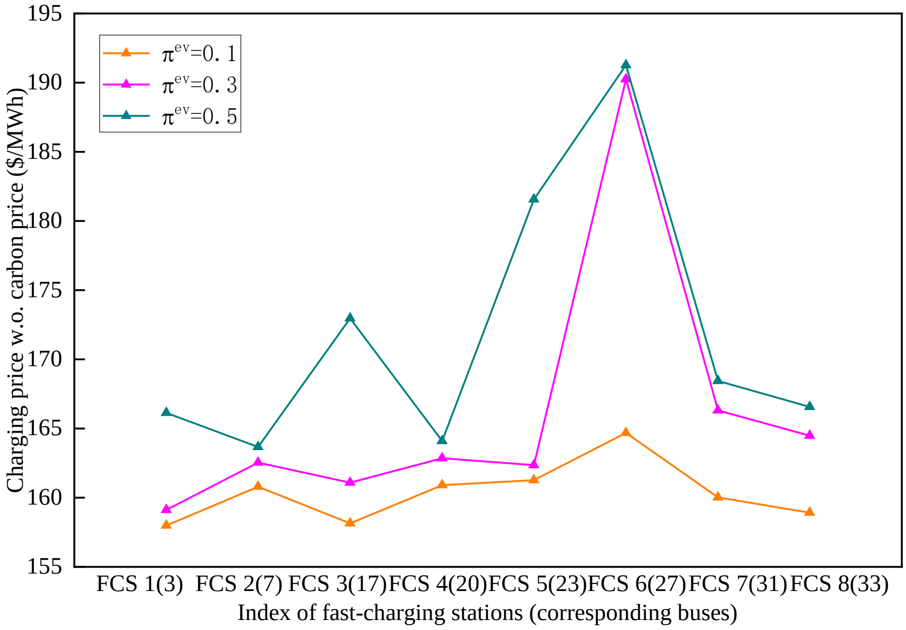


Fig. 1a. Charging price of each FCS w.o. the carbon price at different EV penetration levels.

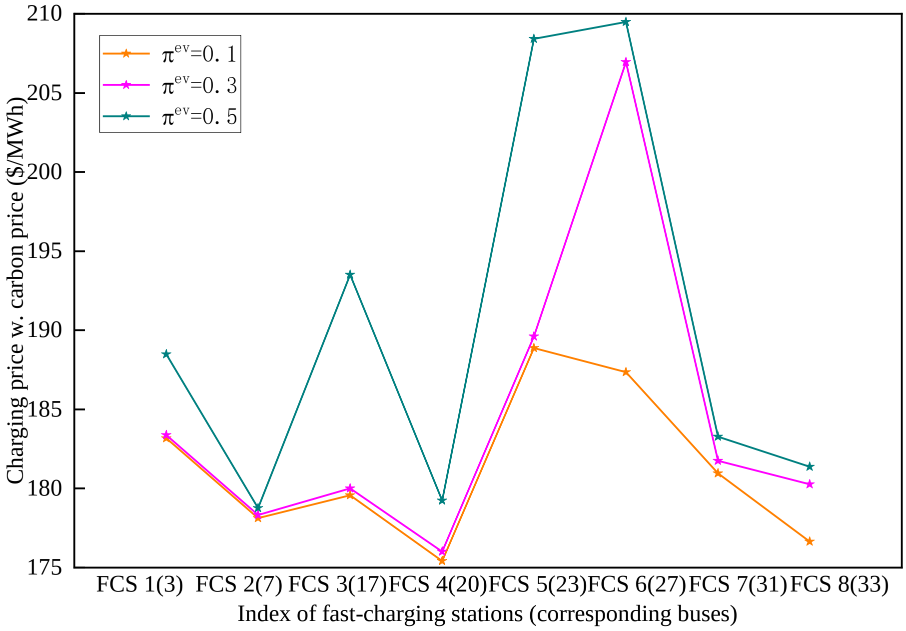


Fig. 1b. Charging price of each FCS w. the carbon price at different EV penetration levels.

*2) Sensitivity analysis of the carbon tax:* Fig. 2 presents the impact of the value of the carbon tax on the scheduling results and the EV flow distribution and charging price of FCSs. Initially, the carbon tax plays a major role in the locational ECIPs. Generally, buses with lower NCIs result in lower charging price increases (see Fig. 2b); thus, EV users are incentivized to get charged in FCSs with lower charging prices, facilitating the decrease of total emissions and the reduction of total costs. When the carbon tax rises to 30$/t, due to the limit of the low-carbon power output of generators, the total emission shows a slight change, while the total cost still increases significantly. Such an increase in cost has a slight impact on carbon emissions when it is up to 30$/t, and it hurts the interests of users. The results show that users would be incentivized to get charged with more low-carbon energy with the carbon price incorporated and the carbon tax needs to be properly formulated. (*2) Sensitivity analysis of the carbon tax* is provided on page 10 of this work)

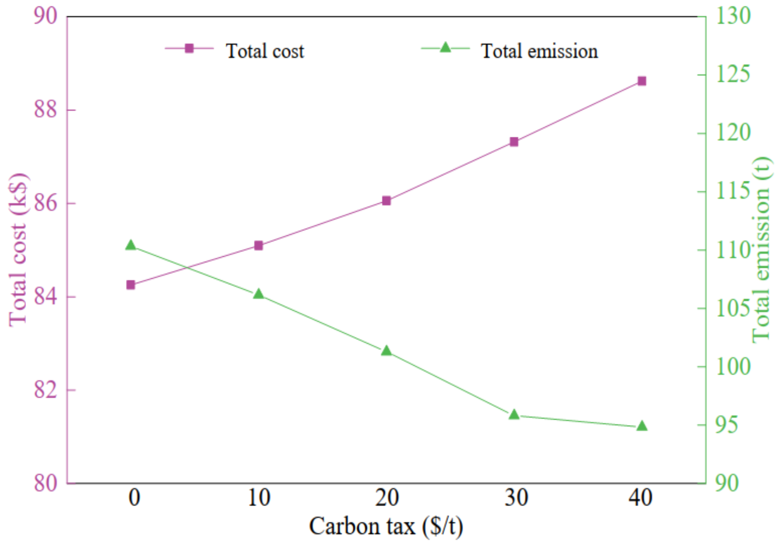


Fig. 2a. Sensitivity analysis of carbon tax on total cost and total emission of test system 2.

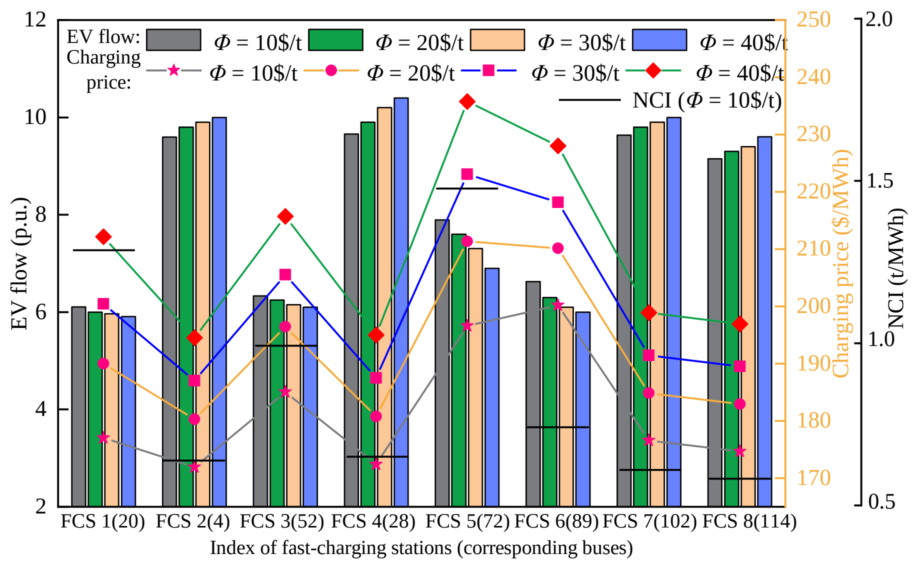


Fig. 2b. EV flow distribution and charging price of FCSs for different values of the carbon tax of test system 2.